GREEN CLIMATE FUND

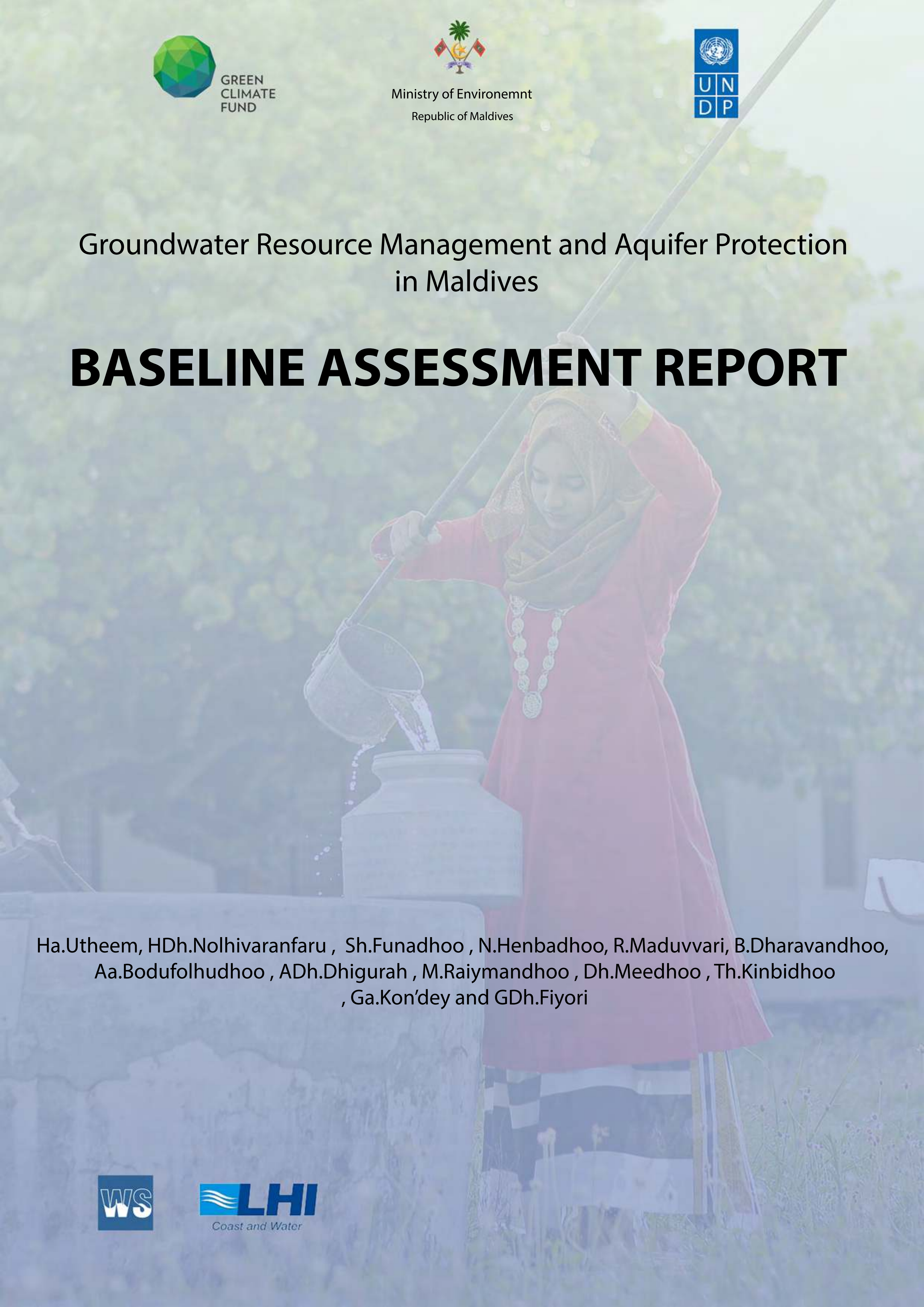
Ministry of Environemnt

Republic of Maldives

UNDP

Groundwater Resource Management and Aquifer Protection in Maldives

BASELINE ASSESSMENT REPORT



Ha.Utheem, HDh.Nolhivaranfaru , Sh.Funadhoo , N.Henbadhoo, R.Maduvvari, B.Dharavandhoo, Aa.Bodufolhudhoo , ADh.Dhigurah , M.Raiymandhoo , Dh.Meedhoo , Th.Kinbidhoo , Ga.Kon'dey and GDh.Fiyori

WS

LHI Coast and Water

Project: Supporting vulnerable communities in Maldives to manage climate change-induced water shortages Project

Funding Agency: Green Climate Fund

Implementing Agency: Ministry of Environment

Accredited Entity: United Nations Development Programme

Assignment: Groundwater Resource Management and Aquifer Protection in Maldives

Consultant: Water Solutions Private Limited

Deliverable: Baseline Assessment Report

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List of abbreviations and acronyms

EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
DTM	Digital Terrain Model
DSM	Digital Surface Model
FS	Feasibility Study
ME	Ministry of Environment
PMU	Project Management Unit
LHI	Lanka Hydraulics Institute
WS	Water Solutions Pvt.Ltd
GCF	Green Climate Fund
EPA	Environment Protection Agency
HDPE	High Density Polyethylene
EC	Electrical Conductivity
DO	Dissolved Oxygen

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Executive Summary

Background and Methodology

The Government of Maldives has received funding from the Green Climate Fund (GCF) for the project "Supporting Vulnerable Communities in Maldives to Manage Climate Change-induced Water Shortages". This Baseline Assessment Report compiled as a part of the broader project aforementioned and focusing on Groundwater Resource Management and Aquifer Protection in Maldives Project (under GCF Project) submitted to Ministry of Environment, Republic of Maldives presents the results of a study of baseline assessment to establish the current status and catchment characterization with the main objective of undertaking an assessment of the groundwater quality and recharge rates and develop a groundwater resources management plan with clear recommendations (including specific management and policy or legal recommendation) to ensure improved aquifer recharging and protection.

The target 13 islands of the assignment are: AA. Bodufulhadhoo, ADh. Dhigurah, Dh. Meedhoo, Ga. Kon'dey, GDh. Fiyoari, Ha. Utheem, HDh. Nolhivaramfaru, M. Raiymandhoo, N. Hen'badhoo, Sh. Funadhoo, Th. Kin'bidhoo, B. Dharavandhoo, and R. Maduvvari.

The study was conducted as per the conditions and tasks stipulated in the Terms of Reference and the report includes a detailed description of the methodologies followed and detailed data collected based on literature sources, conducted baseline assessment of geological, hydrological (physiochemical, microbiological, geo-physical) and land-use investigations for 13 islands.

The freshwater lens groundwater quality was studied based on physiochemical measurements (pH, Dissolved Oxygen, Electrical Conductivity, Turbidity, Temperature, Salinity, Ammonia, Nitrate, and Phosphate) and microbiological parameters (Total coliform and Fecal coliform) to identify the water quality and level of contamination, if any. A comprehensive social and institutional survey was conducted targeting households and local organizations/official of local councils to gather information on usage characteristics of water for domestic/commercial/agricultural/recreational purposes and root level issues with groundwater and other water sources.

The spatial and volumetric extents of the freshwater lens in each island was estimated based on the geo-physical investigations using Electrical Resistivity (ER) method to establish depth to groundwater table and freshwater-saline water interphase. A robust assessment of the present impacts on the freshwater lens and quality of other water sources has been carried out based on the information gathered and with an estimation of rates of groundwater recharge and discharge and safe yield for extraction in each island following a freshwater lens water balance approach.

General Findings and Remarks

The target 13 islands for the study have been selected to represent broader categories of dissimilar island characteristics in terms of land cover, population density, island size and shape factor, location and locality, water use traits, etc., which may be reflected in and inflicted upon the measured water quality and geophysical parameters.

The area extents of the selected islands vary from the smallest Bodufulhadhoo (11.4 ha) and Henbadhoo (13.6 ha) to the largest Nolhivaranfaru (171 ha) and Kon'dey (119.5 ha). The Population density (Persons per hectare) and Roof area coverage (Percent of total area) were generally higher for the small islands (i.e. 65.86 persons per hectare and 21.2% for Maduvvari (22 ha) and 53.22 persons per hectare and 21.2% for Bodufulhadhoo compared to 6.32 persons per hectare and 4.8% in Nolhivaranfaru and 2.28 persons per hectare and 1.7% in Kon'day, respectively) highlighting the increased environmental pressure in such islands due to limited resource constraints, especially affecting freshwater lens due to groundwater over extraction.

The groundwater samples collected from the freshwater lens using household dug wells indicated that groundwater aquifers in all 13 islands are exposed to faecal contamination to lesser or greater degrees and this is prevalent in the samples collected in shoreline and densely populated areas. Almost all the samples collected in Bodufulhadhoo, Maduvvari and Henbadhoo among densely populated islands tested odorous, while all samples from even Nolhivaranfaru where the population density is relatively low (6.32 persons per ha) produced odour presumably due to concentration of built up areas in the northern central part of the island. In general, random water samples from dug wells Meedhoo, Henbadhoo and Bodhufulhadhoo were found to be still clear but with a very extreme or intense odour (foul stench) while samples collected in Madhuvvari were moderately odorous (this is arguably a subjective measure or perception).

Extremely high Electrical Conductivity (EC in µS/cm) and Salinity (PSU) were recorded mostly in shoreline samples in Dhigurah, Utheem, Nolhivaranfaru, Funadhoo, Maduvvari, and Raiymandhoo islands presumably due to pumping induced seawater intrusion while a sample collected from a centrally located well in Bodufulhadhoo as well produced a similar high EC due to probable traces of contamination.

The Electrical Resistivity measurements to identify the spatial extents and vertical depths of freshwater lens were conducted during the period February to June at a time the aquifers are presumably stressed prior to the beginning of the monsoonal season. The measured average depth to groundwater table which is the upper boundary of the freshwater lens varied from ~0.70 m to 2.15 m (with an absolute groundwater table range of 0.30 m – 0.80 m AMSL) while the depth to freshwater-saline interface which demarcate the lower boundary of the freshwater lens varied from ~3.10 m to 9.50 m (with an absolute groundwater table range of -1.50 m to -9.50 m AMSL), indicating that the instantaneous freshwater lens thickness at the time of the measurement varied from 2.00 m (in Bodufulhadhoo) to 8.75 m (in Kin'bidhoo).

The freshwater aquifers in Bodufulhadhoo and Maduvvari were found to be the most stressed and overexploited with the present groundwater extraction rates exceeding their safe yields by 259% and 254%, respectively, based on the robust assessment following water balance approach. The stress level of the aquifer is reflected by the observed, localized drawdown and up-coning effects in the groundwater table and freshwater-saline interface defining the upper and lower boundaries of the freshwater lens in an island and severe irregularities and significant deviations were observed along cross sections and longitudinal sections aligned intercepting such densely populated areas where the aquifers were overstressed due to incessant pumping for household and community water uses. Significant irregularities in freshwater lens thickness as a result of heavy drawdown in groundwater table and severe up-coning in saline interface were observed in the central part of Bodufulhadhoo and Raiymandhoo Islands due to continuous household uptakes and intense pumping near an ongoing construction site in the latter.

The overburden soil permeability was found to vary significantly over the landscapes in the islands both depending on the soil-geological type and land use combinations where relatively high permeable sandy soils were encountered in most locations while very low permeable humic clayey sands were found in thick vegetation areas as well as residential built up areas in Kinbindhoo Island leading to very low infiltration and long period ponding during storm events. The infiltration rates as measured using constant head method ranged from the lowest 1.13 ± 0.10 m/day in Bodufulhadhoo and 1.24 ± 0.52 m/day in Kinbidhoo to the highest in Raimandhoo (27.53 ± 18.81 m/day), Dhigurah (25.83 ± 18.23 m/day), and Dharavandhoo (25.35 ± 18.71 m/day).

Specific Considerations and Recommendations

The available literature sources and findings from the past studies were referred to recognise the past/existing conditions of the groundwater aquifers and usage characteristics in the selected 13 islands under the present study related to Baseline Assessment and Catchment Characterization focusing on hydro-geology, water quality and quantity and in general the catchment status in the islands. Significant variations in existing groundwater resources in terms of groundwater quality and quantity and other associated parameters have been identified. The extremely diverse conditions recognized based on the findings of the present study emphasizes that distinct solutions will be required for different islands based on the level of water quality degradation, catchment and water use characterization and freshwater lens stress level. The findings further highlight the urgent requirement of implementing groundwater conservation and protection measures for the contributory catchments for recharge zones to maintain prevailing healthy conditions in islands where the groundwater aquifers and water resources are still within acceptable limits and adopting immediate restoration and recovery processes for the islands with already degraded freshwater lens status or the conditions have been continuously deteriorating.

The water quality deterioration is a serious issue to be addressed as all 13 islands have been exposed to groundwater contamination to a lesser or greater degree as per the findings of the study while the increased salinity and traces of faecal contamination have been detected in the majority of the samples tested for biological contamination. Seawater intrusion in shoreline areas may be influenced by groundwater overexploitation exceeding the safe yield in densely populated islands. Faecal contamination can be resulted from direct contact with the contaminated sources or may be due to the leachate from septic tanks, already abandoned or presently in use which can also be exacerbated due to over pumping. It has been found that 9 or 10 (without local systems) out of 13 islands studied do not have sewer networks while a staggering 13 out of 13 islands do not have proper, centralized water supply schemes. The study findings further reveal that the groundwater availability in freshwater lenses in strictly limited, majority of the aquifers are stressed towards the middle or end of the dry period and the thin lenses are highly vulnerable to increased, intense, continuous pumping. Improving sewerage collection/ treatment /proper disposal and providing access to alternate clean water sources (Desalinated water in densely packed islands) will help conserving the limited groundwater resources while catchment protection measures are essentially required to address concerns regarding deteriorating water quality.

The feasibility of implementing restoration measures by improving groundwater recharge with the provision of artificial recharge pits and recharge galleries is restricted in densely packed islands with higher percent of built up areas and limited vegetation cover. The elevated groundwater tables or shallow groundwater tables (in the range of 0.3 m ~ 0.6 m) as observed even during the dry period hinder using centralized recharge infrastructure, highlighting the need for promoting rainwater harvesting with over spillage connected to individual household recharge pits.

The feasibility of implementing restoration measures by improving groundwater recharge with the provision of artificial recharge pits and recharge galleries is restricted in densely packed islands with higher percent of built up areas and limited vegetation cover. The elevated / shallow groundwater tables (in the range of 0.3 m ~ 0.6 m) as observed even during the dry period hinder using centralized recharge infrastructure, highlighting the need for promoting rainwater harvesting with over spillage connected to individual household recharge pits.

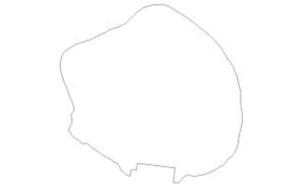
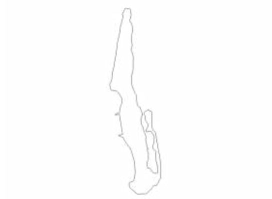
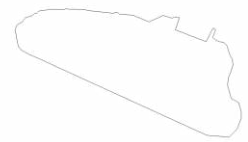
NOTE on Recommended Actions:

Restore: Immediate action to reduce present groundwater usage exceeding safe yield and improve recharge (i.e. Introduce alternate sources/Central water supply scheme/Promote recharge to replenish) and Improve degraded water quality (i.e. Catchment protection, decommissioning and emptying unused abandoned septic tanks, provide central sewer networks, promote recharging for flushing contaminated aquifer).

Conserve: Maintain existing favourable groundwater usage conditions and improve degraded water quality (i.e. Catchment protection, Decommissioning and emptying unused abandoned septic tanks, provide central sewer networks, promote recharging for flushing contaminated aquifer).

Good: Hydrologically Good or Acceptable but Contaminated aquifer.

The summary of the overview and findings from the study and the overall observations/ recommendations based on the study findings are summarised as follows.

Island	Utheemu	Nolhivaranfaru	Funadhoo	Henbadhoo	Maduvvari	Dharavandhoo
Atoll	**Haa Alifu**	**Haa Dhaalu**	**Shaviyani**	**Noonu**	**Raa**	**Baa**
Shape of the island						
General Overview of Island and Demography						
Area (Ha)	65	171	100	13.6	22	65
Length (m)	865.49	3550	3373	463.44	670.59	1497
Width (m)	736.22	1100	415	359.74	342.29	525
Population	569	1081	2104	491	1449	839
Pop. density (per /hectar)	8.75	6.32	21.04	36.10	65.86	12.91
Land Cover and Built up Area (As a percentage of total land area)						
Roof area (%)	9.3%	4.8%	9.2%	22.0%	27.2%	6.7%
Thick Vegetation (%)	39.5%	61.1%	32.1%	13.8%	0.0%	16.8%
Thin Vegetation (%)	13.3%	10.0%	10.9%	26.9%	23.0%	7.5%
Bare lands (%)	37.8%	21.2%	47.8%	37.2%	49.8%	69.0%
Farm lands (%)		3%				
Socio-economic Condition						
Overview	Important and popular historical site	Over 70% vegetation and 6 ha for farming	Highest population & new airport		Highest population density	Fast growing, domestic airport, focus on tourism
Number of restaurants	2	3	4	-	3	5
No. of Guesthouses	1	1	-	-	-	11
Present Sanitation and Water-use Characteristics						
Presence of Sewer Network	None	None	Yes	None	Yes	None
Presence of Water Supply	None	None	None	None	None	None
Households with RW tanks	80%	100%	100%	100%	97%	95%
Rainwater use for drinking	70%	95.65%	96.67%	100%	70%	70%
Groundwater non-potable use	100%	100%	100%	100%	100%	100%
RW Storage Capacity (m^3)	432.5	1087.5	3930	315	850	630
Water Quality Aspects (Selected Parameters; please refer to respective chapters for other details and data)						
Elect. Conductivity (µS/cm)	1,744 ± 2,683	2,240 ± 3,522	7,547 ± 9,712	4,239 ± 1,631	3,689 ± 4,155	1,008 ± 399
Ammonia (mg/L)	2.93 ± 4.22	6.72 ± 8.42	7.49 ± 10.01	12.91 ± 8.17	6.16 ± 12.84	1.43 ± 1.24
Faecal Cont. & Odour	Yes & 7/10	Yes & 10/10	Yes & 13/13	Yes & 15/15	Yes & 22/22	Yes & 9/13
Groundwater Availability, Usage, Water Balance and Recharge Potential						
Freshwater Lens Volume (m^3) & Thickness (m)	250,231 m^3 & 5.90 m	335,176 m^3 & 4.52 m	5,473 m^3 & 2.70 m	21,989 m^3 & 2.87 m	40,316 m^3 & 4.96 m	285,925 m^3 & 4.86 m
Rainwater Harvesting (m^3)	1,298	3,263	11,790	945	2,550	1,890
GroundwaterExtraction (m^3/day)	112	305	488	90	284	256
Safe Yield M1 & M2 (m^3/day)	572 & 234	1196 & 830	1694 & 594	129 & 66	169 & 114	1455 & 340
Usage / Safe Yield (%)	20% & 48%	25% & 37%	29% & 82%	70% & 135%	168% & 248%	18% & 75%
Present Aquifer Condition	Good	Good	Stressed	Stressed	Highly Stressed	Good
Potential for GW Recharge	High	Moderate	Low	Moderate/Low	Moderate/Low	High
Priority for GW Improvement	Conserve	Conserve	High/ Restore	High/ Restore	High/ Restore	Conserve

Island	Bodufulhadhoo	Dhigurah	Raimandhoo	Kinbidhoo	Meedhoo	Kon'dey	Fiyoari
Atoll	Alifu Alifu	Alifu Dhaalu	Meemu	Thaa	Dhaalu	Gaafu Alifu	Gaafu Dhaalu
Shape of the island							
General Overview of Island and Demography							
Length (m)	414.81	3759	910	990	885	2240	1660
Width (m)	388.89	286.02	450	860	593	700	640
Population	608	610	112	768	929	272	737
Pop. density (per /hectar)	53.33	14.54	3.80	20.33	29.10	2.28	9.22
Land Cover and Built up Area (As a percentage of total land area)							
Roof area (%)	21.2%	7.6%	3.3%	10.0%	11.9%	1.7%	5.8%
Thick Vegetation (%)	6.4%	51.0%	60.8%	39.2%	0.0%	91.3%	36.0%
Thin Vegetation (%)	19.9%	12.2%	12.1%	21.4%	6.6%	4.9%	26.0%
Bare lands (%)	52.5%	28.8%	23.4%	29.4%	81.5%	1.0%	20.4%
Farm lands (%)						1%	7%
Wetlands (%)							5%
Socio-economic Condition							
Overview	High population density with Tourism / fishing	Extremely popular tourist destination	Slow growing island with low population	Fast growing island close to atoll capital	Highly built-up, densely packed, 50% reclaimed	Several scattered farms	Significant farming with large farms
No. of restaurants	4	2	1	1	2	1	3
No. of Guesthouses	6	14	-	-	-	-	-
Present Sanitation and Water-use Characteristics							
Presence of Sewer Network	Yes (Local)	Yes (Local)	None	None	Yes	None	None
Presence of Water Supply	None	None	None	None	None	None	None
Households with RW tanks	100%	94%	100%	100%	100%	100%	100%
Rainwater use for drinking	73%	35%	100%	100%	70%	83%	82%
Groundwater non-potable use	100%	100%	100%	100%	100%	100%	100%
RainWater Storage Capacity (m^3)	357.5	462	200	510	65	135	1373
Water Quality Aspects (Selected Parameters; please refer to respective chapters for other details and data)							
Elect. Conductivity (µS/cm)	6,182 ± 3,748	2,725 ± 4,347	5,039 ± 8,474	939 ± 271	952 ± 498	636 ± 119	997 ± 405
Ammonia (mg/L)	0.31 ± 0.32	0.54 ± 1.48	5.14 ± 9.80	1.18 ± 1.16	1.20 ± 1.49	0.99 ± 2.31	3.62 ± 7.66
Faecal Cont. & Odour (Samples)	Yes & 10/10	Yes & 3/20	Yes & 7/9	Yes & 8/10	Yes & 15/20	Yes & 4/13	Yes & 7/12
Groundwater Availability, Usage, Water Balance and Recharge Potential							
Freshwater Lens Volume (m^3) & Thickness (m)	10,298 m^3 & 1.51 m	145,149 m^3 & 5.34 m	45,368 m^3 & 3.41 m	113,029 m^3 & 8.46 m	117,827 m^3 & 4.11 m	601,600 m^3 & 4.18 m	123,878 m^3 & 2.03 m
Rainwater Harvesting (m^3)	1,073	1,386	600	1,530	195	405	4,118
Groundwater Extraction (m^3/day)	239	199	53	316	324	132	307
Safe Yield M1 & M2 (m^3/day)	54 & 68	824 & 314	403 & 159	535 & 241	798 & 189	1495 & 720	1690 & 501
Usage / Safe Yield (%)	439% & 353%	24% & 63%	13% & 34%	59% & 131%	41% & 171%	9% & 18%	18% & 61%
Present Aquifer Condition	Highly Stressed	Good	Good	Stressed	Stressed	Good	Good
Potential for GW Recharge	Low	Moderate	High	High	High	High	High
Priority for GW Improvement	Very High/ Restore	Conserve	Conserve	Moderate/ Restore	Moderate/ Restore	Conserve	Conserve

The Overall Observations and Summary Recommendations

Name of the island	Hydrological conditions	Water Quality Aspects	Mean EC (µS/cm)	Availability of Space	Recharging potential	Overall Recommendation
Ha. Utheem	Good	Contaminated	1,744.29 ± 2,683.09	Moderate	High	Use recharging trenches (in roads & forest area) and recharging pits (individual households and land blocks)
HDh. Nolhivaramfaru	Moderate to Low	Contaminated	2,240.18 ± 3,522.33	High	Moderate	Use recharging ponds in low lying areas and recharging trenches in other areas
Sh. Funadhoo	Moderate to Low	Contaminated	7,547.90 ± 9,712.59	Low	Low	Low potential and Recharging pits within individual land blocks (if space is available)
N. Hen'badhoo	Moderate	Contaminated	4,239.95 ± 1,631.26	Low	Moderate to Low	Trenches along the roads and recharging pits (space in the individual land blocks)
R. Maduvvari	Good	Contaminated	3,689.58 ± 4,155.67	Low	Moderate to Low	Trenches along the roads and recharging pits with individual blocks
B. Dharavandhoo	Good	Contaminated	1,008.57 ± 399.20	High	High	Trenches and ponds, recharging pits within individual land blocks (if space is available)
AA. Bodufulhadhoo	Moderate to Low	Contaminated	6,182.47 ± 3,748.82	Low	Low	Very low recharging potential. Use individual household pits
ADh. Dhigurah	Moderate	Contaminated	2,725.81 ± 4,347.49	High	Moderate	Trenches and ponds, recharging pits within individual land blocks (if space is available)
M. Raiymandhoo	Moderate	Contaminated	5,039.33 ± 8,474.21	High	High	Recharging pits, for individual land blocks and trenches, ponds and recharging pits in other areas
Th. Kin'bidhoo	Moderate	Contaminated	939.23 ± 271.15	High	High	Recharging ponds and trenches with recharging pit areas in individual households and land blocks
Dh. Meedhoo	Moderate	Contaminated	952.84 ± 498.45	High (Reclaimed area)	High	Recharging trenches and ponds
GDh. Fiyoari	Good	Contaminated	997.83 ± 405.63	High	High	Ponds, trenches, pits and laterals in built up area and Impounded earth dams in open areas. In addition, recharging pits could be used for other individual households and land blocks
GA. Kon'dey	Moderate	Contaminated	636.83 ± 119.45	High	High	Recharging trenches and ponds

1 INTRODUCTION

1.1 Background

The Republic of Maldives is a low lying, atoll based, archipelagic nation in the central Indian Ocean. It comprises 1,190 islands grouped into 26 atolls that together occupy a land area of 298 km^2 and form a chain over 820 km in length, spread over an area of around 90,000 km^2. With a total population of 341,256 (National Bureau of Statistics, 2014), it is the smallest Asian country in terms of area and population. The country has an average elevation of 1.5 m above sea- level. The two most important sectors of the economy are tourism and fisheries which contribute nearly 80% of the country's Gross Domestic Product (GDP). Maldives is among the most susceptible and vulnerable small states to climate change.

The outer islands of the Maldives experience drinking water shortages during the dry season. These shortages have had significant adverse human, environmental and social impacts on the outer islands. The key problems pertaining to freshwater security relate to the increasingly variable rainfall patterns induced by climate change and sea-level rise induced salinity of groundwater. The Government faces constraints in responding to the challenge at hand without assistance, especially in the context of anticipated impacts of climate change.

In response to this climate challenge, the 5-year Green Climate Fund (GCF) funded project targeting 'Supporting Vulnerable Communities in Maldives to Manage Climate Change-Induced Water Shortages' by the United Nations Development Programme (UNDP) was launched. The project has the objective to deliver safe and secure freshwater to 105,000 people in the islands of Maldives in the face of climate change risks. This will be achieved by delivering the following results:

a. Scaling up integrated water supply system to provide safe water to vulnerable households (at least 32,000 people, including 15,000 women);
b. Decentralized and cost-effective dry season water supply system introduced benefiting 73,000 people across 7 Northern Atolls;
c. Groundwater quality improved to secure freshwater reserves for long term resilience on 49 islands.

As an integral component of the project, the Maldivian Government has awarded Water Solutions (WS, Maldives) and Lanka Hydraulics Institute (LHI, Sri Lanka) to undertake a Baseline assessment of groundwater in 13 islands and development of a groundwater management system for Maldives.

1.2 Specific Objectives

The scope of work of this consultancy service is broadly categorized into four (4) areas with specific objectives as outlined below.

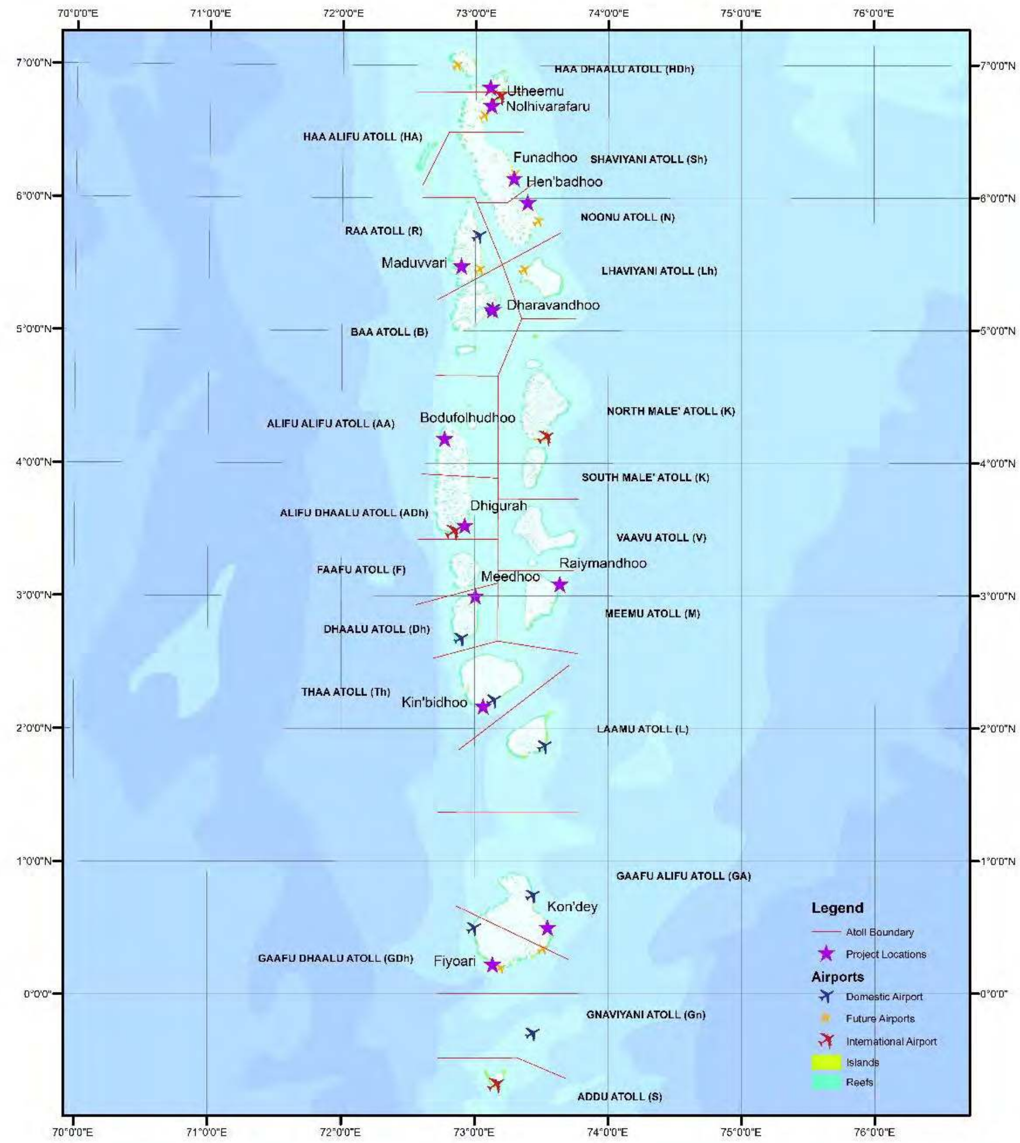
a. Undertake baseline assessment to establish the current status and catchment characterization of each island.
b. Develop groundwater resources management plan for improved aquifer recharge and protection with clear action plan for its implementation.
c. Development of a groundwater monitoring framework with monitoring protocols, institutional roles and responsibilities for its implementation with on the job training and technology transfer component.
d. Make relevant recommendations on required interventions, in particular on policy and regulatory framework for improved coastal land use and aquifer protection.

This report outlines the results of the baseline assessment surveys undertaken in the following thirteen (13) islands. The islands locations are indicated on Figure 1.1.

1) AA. Bodufulhadhoo

2) ADh. Dhigurah
3) Dh. Meedhoo
4) GA. Kon’dey
5) GDh. Fiyoari
6) Ha. Utheem
7) HDh. Nolhivaramfaru
8) M. Raiymandhoo
9) N. Hen’badhoo
10) Sh. Funadhoo
11) Th. Kin’bidhoo
12) B. Dharavandhoo
13) R. Maduvvari

Figure 1.1: Map indicating locations of 13 islands



1.3 Structure of the report

The report has been structured in to three broad categories.

First, it provides the reader with a general overview and introduction of the broader project, the objectives and detail methodology used to collect data.

The second part of the report will provide an overview of the groundwater, its occurrence and characteristics in Maldives, which is vital to understand the broader context of water resource management in Maldives.

Thirdly, the report outlines the findings of the survey in the islands. For each island, the following information will be provided.

- General overview of the island including location and geography
- Geology and vegetation
- Topography
- Climate
- Demography
- Socio-economic condition
- Existing Water and sanitation situation.
- Results
    - Water sources and water use
        - Domestic water use situation
        - Commercial water use situation
        - Institutional water use situation
    - Groundwater quality
    - Geophysical survey
    - Aerial surveys
    - Water Demand
    - Freshwater lens
    - Water balance and recharge
    - Sustainable yield of the lens
    - Permeability test
    - Groundwater availability
- Conclusive Remarks and Recommendations

1.4 Methodology of Data Collection

The baseline surveys were undertaken by visiting each island to undertake all the required data as outlined in the TOR.

In each island, six (6) types of surveys (investigations) were undertaken. They are;

1- Groundwater well surveys – (physiochemical and microbiological).
2- Water usage survey (socio-economic survey).
3- Measurement of changes in groundwater level.
4- Soil permeability test.
5- Rainwater catchment and infiltration survey.
6- Geo-physical surveys.

The following sections outline the detailed methodology of how the above surveys and data collection were undertaken in the field.

1.4.1 Groundwater well survey – (Physiochemical and Microbiological)

The scope of the assessment required collection of data on the physiochemical and microbiological status of groundwater. Thus, in each of the islands, groundwater quality was tested for the selected physicochemical parameters outlined in the TOR.

The aim of the survey was to provide a structured and consistent approach to collect data on the existing quality of groundwater in each island covering in its entirety. Since each household, mosque and in most cases, institutions had shallow dug wells where groundwater can be sampled and tested, this was the preferred method to test the water quality. In islands where there are large vegetated areas or barren land with no wells, groundwater was extracted by digging a small hole and extracting the water using a manual pump. Digging was undertaken using a fuel driven mechanical auger.

1.4.1.1 Sampling methodology – Physiochemical parameters

For the physicochemical survey of the groundwater, pre-selection of a sample size was not preferred due to individual differences in each island. Population, housing and land use for various activities are not evenly distributed throughout the island, making this method unpractical and biased. Some islands have large unused / undeveloped areas with tree cover segregated from the main residential areas. Other islands are more saturated with houses evenly distributed throughout the island. Hence, testing water from existing wells only would not provide a complete picture of the groundwater quality of the entire island. Proximity of contamination sources such as septic tanks would affect the quality of groundwater in localized areas. Type of land usage, amount of water extraction from the ground, type of plantation in the area, proximity to the shoreline, etc. are all factors which could affect the quality of groundwater in localized areas in each island. Therefore, sampling locations were selected in a way that represents the whole island with various land use areas.

Sampling was undertaken from pre-determined random points throughout the island (refer to the results section of each island that will provide the sampling locations). Selecting sampling points in this manner ensured that the entire island's groundwater quality was evenly represented.

The sampling points were selected keeping in mind the following factors:

1- Sampling locations were evenly distributed throughout the island to cover the entire aerial or spatial extent.
2- The sampling points needed to be proximal to where the ER surveys were be undertaken for comparison.
3- Sample locations included areas from the centre of the island and around the coastal belt.
4- Sampling locations represented residential areas, agricultural areas and tourism zones in the island.
5- Sampling locations covered the vegetated areas, built up areas barren lands, reclaimed lands, etc.

1.4.1.1.1 Parameters tested

The following physiochemical parameters were measured for each island: pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), Turbidity, Temperature, Salinity, Ammonia, Nitrate and Phosphate. The electrical conductivity measurements were used to determine the areal extent of the freshwater lens. For the survey, the practical limit of freshwater was considered to be 2,500 µS/cm, which approximately correlates to a concentration of 600 mg/l Cl, a salinity of which has a discernible salty taste (GWP).

The sampling was conducted such that the whole island was covered, and a detailed overview of the groundwater quality and quantity of each island was obtained. Minimum requirements of the physiochemical and microbiological studies as per the TOR are as follows:

- Physiochemical: The following parameters were tested for each island: pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), Turbidity, Temperature, Salinity, Ammonia, Nitrate, Phosphate
- Microbiological: The following parameters were tested for each island: total coliform and fecal coliform

The odor was also classified as yes (odor is available) or no (odor is not available) based on sense.

Samples for laboratory testing was collected using properly decontaminated and labelled HDPE sampling containers or Standard Thio-bags. Samples were preserved as required and stored at 4 ± 2 °C until they were transported to the laboratory for testing.

All groundwater samplings and water quality testing were conducted following the standard methods as stipulated by US EPA Standards and Guidelines for Groundwater Sampling (US EPA, 2013); ASTM D4448: Standard Guide for Sampling Ground-Water Monitoring Wells (ASTM, 2007/2019).

1.4.1.1.2 Equipment used

The following methods and equipment were used for water quality sampling and testing purposes.

1.4.1.1.2.1 Equipment for sampling

A mechanical earth auger drill was used to drill holes deep enough to obtain the groundwater from areas where there are no dug wells, such as non-residential and vegetated areas. The holes drilled had a diameter wide enough to obtain water through, either by a pipe or a pump. In situations where the auger could not be used, the hole was dug manually using a spade.

1.4.1.1.2.2 Instruments for water quality testing

For the measurement of the physiochemical properties of groundwater, a YSI proDDS water quality meter was used. This device is a handheld multi-parameter probe/meter with a digital sampling system. The proDDS is suitable for data collection in surface water, groundwater, coastal, and even wastewater. However, some sensors are limited to only fresh water measurements. This instrument was used to measure all the physiochemical parameters at each location on site.

1.4.1.2 Sampling methodology – Microbiological surveys

To understand the microbiological contamination of the groundwater, Total coliform and Faecal coliform were measured at selected sampling locations for each island. Similar to the physical parameters, sampling was undertaken from household wells, wells at identified institutions/locations, and from taps which are connected to groundwater from wells through pumps. The taps were flushed before the samples were taken.

Unlike the physiochemical surveys, the number of samples tested for microbiological contamination were less and concentrated more on the residential areas.

Water samples were collected and labelled in Standard Thio-bags for the coliform tests. Samples were kept in dry ice until delivered to the laboratory for testing. Coliform and faecal coliform tests were performed at Male' Water & Sewerage Company Pvt. Ltd. (MWSC) after transferring the bottles to Male’ within 24 hours. The samples were transferred in a cool box. Ideal temperature for the sample to be stored is between 4 and 10 degree Celsius and hence, this temperature was maintained throughout its transit.

The details of test procedures are briefly explained below and the summary is provided in Table 1.1.

Table 1.1 Summary details of Physiochemical and Microbiological parameters measured

Physiochemical Parameters				
Parameter	**Test Method**	**Unit**	**MDL**	**Reference**
pH	In-situ Multi-probe	Standard Units	0.1	YSI proDDS Multi-probe
DO	In-situ Multi-probe	mg/L or %	±0.1 mg/L	YSI proDDS Multi-probe
EC	In-situ Multi-probe	mS/cm	±0.5%	YSI proDDS Multi-probe
Turbidity	In-situ Multi-probe	NTU	±2.0%	YSI proDDS Multi-probe
Temperature	In-situ Multi-probe	°C	±0.2°C	YSI proDDS Multi-probe
Salinity	In-situ Multi-probe	mg/L or PSU	±0.1	YSI proDDS Multi-probe
Ammonia	In-situ Multi-probe	mg/L as N	0.01 mg/L	YSI proDDS Multi-probe
Nitrate	In-situ Multi-probe	mg/L as N	0.01 mg/L	YSI proDDS Multi-probe
Phosphate	Laboratory	mg/L as P	0.01 mg/L	
Microbiological Parameters				
Parameter	**Test Method**	**Unit**	**MDL**	**Reference**
Total coliform	Laboratory	MPN/100 mL		
Faecal coliform	Laboratory	MPN/100 mL		

1.4.1.2.1 Data entry

Water quality tested in situ was stored on the YSI proDDS water quality meter, which was later exported to Windows based main database. A Trimble Juno (hand held mobile GIS data logger with GPS) was used to record the location where each water sample was taken. The Trimble Juno has an accuracy of 2 to 5 meters. This method eliminates the need to carry paper and record readings manually under constrained outdoor conditions. The use of GPS eliminated the need for recording manual location data as each sampling point was recorded with the exact geographical coordinates. The data was then directly exported to GIS, thus saving time in creating the final output. Before each field visit, the base map of each island was loaded on to a Trimble Juno with predefined sample locations. Each point had a set of attributes including all the parameters to be tested as well as name of the house / institution / place.

1.4.1.2.2 Quality assurance

Quality assurance during the groundwater well survey minimized the uncertainties during data collection and provided accurate and unbiased results. Below is a list of quality control measures that were followed during the survey.

1- The water quality equipment was calibrated before use.
2- When existing wells were sampled, the probe was directly dipped in the water for measurements. Probe was immersed in mid water to ensure that the water being tested was an accurate representation of well conditions.
3- If water was drawn from a well using a pump or other means, it was carried out using a clean container and the sensors were washed at least twice with the sample water.
4- The sensors were immersed into the water completely.
5- While testing, recordings were taken after the reading stabilized.

For microbiological parameters:

1- Hands were thoroughly washed before collecting samples.

2- If the sample was drawn from a dug well, a clean container was used to draw water.
3- The rinsing of Thio bags with sample water was avoided as this would remove some or all of its preservatives and ruin the sample.
4- Touching the inside or the lip of the sampling bag was avoided, to ensure the sample does not get contaminated.
5- The bag was tightly sealed immediately after collecting enough water.

1.4.2 Geophysical surveys

1.4.2.1 General background

For developing groundwater conservation strategies and aquifer management plans, it is crucial to estimate the extents and volumes of freshwater lens in the islands. The TOR further stipulates the requirement for assessing the present impacts on the freshwater lens and quality of other water sources. The freshwater lens configuration was evaluated by using electrical conductivity (or resistivity) data while groundwater levels, topographical and geological features were also discussed in the detailed evaluation process. Further during this process, the thickness of the freshwater lens is required to be assessed in the field by measurements and further verified by providing reasons. Thickness of the groundwater aquifer in the islands depends on the net rainfall recharge, size of the island and permeability of the soil column and required data for verification was collected during the course of the project.

In addition, these baseline conditions related to presently existing groundwater resources at individual islands were properly established in order to have better insight into the rates of groundwater recharge and discharge as well as targeting future assessment of potential improvements due to proposed interventions under the present study. The quantitative volumetric estimates of the groundwater resource availability were derived based on the identified extents and thickness of the freshwater lens following Electrical Resistivity (ER) surveys as described below and verified with the help of existing literature and generated maps which were produced using available data and the other supplementary data collected during the course of the present study. These established baseline conditions will help developing groundwater extraction/recharge monitoring protocols and other groundwater and aquifer management strategies and methodologies to be developed following water balance approach or numerical modelling to simulate the behaviour of the freshwater lens in each island.

1.4.2.1.1 Selection of methodology

Geophysical methods for groundwater exploration (mainly, Electrical Resistivity (ER) methods based on conductance and Electro-Magnetics (EM) methods based on penetration/reflectance) are useful for providing relatively quick and cheap assessments of freshwater lens locations, extents and thicknesses. Both ER and EM methods have been widely applied in groundwater explorations under different conditions. However, the results from ER and EM surveys are subject to differing interpretations and require independent calibration to be used with confidence.

The emerging EM methods are based on the electrical properties of sub-surface layers while it overcomes the problem of establishing good galvanic (electrical) contact between source of current and (earth) media, such as encountered in resistivity measurements. This enables use of airborne EM technologies which are relatively faster and easier in application over wider areas. With presently available helicopter-borne and drone mounted sensors, groundwater studies can be designed to obtain a high resolution three-dimensional (3-D) view of the internal resistivity structure. However, the choice of method is entirely dependent on the availability of time and funds and the degree of accuracy required. Further, the relatively small dimensions and extents of the islands involved in comparison to the ranges of detectable depths (Fig. 1-1) and the specific need for differentiating saline groundwater from fresh groundwater to identify saline-freshwater interphase to detect lens thickness in this project exclude the use of EM methodologies in the present study.

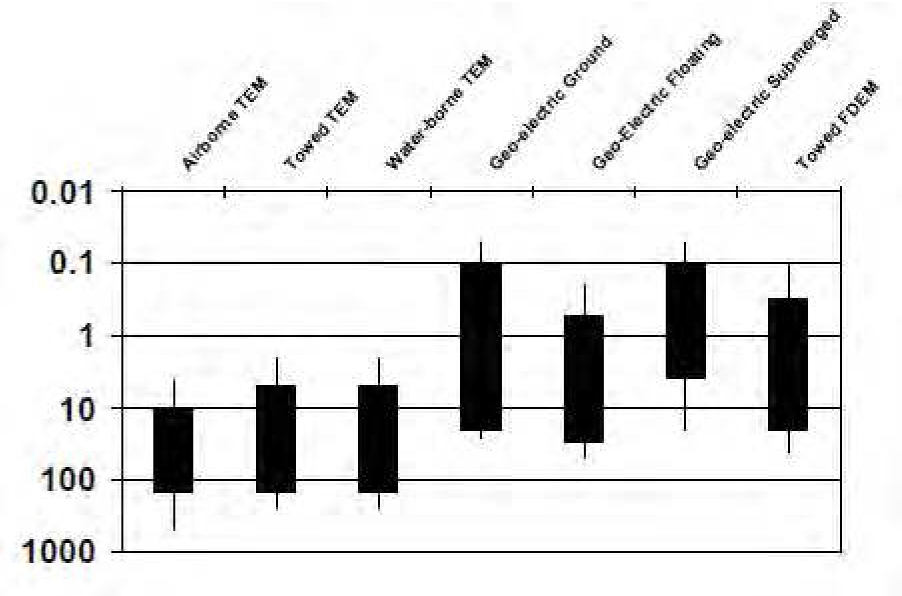


Figure 1.2: Ranges of detectable depths of various ER/EC imaging devices (in metres). Note that airborne FDEM (not shown) has a range similar to but shallower than airborne TEM (Source: ASEG Preview Magazine)

On the contrary, Electrical Resistivity (ER) based methods can be effectively used to estimate depth to groundwater table as well as to delineate saltwater and freshwater interphase. With proper survey design with ER methods, 2-D as well as 3-D pictures of the subsurface can be obtained. The ER surveys are normally conducted in conjunction with a drilling program to assess freshwater lens locations and thicknesses on atolls and sand islands, however, in Maldives Islands, drilling is not viable due to non-availability of required heavy machinery and equipment for drilling and/or excessive mobilizations costs. Therefore, the possibility of utilizing water level records from existing dug wells in household/community/institutional premises was considered and verified during pilot tests and adopted for the rest of the study.

For the present study, a pilot test was carried out in two selected islands (AA. Bodufolhudhoo Island and Adh. Dhigurah Islands) with the assistance of the Earth Resources Engineering Department of University of Moratuwa, Sri Lanka to assess the capability of ER and EM approaches for effective assessment of freshwater lens (FWL). Further, the technology service providers and commercial ER/EM equipment developers were consulted to establish the most suited ER/EM based application while additional information were referred from available literature.

Based on further considerations and following pilot tests carried out, the ER based method was selected as the most suited application for identifying and mapping of FWL in selected atoll islands.

1.4.2.1.2 Methodology for ER Based Pilot Tests

The methodology for the ER based tests for identifying and mapping of FWL in selected atoll islands is elaborated as follows.

Geophysical Investigation (Resistivity Survey)

A resistivity survey was carried out on the selected available land section of the Maldives Islands. The ER survey was conducted following a pre-determined set of transverse transects identified based on GIS and UAV maps considering representative land use, accessibility, close proximity to existing dug wells for verification purposes and to adequately comprehend the extents of groundwater layer in the form of freshwater lens. Therefore, selected representative number of locations along these pre-identified transects were surveyed to properly understand the depth to groundwater level and the freshwater-saline water interface. Existing unpaved gravel or sandy road traces where possible were selected in the present study for aligning the transects due to easy accessibility to the points.

Resistivity surveying methods available

Generally, resistivity values of geological materials show a wide range varying from 10^{-1} Ωm to 107 Ωm. Moreover, the resistivity range of any given formation can be wider and may overlap with that of other formations. The resistivity of a particular site can vary due to several factors such as properties of the water, soil moisture, temperature, nature of the subsurface material, decomposition level, depth, textural features of different strata, etc. In any given site, subsurface is not uniform and always shows heterogeneous conditions both laterally and vertically. Therefore, background data and information are collected from the available reports, core log records, and field observation before the field investigation. Types of soil/wastes, thicknesses, the orientation of geological bands, groundwater conditions, man-made structures and climatic conditions of the site are used to plan the layout or outline of resistivity surveys to obtain more realistic values to yield an equivalent model for the electrical performance of the earth.

There are several standard electrode configurations used in resistivity surveys such as Wenner array and Schlumberger arrary. The Wenner array is mostly used for profiling to investigate the lateral resistivity variation whereas Schlumberger array is used for vertical profiling. Schlumberger array is the method used in this study. Figure 1-2 shows the two different electrode arrays.

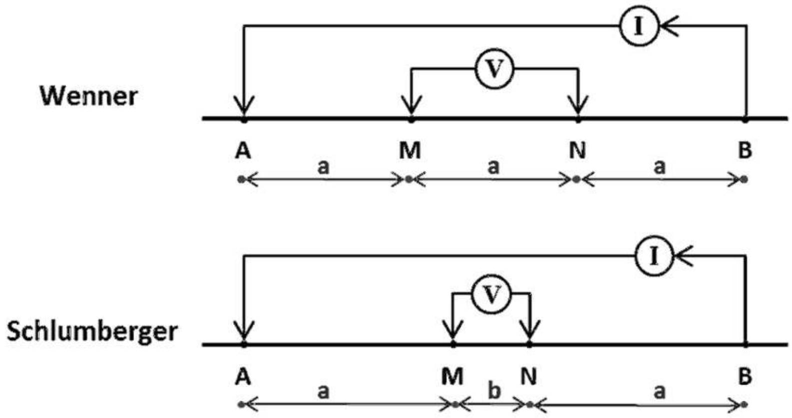


Figure 1.3: Electrode configurations -- Wenner and Schlumberger Arrays

Electrode spacing and measurement of test reading

The planned current and potential electrode spacing are given in the following tables (Table 1.2).

Table 1.2. Electrode Spacing for Schlumberger Array (Vertical Electrical Sounding)

AB/2 (m)	MN/2 (m)	Apparent resistivity (Ωm)
1.5	0.5	
2.1	0.5	
3.0	0.5	
4.4	0.5	
6.3	0.5	
9.1	0.5	
13.2	0.5	
13.2	0.5	
19.0	0.5	

Interpretation of field resistivity data

The field resistance data collected at each electrode spacing was converted to the apparent resistivity using Equation 1 for the Schlumberger array.

$$\rho_a = \frac{(\frac{AB}{2})^2 - (\frac{MN}{2})^2}{MN} \pi (\frac{V}{I}) \quad \text{..(Equation 1)}$$

Note: Apparent Resistivity (ρ_a), Current electrode spacing (AB), Potential electrode separation (MN), Field resistance(V/I).

Standard curve matching and computer modelling along with 1-D/2-D/3-D visualization software with geographic information system (GIS) interphase were used for the interpretation of field sounding curves.

Equipment for the resistivity survey

An ABEM Terrameter (Model SAS 1000) and an IRIS Resistivity Instrument (Model SYSCAL Pro) were used to carry out the island wide ER surveys in selected atoll islands.

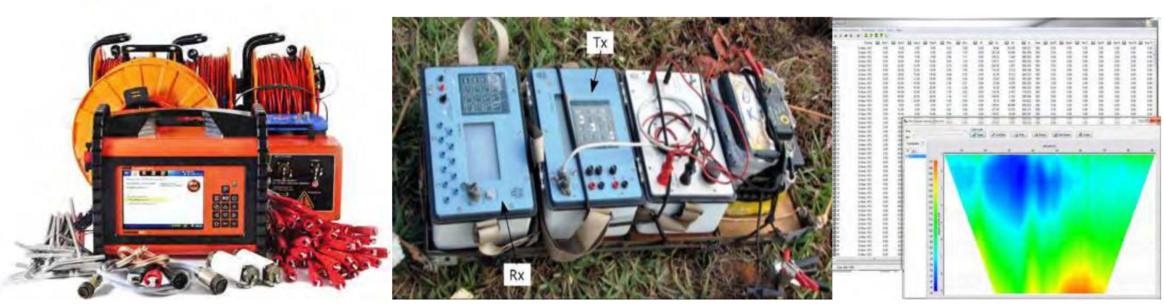


Figure 1.4. Electrical Resistivity (ER) equipment used for the field pilot tests

1.4.3 Socio-economic surveys (Water-usage survey)

In order to understand the water usage in each island, data and information were collected using a questionnaire. The survey questionnaire is attached as an annex (Annex V).

The main objective of the questionnaire was to obtain data on the water usage in each island. This data is essential to calculate the water balance for each island and to use them in the development of the aquifer management plan and the monitoring protocol.

Based on the literature review and background data collection, water usage in each island was divided into four (4) categories of users based on the pattern of water use. Sample Size to be surveyed was determined for each category based on previously conducted research such that the data is an accurate representation of the research target. The details for the categories are shown in Table 1.3. Not all the islands have these same four categories. However, in order to accurately estimate the water use in an island, information from all these categories were collected. Therefore, for each island, a socio-economic survey questionnaire was developed to collect information on these different (4) types of users. Below is the list of these categories and the following table outlines the sampling methodology for each of them.

1- Household water usage.
2- Commercial water usage (guest houses, cafes, restaurants, etc.)
3- Institutional water usage (offices, schools, hospitals, health centres, etc.).
4- Water use by farming and small industries

The 13 islands in the study have very different socio-economic setup and thus, to average the water usage in an island, these four (4) focus areas need to be assessed.

Based on the survey data collected and auxiliary information available through other secondary sources, the specific groundwater uses at island level were quantified. Further, the findings from the previous study by the Ministry of Environment and quantifications based on present surveys were verified based on literature from other similar studies.

Table 1.3: Categories for socio-economic survey

	Category 1	**Category 2**	**Category 3**	**Category 4**
Type	Households	Commercial	Institutional	Farming and Industrial (Fisheries, Mari culture etc.)
Description	Only households will be interviewed.	Guest houses, cafes, restaurants,	Schools, hospitals, health centres, government offices (Island Council, Atoll Council etc.), airports.	Farms
Sample size	10% of the households.	50% of all commercial outlets.	Minimum 50% of all the institutions.	20% of the farms
Questionnaire	Yes	Yes	Yes	Yes
Questionnaire code	C1	C2	C3	C4

1.4.3.1 Sampling methodology

1.4.3.1.1 Household surveys

Household water usage has been well studied and documented in multiple reports in the Maldives. Most notably, studies done by Tony Falkland in 2000 and various other studies that followed the 2004 tsunami have outlined the domestic water usage in very detail. These reports have been reviewed and all of them have established household water use information which are accepted as standards in the Maldives. These figures on domestic water usage are still valid, therefore a 10% sampling size was used to verify this.

For the household surveys, a 10% sample size was used. Houses were selected randomly such that the whole area of each island was covered. In selecting the samples, houses where well water sampling was undertaken were prioritised.

1.4.3.1.2 Commercial water usage.

To estimate the commercial water usage, a sample size of minimum 50% was used. Due to the variable and high groundwater usage of guesthouses, all of the guesthouses on 13 islands were surveyed on their water usage patterns. The guesthouse water usage was estimated based on the total number of bed/rooms, seasonal occupancy and also includes consideration for in-house restaurants, gardens and pools. For cafés and restaurants, a minimum of 50% of all the establishments were visited and data was collected on their water usage patterns.

1.4.3.1.3 Institutional water usage.

To estimate the institutional water usage, 50% of all the institutions were visited and data was collected on their water usage patterns. The institutions to be surveyed were selected randomly.

1.4.3.1.4 Industrial water usage

To estimate the water usage by small industries and farmers, a 20% sample size was used. A representative 20% of all the farms and other small industries that used groundwater were visited and data was collected on their water usage patterns.

1.4.3.1.5 Data entry and analysis

Data collected during the questionnaire surveys were entered and recorded on each questionnaire. All the results and responses were then entered into an excel spreadsheet and calculations were performed for individual islands. For each individual island, data for the four (4) categories of water uses was analysed separately.

1.4.3.2 Estimation of rainwater catchment / infiltration and run off

Development of an aquifer management plan requires understanding of rainfall, catchment characteristics of each island, catchment potential and estimation of infiltration and recharge as a percentage of rainfall for each island. According to Falkland (2000), approximately 30% of the rainfall will infiltrate into the groundwater aquifers as recharge and this has been used as a reasonable estimate in the Maldives and other similar small islands. Falkland also estimates 20% to be used if the area is heavily vegetated and 40% to be used if it is barren. In addition, total roof area cover and how the water is discharged will be essential to calculate the water balance.

Based on the above facts, it is therefore important to estimate these required values. To estimate the aforementioned factors, Unmanned Aerial Vehicles (UAV) surveys were completed for each island. Through the use of UAV survey, many required variables for the study were calculated.

1.4.3.2.1 Basic outline of UAV survey

Unmanned Aerial Vehicles (UAV) are being used increasingly by surveyors, project managers and GIS professionals around the world to save time and costs on surveying and mapping of projects. In the field, time spent collecting accurate data is vastly reduced by using UAV. By acquiring raster data from the sky – in the form of geo-referenced, ortho-corrected digital images, with resolutions down to 2 cm per pixel – millions of data points can be gathered in one short flight.

1.4.3.2.2 Planning the UAV survey

A pre-programmed flight plan was used because of the need to fly and maintain a very specific, accurate flight pattern. For each island, the site map and flight plan was pre-programmed, saved, and uploaded to the UAV before the mission commenced (See the following figure). DJI phantom 4 pro v2 was used for UAV surveying due to its large imaging 20MP sensor and long battery life.

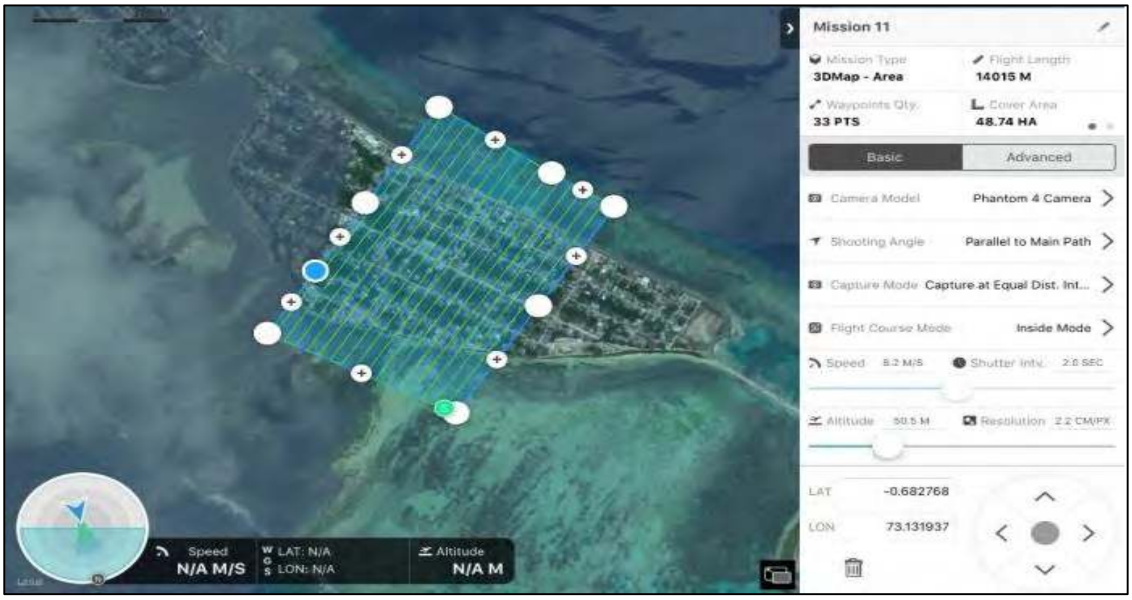


Figure 1.5 - Run lines defined & ready to be transmitted to UAV from imagery acquiring software

1.4.3.2.3 Outputs from UAV mapping

The main outputs from UAV mapping was the Orthomosaic and Digital Surface Model (DSM). The Orthomosaic was produced in very high resolutions at 2 cm per pixel. This data was used in a GIS application to extract multiple data sets such as, buildings, roof cover, roof aspect, land cover, change detection, shoreline, etc. The following image illustrates all the roof area (in red) in an island extracted using UAV survey. The total roof areas can then be easily calculated without having to measure them individually from house to house. The results were used to accurately estimate the rainwater catchment potential or how much water can be discharged into the ground. Similarly, all empty areas, vegetated areas and other similar features were extracted to estimate the runoff, infiltration rates, etc. These data was used by hydrogeologists to accurately model rainwater data and provide vital estimates on groundwater recharge, which would thereby help to develop better management plans for water.

Figure 1.6 – Calculation of Roof Cover in an island using UAV survey in Maldives

1.4.4 Present Impacts on the Freshwater Lens and Quality of Other Water Sources

The assessment of the present impacts on the freshwater lens was carried out based on the findings of the geophysical surveys, social surveys and using water balance based groundwater modelling approach for the freshwater lens in each island, considering its present subsurface volumetric extent together with associate gains (recharge) and losses (discharge).

This procedure involves the use of measured Electrical Resistivity (ER) data to estimate depth to groundwater table and saline-freshwater interphase in each cross section and along the longitudinal transect.

A robust modelling approach to estimate the volume of available groundwater in the freshwater lens in each island under steady-state conditions was developed based on the approach presented in 'Method for estimating available groundwater volume of small coral islands' by Bailey and Kivi (2017). Model inputs include average annual rainfall depth, island width for cross-sections along the ER transects and length of the island based on longitudinal ER transect, aquifer hydraulic conductivity, aquifer porosity, depth to the contact between the upper sand aquifer and the lower limestone aquifer (based on estimated depth to groundwater table and saline-freshwater interphase as per ER measurements). The required land use data including vegetation cover, road/bare-land/farmland/built-up area composition in each island were derived from the digitized land cover GIS maps and the impermeable layer extents and roof cover were extracted from high resolution UAV drone maps using hyperspectral image processing software.

The methodology proposed by Bailey and Kivi (2017) has been tested for nine islands of varying size in the Maldives and Micronesia during the course of the initial study. According to the sensitivity analysis carried out in the study, the lens volume on large islands is typically governed by the depth to the discontinuity (freshwater-saline water interphase), whereas lens volume for smaller islands is governed by rainfall rate and hydraulic conductivity. Volume curves, which relate lens volume to lens thickness, have been developed for each of the nine islands studied and for three generic island shapes to allow rapid estimation of lens volume given field-estimated lens thickness and the methods presented in the study have been recommended for any small atoll island.

Instead of using the proposed empirical equations for the maximum freshwater lens thickness which depends on the recharge rate and island width, the estimated layer thickness based on ER measurements were used in the model estimates for generating volumetric estimates of the freshwater lens. Furthermore, it is noted that the above algebraic equations can be effectively used in estimating possible growth of freshwater lens following the replenishment due to the recharge generated from monsoonal rainy period. The initial ER measurements in the islands were carried out during the period from February to March towards the end of the dry period in Maldives and the above presently existing and maximum possible estimations of freshwater lens volumes can be derived to have further distinct insight into the present stress level of the aquifers in individual islands.

Additional soil permeability field tests and steady state pumping tests were carried out at selected representative locations in the islands to gather supplementary aquifer hydraulic conductivity, transmissivity and groundwater yield estimates required to facilitate the procedure aforementioned. The data on usage characteristics and quality of other water sources were collected based on the social surveys and water quality tests carried out as described in the previous sections.

1.4.4.1 Soil permeability field tests

Field permeability testing in the unsaturated zone was carried out by measuring water absorbance at a constant head in a 4-inch hole. The permeability test is a measure of the rate of the flow of water through the soil. The methodology for Constant Head Gravity Permeability Tests is shown in Figure 1.6. A minimum of 2-5 representative locations were selected in each island depending on the size of the island, land use and hydrogeological and soil over burden characteristics.

The natural or artificial recharge of groundwater aquifers directly depends on the infiltrated water moving through the impeding upper subsurface soil layers which is largely affected by their permeability, among various other parameters. Permeability tests were carried out at selected representative locations in each island, following Standard Test Method for Field Measurement of Hydraulic Conductivity Using Borehole Infiltration (ASTM D6391-11) and Borehole Infiltration Test (Direct Push Casing Approach) – Maryland Stormwater Manual (2009).

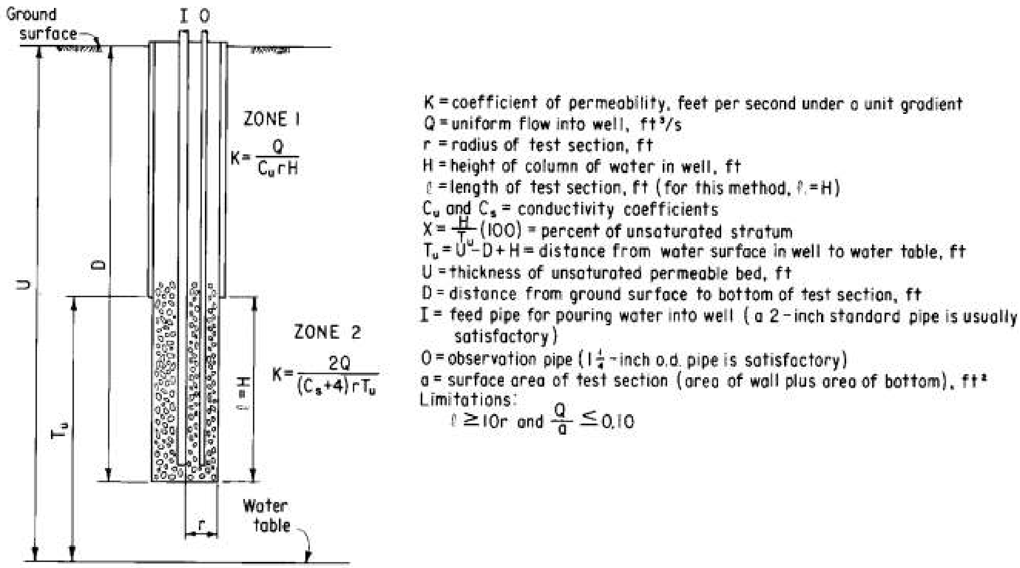


Figure. 1.7. Methodology for Constant Head Gravity Permeability Tests

An average depth of 1.2 m – 1.5 m in the unsaturated zone above groundwater table was selected to represent the active recharge zone in the islands and manual drilling or petroleum gas powered hand-operated power auger was used with minimum disturbance to the soil overburden which was mostly either sand, clayey sand or sandy gravel in these atoll based coastal aquifers.

1.4.4.2 Steady state pumping tests

A pumping test is a field experiment in which a shallow dug well in the aquifer to be tested is pumped at a controlled rate and water-level response (drawdown) is measured in one or more surrounding observation wells and optionally in the pumped well (control well) itself. The response data from pumping tests in the present study were used to estimate the hydraulic properties of aquifers while they can further be used to evaluate well performance and identify aquifer boundaries.

The typical well configuration for conducting a pumping test in a nonleaky confined aquifer and the procedure for estimation of aquifer properties by matching Theis (1935) type-curve solution to time-drawdown data is presented in Fig. 1.7. However, the bottom layer was karstic limestone bed and the freshwater lens is limited to the upper soil overburden in the islands, and thus the well penetration was only limited to the saturated zone below the water table.

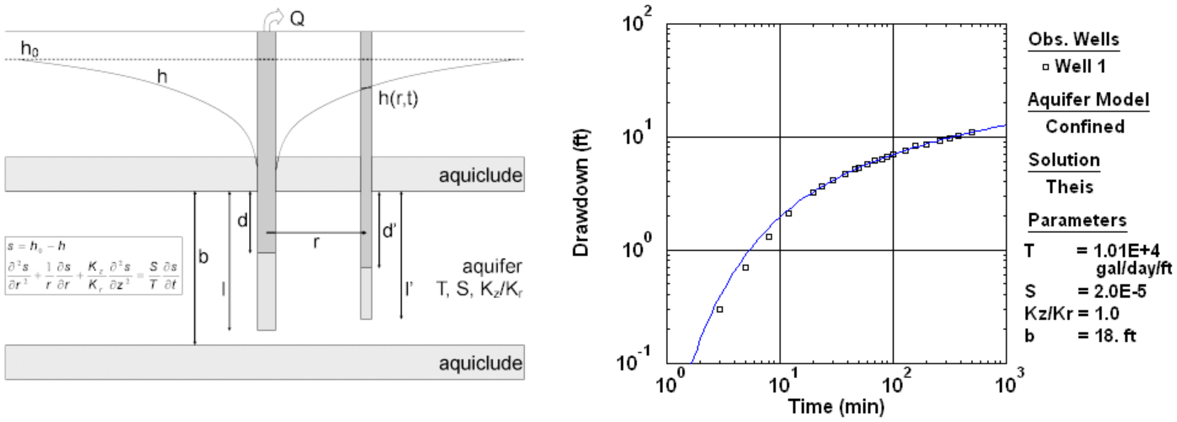


Fig. 1.8.Typical well configuration for pumping test in nonleaky confined aquifer and Estimation of aquifer properties by matching Theis (1935) type-curve solution to time-drawdown data

The aquifer properties are estimated from the constant-rate pumping test in the unconfined aquifer by fitting mathematical models (type curves) to drawdown data through the procedure known as curve matching. In addition to the Constant-rate tests carried out maintaining the pumping at the control well at a constant rate which is the most commonly used pumping test method for obtaining estimates of aquifer properties, recovery tests at selected well locations were carried out with water-level (residual drawdown) measurements after the termination of pumping to determine well performance characteristics such as well loss and well efficiency (Fig. 1-8).

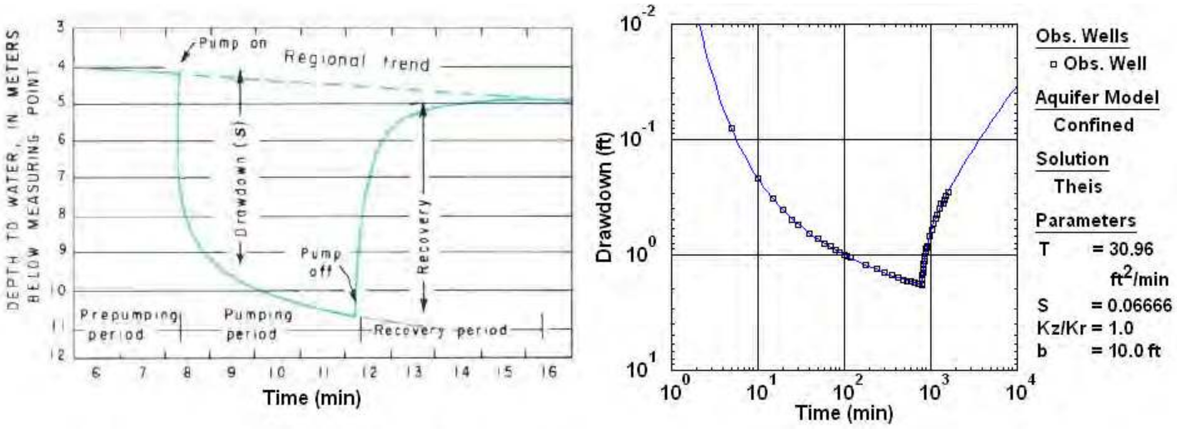


Figure 1.9.Typical well configuration for pumping recovery test in a confined aquifer and Estimation of aquifer properties by matching Theis (1935) type-curve solution to time-drawdown data

1.4.5 Estimation of rates of groundwater recharge and discharge

The groundwater recharge and discharge characteristics of the freshwater lens and associated aquifers in individual islands were estimated based on the findings of the household social surveys, institutional data and results of the water balance modelling approach. The recommendations for the potential groundwater development and artificial recharge is derived based on above and collected land use, built-up area, local flood extent data and terrain data.

2 Groundwater in Maldives

This section briefly outlines the background of groundwater development in Maldives, a vital source of information for the reader in order to understand the broader context of water resource management. The following information is extracted from the report, Integrated Water Resource Management and Sustainable Sanitation in Maldives (Falkland, 2001).

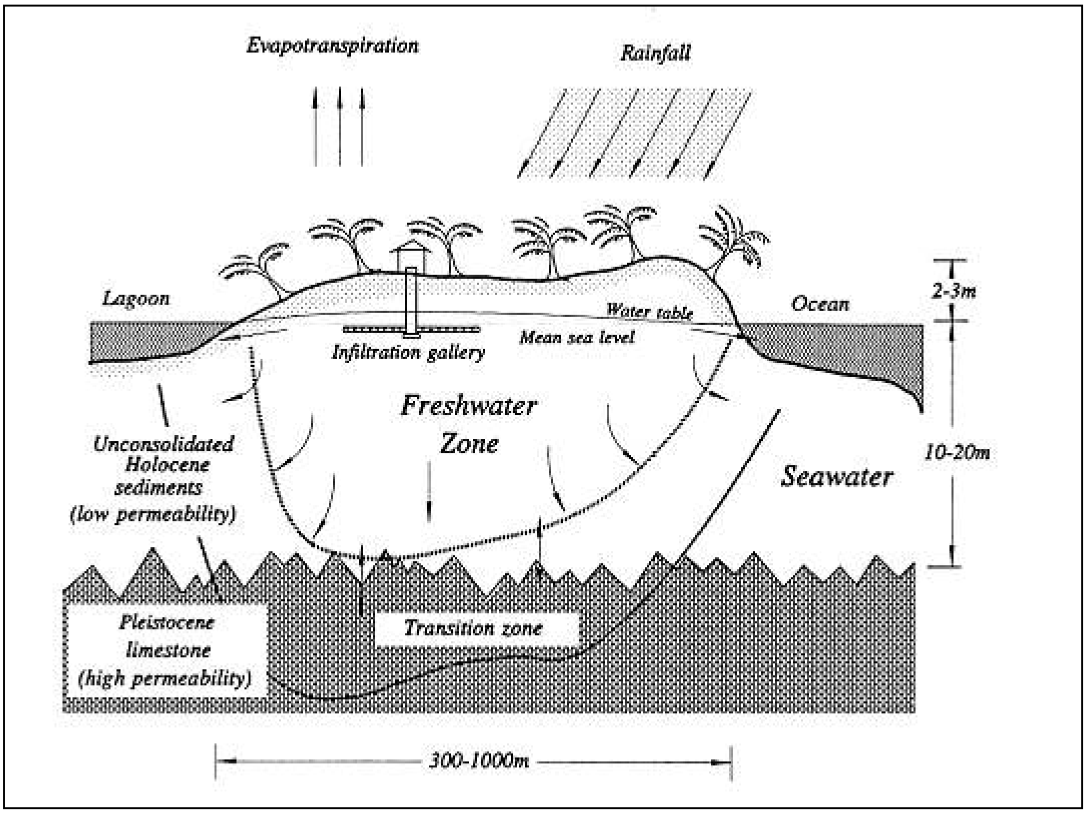
2.1 Groundwater Occurrence

Fresh groundwater occurs in the form of 'freshwater lenses' on medium to large sized islands in the Maldives. These freshwater lenses are an important and valuable source of water supply on most of the islands. They are highly susceptible due to saline intrusion as a result of pumping and vulnerable to pollution from surface and sub-surface waste disposal, particularly from sanitation systems.

The term "freshwater lens" can be misleading as it implies a distinct freshwater aquifer. In reality, there is no distinct boundary between freshwater and seawater but rather a transition zone (refer to the following Figure 2.1). The upper surface of a freshwater lens is the water table.

The base of the freshwater zone can be accurately determined by establishing a recognisable salinity limit for freshwater and drilling through the lens to find where the limit occurs. The salinity limit adopted for freshwater (suitable for drinking water) is often taken as the WHO guideline value for chloride ion of 250 mg/L (WHO, 1993). This is approximately equivalent to an electrical conductivity (EC) of 1,500 µS/cm. In some islands, a higher value of EC (e.g. 2,500 µS/cm) has been used as an upper limit, noting that the WHO guidelines are based on taste and not health considerations.

Figure 2.1: Cross section through a small coral island showing main features of a freshwater lens



(exaggerated vertical scale)

Freshwater lens thickness on a small coral island is dependent on many factors including:

- Geology, particularly in top 20 m of island
- Hydrogeological properties, particularly porosity and permeability

- Size of island, particularly width from coast to coast
- Recharge to groundwater (which is dependent on the magnitude and variability of rainfall and on evapotranspiration from the surface of the island and the vegetation)
- Sea level movements
- Groundwater withdrawal from wells or other systems.

Another potential factor is height above sea level and the frequency of seawater inundation in very low-lying parts of islands.

The water balance between rainfall (input of water to the surface of the island) and evapotranspiration (output of water from the surface of the island), as depicted in Figure 2.1, determines the amount of recharge to the groundwater. The amount and variability of recharge is a chief determining factor of freshwater lens thickness (amount of water stored) and is a key element in determining the sustainable yield of a freshwater lens.

Freshwater lens conditions in selected islands in the south and north of the Maldives have been described in several other reports by Falkland (Falkland; 2000a, 2001). These reports are based on extensive investigations including drilling, geophysics and well surveys to assess the occurrence and behaviour of freshwater lenses. The investigations revealed that there are considerable variations in thickness, area and volume of freshwater lenses between the islands. Some islands show quite thick and extensive freshwater zones, while others have very small and thin freshwater zones.

It is noted that a relationship was investigated (from the boreholes on Addu atoll) between freshwater lens thickness and width of the island, and it was found that a reasonable relationship did exist (refer Falkland, 2000a).

Detailed studies on other atolls in the Pacific and Indian Oceans, including extensive coring on the Cocos (Keeling) Islands in the Indian Ocean (Woodroffe and Falkland, 1997), have commonly found the existence of two layers of sediments. A geological unconformity, separating these two layers at typical depths of 10-15 m below mean sea level, is one of the main controls to freshwater lens thickness (refer Figure 2.1). The freshwater zone is mainly or solely contained in the relatively low permeability coral sediments as mixing of freshwater and seawater occurs readily in the high permeability limestone. Based on limited coring on Addu atoll, similar conditions were found on that atoll (Falkland, 2000a). While no cores were obtained from the drilling in 11 islands in Haa Dhaalu and Haa Alifu, there is sufficient evidence from bore logs and permeability tests to suggest that those islands are also similar (Falkland, 2001). Hence, it would be expected that similar conditions apply throughout the islands of the Maldives and that the model shown in Figure 2.1 is a reasonable representation of geological and groundwater conditions. Of course, the thickness of fresh groundwater is variable, depending on the factors listed above.

In addition to the vertical variation in permeability, there is often an across-island variation in permeability. Often finer sediments with lower permeability accumulate on the more tranquil side of the island while coarser, higher permeability sediments are found on the more exposed shorelines. In this context, exposed shorelines are those that are most affected by storms and wave action. Where finer sediments are found, the freshwater lens tends to be thicker due to less mixing of fresh and saline water than in coarser sediments. For this reason, wells at a given distance from the more tranquil shoreline tend to have much lower salinity than wells at the same distance from the more exposed shoreline. This is most noticeable for wells within about 50 m of the coastline.

2.2 Salinity Criteria for 'Fresh' and Potable Groundwater

In order to interpret the salinity data for wells and other locations, it is necessary to have an objective means of assessing groundwater as either 'fresh' or 'brackish'. Without such criteria it is not possible to define the available fresh groundwater resources including the areal extent and thickness of freshwater lenses on islands.

There is no clear definition of 'fresh' groundwater for islands in the Maldives to date.

There are a number of ways to define criteria for 'fresh' groundwater. It can be assessed in terms of appropriate guidelines for potable (drinking) water and/or can be assessed for non-potable uses.

In order to assess the salinity of water samples, particularly groundwater samples, in terms of suitability for potable (drinking) purposes, the Guidelines for Drinking-Water Quality published by the World Health Organisation (WHO, 1993) are generally used. There is no specific drinking water guideline provided for electrical conductivity (EC) but guideline values are provided for other measures of salinity, including chloride ion concentration (250 mg/L) and total dissolved solids (1,000 mg/L). Both guidelines are based on taste and not health considerations. From previous comparisons of chloride ion concentrations and EC values on coral islands, including those in the Maldives, a chloride value of 250 mg/L is approximately equivalent to an EC value of 1,200-1,500 µS/cm.

In some other similar coral islands (e.g. Kiribati, and coral islands within the Cook Islands and Tonga), a higher value of EC (e.g. 2,500 µS/cm) has been used as an upper limit for potable water, noting that the WHO guidelines are based on taste and not health considerations. Above an EC value of about 2,500 µS/cm (approximately equivalent to a chloride concentration of 600 mg/L), the taste of groundwater becomes noticeably saline and the level of corrosion of susceptible metals and scaling (e.g. on heating elements in electric jugs, etc.) becomes greater.

Typical EC values for different types of water are provided in Table 2.1 for comparison with the results obtained from the baseline assessment of the selected islands.

Table 2.1: Typical salinity (EC) values for water

Type of Water	Typical EC range (µS/cm)
Rainwater	50 – 100
Very fresh groundwater	250 – 500
Fresh groundwater	500 – 1,500
Maximum limit for potable water ***Suggested desirable limit of 'freshwater' for non-potable purposes,***	***1,500*** ***(based on WHO guideline for chloride (250 mg/L)***
Suggested maximum limit of freshwater for non-potable purposes	***2,500***
Mildly brackish water	2,500 – 5,000
Very brackish water	10,000 – 50,000
Seawater	50,000 – 55,000

Note: WHO = World Health Organisation drinking water quality guidelines (1993)

Hence, for the purposes of this report, the following EC limits are suggested as water quality objectives:

- Potable water 1,500 µS/cm
- Non-potable freshwater (desirable): 1,500 µS/cm
- Non-potable freshwater (maximum): 2,500 µS/cm

Above 2,500 µS/cm, the groundwater can be described as brackish.

It is recognized that groundwater with salinity above the suggested maximum limit for freshwater (2,500 µS/cm) can be used for a number of purposes (e.g. bathing, washing and toilet flushing) without significant impacts, provided that the salinity is not much greater. Water for toilet flushing can exceed this limit.

It is noted that of the non-potable water, there are essentially two sub-types with different water quality requirements. Firstly, water used for bathing and washing should be acceptable in terms of both salinity and bacteriological quality. Secondly, water used for toilet flushing could be of a lesser standard in terms of salinity and bacteriological quality. However, even the water used for toilet flushing should not have too high a salinity.

3 HA. UTHEEMU ISLAND

3.1 General overview of the island

The Island of Utheemu is located at 06°50'04"N and 73°06’47”E within the Haa Alif Administrative Atoll. The Island is 865 m long and 736 m wide resulting in the island having an area of 48.7 Hectares. The Island has a population of 569 people, via the 2014 Census. The islands’ existing sewage is comprised of septic tanks and small bore sewers. Most households have septic tanks to dispose of human waste. A harbor has been built on the Southern side of the island as of 2016. The island does not have a water supply network. The primary source of drinking water for inhabitants of the island is water collected in rainwater tanks. It is an important historical site as the birthplace of Sultan Mohamed Thakurufaanu and where the Utheemu Ganduvaru is located.

Table 3.1: Basic statistical information on Utheemu island in HA Atoll.

Name of the island	HA.Utheemu
Longitude and Latitude	73° 7'56.05"E, 5° 9'26.83"N
Area	49.4 ha
Population (Census, 2014)	839
Distance from Atoll Capital (HA. Dhidhdhoo)	9km
Distance from Male’	122km
Harbour	Present
Island sewerage network	No
Water supply network	No
Other infrastructure	

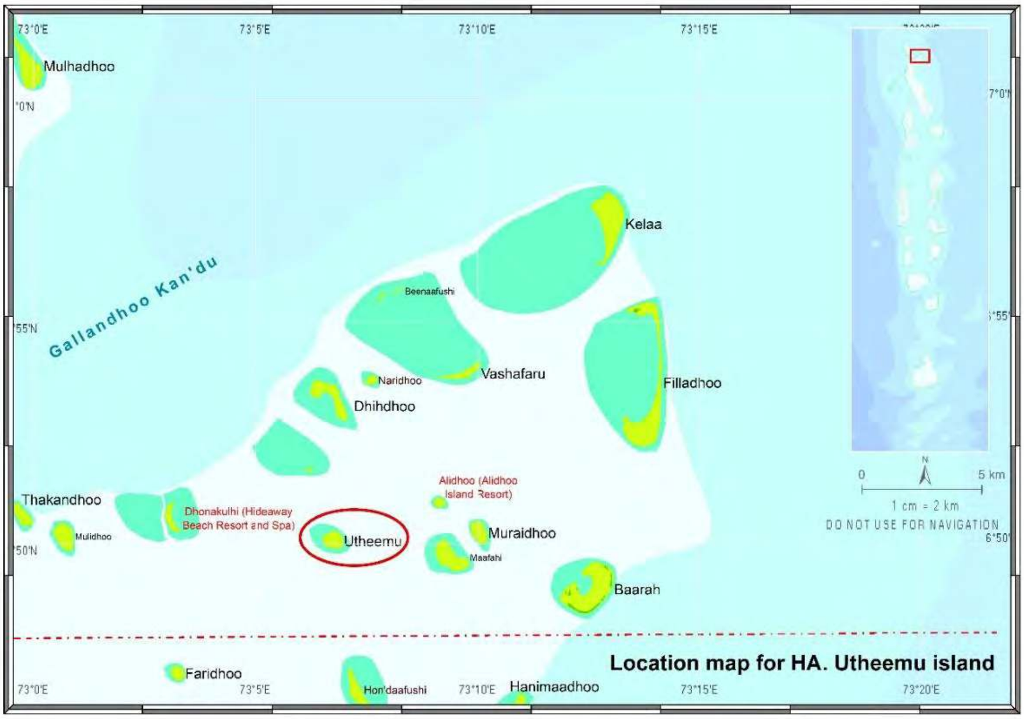


Figure 3.1: Location map for Utheemu Island, Haa Alif Atoll.

3.2 Geology and vegetation

About 47% of the island is vegetation, which is located at the outer part of the island on the eastern and western sides. The island is about 865 m long and 736 m wide. There is a harbor on the southern side of the island which is built upon reclaimed land. With the exception of home gardens, no farming takes place on this island.

3.3 Topography

Utheemu has general characteristics similar to other islands of Maldives with an average elevation of 1.96 metres from mean sea level. The island has a topography that ranges from an elevation of 0.06 meters to 4.50 meters above Mean Sea Level. Figure 3.2 shows map of Utheemu Island showing spot heights and digital surface model (DSM).

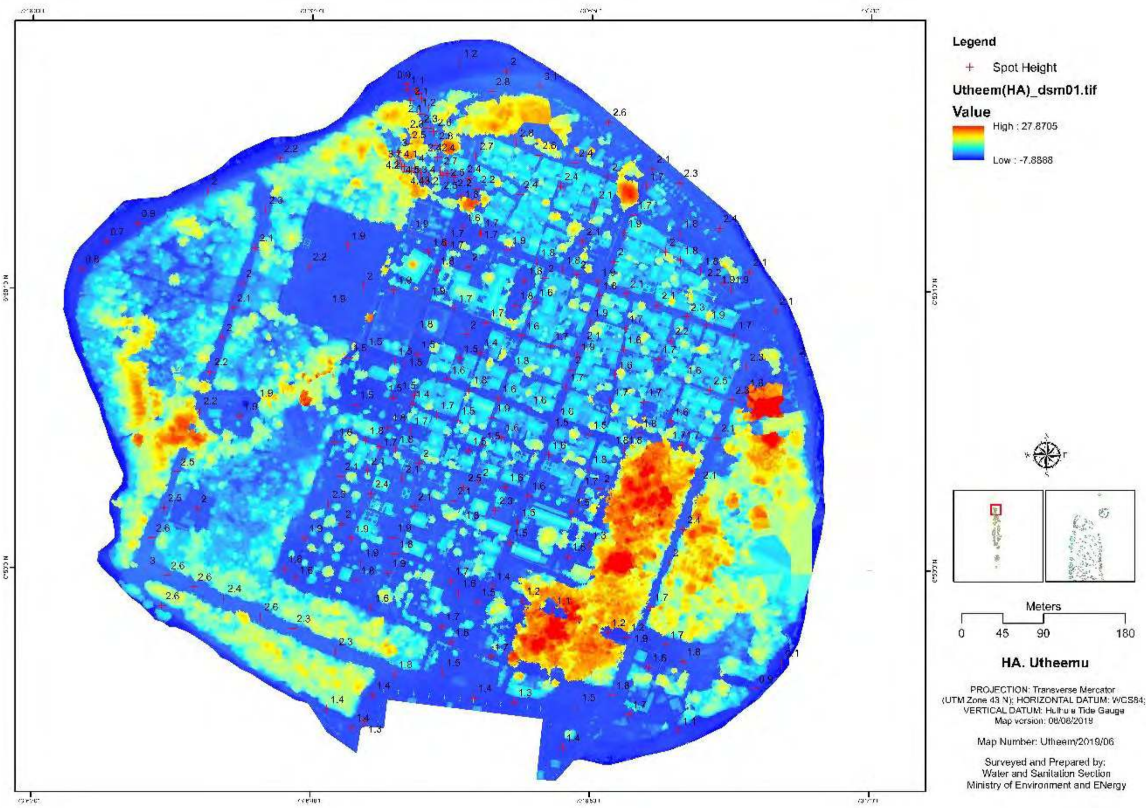


Figure 3.2: Map of Utheemu Island showing spot heights and digital surface model (DSM)

3.4 Climate

Utheemu experiences the typical two monsoons namely, north east monsoon from November to April and South-west monsoons from April to November. There are no specific wind and rainfall data available for Utheemu as there are no weather monitoring stations on the island.

3.5 Demography

HA. Utheemu has a registered population of 569 via the 2014 census, with 538 locals and 31 foreigners. These figures may not be accurate as the population given by the island council is higher. For the total population there are 87 more females than males (57:43 percent). This ratio is more prominent when only the local population is considered as there are 102 more females than males (59:41 percent). The foreign population in the island on the other hand, has more males than females. The following tables and graphs illustrate the demographic breakdown of Utheemu.

Table 3.2: Demographic Breakdown of Utheemu Island

Atoll	**locality**	**Resident population (Census, 2014)**								
		Total			**Maldivians**			**Foreigners**		
		Both sexes	**Male**	**Female**	**Both sexes**	**Male**	**Female**	**Both sexes**	**Male**	**Female**
HA	Utheemu	569	241	328	538	218	320	31	23	8

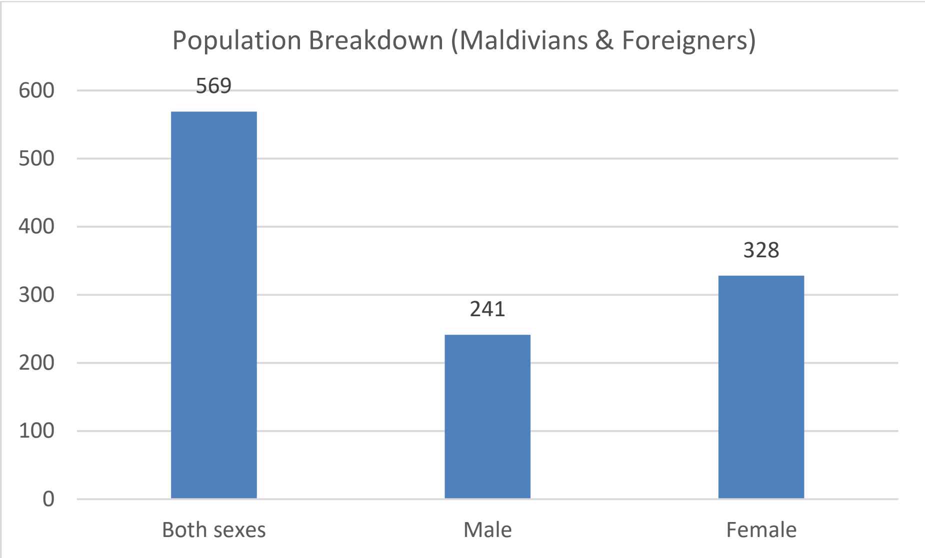


Figure 3.3: Population breakdown of Utheemu (Maldivians & Foreigners)

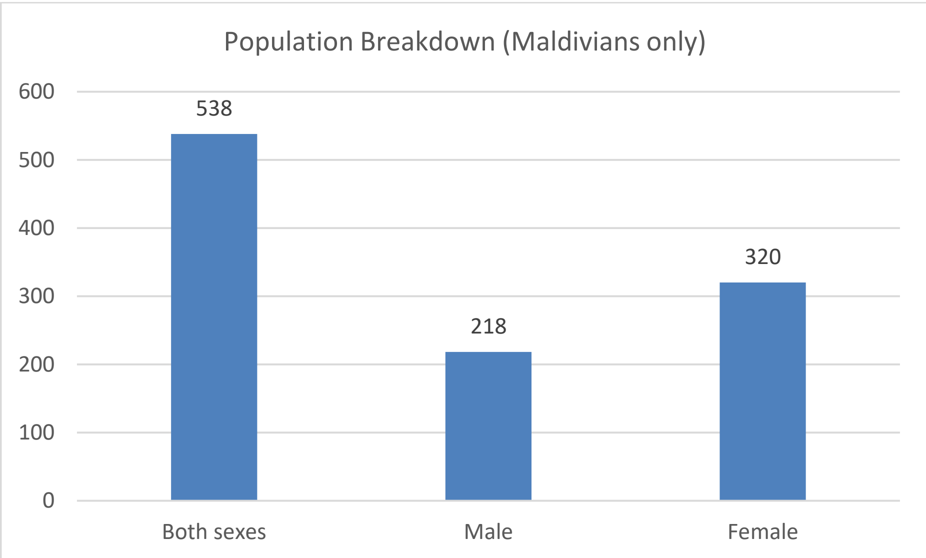


Figure 3.4: Population breakdown of Utheemu (Maldivians & Foreigners)

3.6 Socio-economic condition

Utheemu is an important and popular historical site within the Maldives, being the birthplace of Sultan Mohammed Thakurufaanu. The Utheemu Ganduvaru is a popular historical landmark which has been having a record number of visitors in recent years.

3.7 Existing water and sanitation situation

The island does not have either an island wide sewerage system or a piped water supply system. The main form of sanitation is via the use of septic tanks and small bore sewers. Each household has one or two septic tanks, and the septic tanks are cleaned periodically by disposing and burying the septic waste in other parts of the island. On average, there is an approximate distance of 10.32 meters between septic tanks and nearest well with distances ranging from 4.5 meters to 24.5 meters. A sewerage system in the island is currently under construction.

The main source of drinking water is rainwater collected from roofs and stored in tanks, whether they are community tanks or in households, or bottled water. The main source of water for cooking is rainwater. As this has a tendency to run out during the dry season, many households use rainwater from other houses or bottled water.

3.8 Results

3.8.1 Water sources and water use

Based on domestic, commercial, institutional and industrial water usage, a total of 117,636 liters of groundwater are estimated to be used every day. Otherwise stated, 207 liters of groundwater are used per capita per day. The respective water use situations are detailed in the following sections.

3.8.1.1 Domestic water use situation

Based on the questionnaire to collect data on domestic water consumption, a summary of results are present in this section.

According to the survey, 100% of the households surveyed uses HDPE rainwater tanks as their main storage for water. A total of 80% households use rainwater for drinking while 20% use bottled water for drinking. 100% of households use rainwater for cooking. None of the surveyed houses use rainwater for bathing or washing.

0% of the households use groundwater as drinking. Groundwater is mainly used for non-potable use in all the households surveyed. The following table summarizes the data for Utheemu island.

Table 3.3: Groundwater and rainwater use data for Utheemu Island

Rainwater	
Households with rainwater tanks	8 of 10 i.e. 80%
Rainwater use for drinking	70%
Rainwater use for cooking	100%
Rainwater use for bathing and washing	0%
Groundwater	
Groundwater as drinking source	0%
Groundwater for cooking	0%
Groundwater for non-potable use	100%
Total number of household wells surveyed	10 (10%)
Percentage of wells surveyed fitted with pumps	90%

Based on the survey questionnaire, average daily water demand per capita for domestic purposes has been estimated based on the average amount of water used per person for showering, toilet flushing, laundry and gardening, and this data is shown in Table 3.4. The total domestic water use is estimated to be 197 liters per capita per day.

Table 3.4: Domestic Water Usage in Utheemu Island

Shower/ Liters per capita per day	Toilet/ Liters per capita per day	Laundry/ Liters per capita per day	Gardening/ Liters per capita per day	**Total/ Liters per capita per day**
108	22	21	46	**197**

3.8.1.2 Commercial water use situation

Based on the questionnaire to collect data on commercial water consumption, a summary of results are presented in this section. A total of 1 restaurant and 1 guesthouse was surveyed.

For the guesthouses, the main use of groundwater was for showers, toilet flushing, gardening and dish washing for those guesthouses which contained restaurants. The following table presents a summary. A total of 1472 liters of groundwater are used by 1 guesthouse in Utheem.

Table 3.5: Water Usage in Guesthouses in Utheem

Name of Guesthouse	**Number of rooms**	**Average occupancy throughout the year**	**Total Volume of water per day (Liters)**	**Total Volume of water per guest per day (Liters)**
Bahaaru Inn	3	80%	1,472	307
		Total:	1,472	

For the restaurants, the main use of groundwater was for dishwashing and toilet use. A total of 1 restaurant was surveyed and from this data, the total groundwater consumption for the 2 restaurants on this island was estimated to be 511 liters of water per day.

3.8.1.3 Institutional water use situation

Based on the questionnaire to collect data on institutional water consumption, a summary of results are present in this section. Three institutions were surveyed for this study namely the powerhouse, pre-school, school, health center and council office. Groundwater in the institutions in Utheemu Island are mainly used for gardening, mopping floors and flushing toilets. A total of approximately 7586 liters of groundwater are estimated to be used per day by the institutions. Therefore, a total of approximately 12.4 liters of groundwater are estimated to be used per capita per day by the institutions of Utheemu Island.

Table 3.6: Water Usage in Institutions in Utheemu Island

	Water Flushed (Liters per day)	**Gardening (Liters per day)**	**Mopping (Liters per day)**	**Total Water Usage (Liters per day)**	**Institutional Groundwater Usage (Liters per day)**	**Institutional Groundwater Usage (Liters per capita per day)**
Health Center	70	-	-	70	3727	6.55
Island Council	43	180	-	223		
Convention Center	74	2160	-	74		
School	470	870	39	509		

3.8.2 Groundwater quality

Groundwater quality measurements were made at selected wells in Utheemu for both physical and microbiological testing.

The following table 3.7 summarizes the water quality results.

Table 3.7: Summary of groundwater quality tests from Utheemu, April 2019

Sample No	**Odour**	**Physical Appearance**
gw1	yes	Clear
gw2	yes	Clear with particles
gw3	no	Clear with particles
gw4	yes	8
gw5	no	Clear with particles
gw6	yes	Pale yellow with particles
gw7	yes	Clear with particles
gw8	yes	Pale yellow with particles
gw9	yes	Clear with particles
gw10	no	Clear with particles

Sample No	**EC (µS/cm)**	**TDS (mg/L)**	**pH**	**Turbidity (NTU)**	**DO (mg/L)**	**Temp (°C)**	**Salinity (PSU)**	**Nitrates (mg/L-**	**Ammonia (mg/L)**	**Phosphates (mg/L)**	**Total Coliform (MPN/100 ml)**	**Faecal Coliform (MPN/100**
gw1	947.7	537	7.56	0.18	6.79	32.7	0.4	28.3	1.15	0.05	649	217
gw2	863	500	7.69	0.03	6.14	31.3	0.37	24.5	0.55	0.1	>2420	>2420
gw3	730.8	406	7.67	0.01	5.47	34	0.3	3.6	0.74	0.36	33	33
gw4	1064.8	597	7.53	0.02	5.23	33.3	0.44	34.0	0.96	0.25		
gw5	695.6	401	7.65	0.01	6.46	31.7	0.29	14.3	0.53	0.39	649	206
gw6	1464.3	840	7.17	0.09	1.53	32	0.64	84.9	7.01	0.12	-	-
gw7	1022.5	603	7.32	0.03	2.92	30.4	0.45	40.7	3.81	0.16	-	-
gw8	9341.7	5500	7.18	0.06	7.56	30.5	4.67	70.8	13.36	0.08	-	-
gw9	883.4	509	7.5	0	6.2	31.7	0.38	35.9	0.97	0.06	-	-
gw10	429.1	244	8.1	0.07	6.91	32.4	0.18	2.4	0.23	0.09	-	-

	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)
WHO Standards	Suggested maximum limit of freshwater for potable purposes = 1500 µS/cm Suggested maximum limit of freshwater for non-potable purposes = 2500 µS/cm	-	-	-	-	-

	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
WHO Values	-	Guideline Value = 50 mg/L-NO3	Natural Level of Ammonia < 0.2 mg/L Threshold odour concentration = 1.5 mg/L Taste threshold = 35 mg/L	-	-	-

Figure 3.5: Location of groundwater sampling points in Utheemu Island

Based on the full results and the summary shown in Table 6.6, the following observations are made:

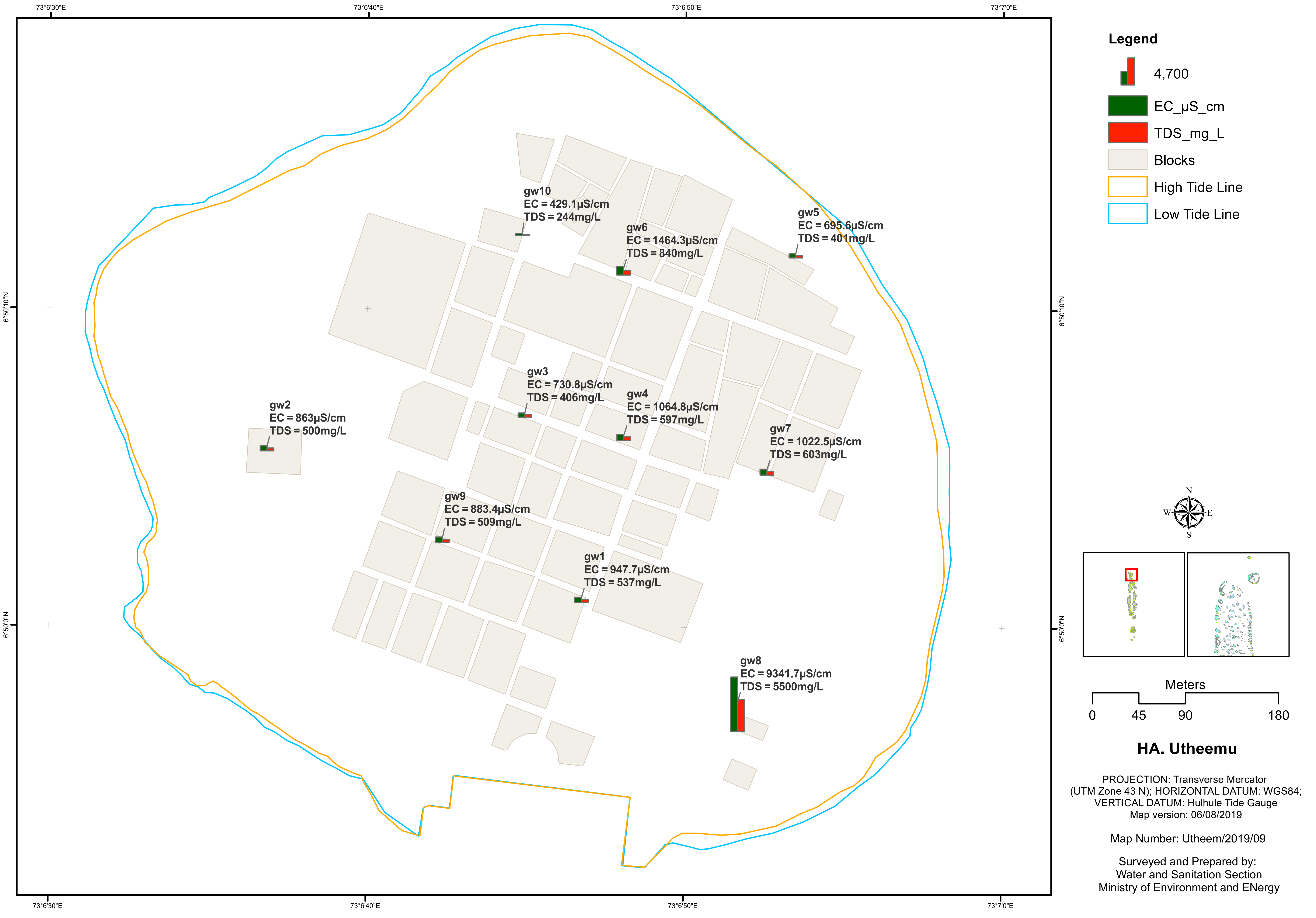
- The average Electrical Conductivity (EC) of the groundwater is generally low, apart from one sample (gw8) which has an EC of 9341.7µS/cm. The average EC is 1744.3 µS/cm including

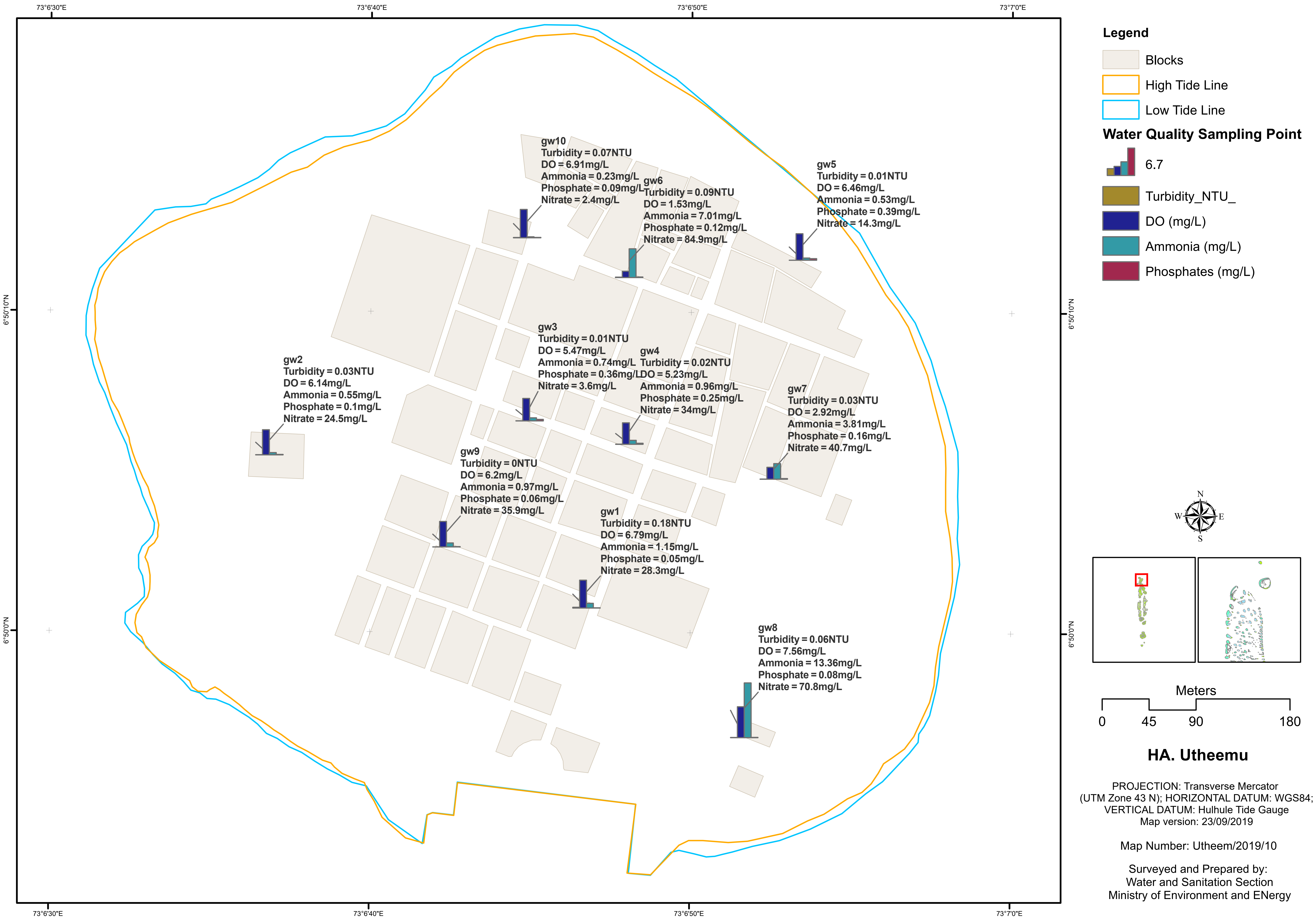
GW8, however, the average reading excluding GW8 is 900 µS/cm which is within an acceptable limit for potable water of 1,500 µS/cm (refer section 2.2). Additionally, the EC of all the samples apart from GW8 are below the acceptable limit for potable water of 1,500 µS/cm.

- Sample gw8 was taken near the waste management center and is also within 100m from the shoreline. Therefore sample gw8 has a high EC, TDS, salinity, DO, Nitrate concentration and Ammonia concentration.
- Total Dissolved Solids ranged from of 244 mg/L to 5500 mg/L with an average of 1013.7 mg/L.
- The pH of groundwater ranged from the 7.17 to 8.10 with an average pH of 7.54.
- Turbidity was generally very low, ranging from 0 NTU to 0.18 NTU with an average turbidity of 0.05 NTU. As a guide, "crystal-clear" water has a turbidity below 1 NTU, and water becomes visibly cloudy at 4 NTU and above. The average turbidity for samples from Utheem is the lowest from the 13 islands.
- Dissolved oxygen levels ranged from 1.53 to 7.56 mg/L. The average value was 5.52 mg/L.
- The salinity of groundwater ranged from 0.18 PSU to 4.67 PSU with an average of 0.81 PSU. The reading of 4.67 PSU is the only reading with a higher salinity value than 0.65 PSU.
- The average Nitrate concentration was 33.9 mg/L which does not exceed the WHO guideline limit of 50 mg/L. The Nitrate concentrations ranged from 2.4 mg/L to 84.9 mg/L.
- Ammonia concentrations were generally high. Ammonia concentrations ranged from 0.23 mg/L to 13.36 mg/L concentration with an average concentration of 2.93 mg/L and. This exceeds the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. However, only 3 of the 10 tested water samples exceeded the WHO guideline. Natural levels of ammonia are generally below 0.2 mg/L (WHO, 1993) and no tests showed concentrations below this level. There is no apparent correlation between increasing levels of ammonia and other nutrients.
- Phosphate concentrations ranged from 0.05 mg/L to 0.39 mg/L with an average concentration of 0.17 mg/L. There is no WHO drinking water guideline value for phosphate concentration. However, it would normally be expected that phosphate concentrations in groundwater are less than 0.1 mg/L, where there are no impacts from human wastewater (e.g. effluent from septic tanks and 'greywater' from kitchens and bathrooms). Only 4 samples (40%) tested were below 0.1 mg/L.
- Faecal Coliform levels were found to be significant and ranged from lowest count of 33 MPN/100mL to the highest count of more than 2420 MPN/100mL with an average of 719 MPN/100mL. Total coliform levels were also found to be significant and ranged from lowest count of 33 MPN/100 mL to the highest count of more than 2420 MPN/100 mL with an average of 937.75 MPN/100mL. Sample gw2 which was taken from the old mosque had the highest faecal and total coliform levels compared to residential areas with lower faecal and total coliform content. As expected, the groundwater layer is contaminated with effluent from septic tanks.

In conclusion, Utheemu Island contains groundwater with generally low Electrical Conductivity with a higher average than WHO guidance value for potable water but lower than the WHO guidance value for non-potable water and low TDS. Nitrate concentration was lower than WHO maximum guidance value, average Ammonia concentration and average Phosphate concentration were higher than expected in natural, undisturbed groundwater. In terms of microbiological contamination, an island wide contamination is observed.

Additionally, the following pages contain maps which show the main physiochemical parameters displayed on map of the island.


73°6'30"E
73°6'40"E
73°6'50"E
73°7'0"E
6°50'10"N
6°50'0"N
gw10
EC = 429.1μS/cm
TDS = 244mg/L
gw6
EC = 1464.3μS/cm
TDS = 840mg/L
gw5
EC = 695.6μS/cm
TDS = 401mg/L
gw3
EC = 730.8μS/cm
TDS = 406mg/L
gw4
EC = 1064.8μS/cm
TDS = 597mg/L
gw2
EC = 863μS/cm
TDS = 500mg/L
gw7
EC = 1022.5μS/cm
TDS = 603mg/L
gw9
EC = 883.4μS/cm
TDS = 509mg/L
gw1
EC = 947.7μS/cm
TDS = 537mg/L
gw8
EC = 9341.7μS/cm
TDS = 5500mg/L
Legend
4,700
EC_μS_cm
TDS_mg_L
Blocks
High Tide Line
Low Tide Line
N
W
E
S
Meters
0
45
90
180
HA. Utheemu
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 06/08/2019
Map Number: Utheem/2019/09
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy



73°6'30"E
73°6'40"E
73°6'50"E
73°7'0"E
6°50'10"N
6°50'0"N
gw10
Turbidity = 0.07NTU
DO = 6.91mg/L
Ammonia = 0.23mg/L
Phosphate = 0.09mg/L
Nitrate = 2.4mg/L
gw6
Turbidity = 0.09NTU
DO = 1.53mg/L
Ammonia = 7.01mg/L
Phosphate = 0.12mg/L
Nitrate = 84.9mg/L
gw5
Turbidity = 0.01NTU
DO = 6.46mg/L
Ammonia = 0.53mg/L
Phosphate = 0.39mg/L
Nitrate = 14.3mg/L
gw3
Turbidity = 0.01NTU
DO = 5.47mg/L
Ammonia = 0.74mg/L
Phosphate = 0.36mg/L
Nitrate = 3.6mg/L
gw4
Turbidity = 0.02NTU
DO = 5.23mg/L
Ammonia = 0.96mg/L
Phosphate = 0.25mg/L
Nitrate = 34mg/L
gw2
Turbidity = 0.03NTU
DO = 6.14mg/L
Ammonia = 0.55mg/L
Phosphate = 0.1mg/L
Nitrate = 24.5mg/L
gw7
Turbidity = 0.03NTU
DO = 2.92mg/L
Ammonia = 3.81mg/L
Phosphate = 0.16mg/L
Nitrate = 40.7mg/L
gw9
Turbidity = 0NTU
DO = 6.2mg/L
Ammonia = 0.97mg/L
Phosphate = 0.06mg/L
Nitrate = 35.9mg/L
gw1
Turbidity = 0.18NTU
DO = 6.79mg/L
Ammonia = 1.15mg/L
Phosphate = 0.05mg/L
Nitrate = 28.3mg/L
gw8
Turbidity = 0.06NTU
DO = 7.56mg/L
Ammonia = 13.36mg/L
Phosphate = 0.08mg/L
Nitrate = 70.8mg/L
Legend
Blocks
High Tide Line
Low Tide Line
Water Quality Sampling Point
6.7
Turbidity_NTU_
DO (mg/L)
Ammonia (mg/L)
Phosphates (mg/L)
N
W
E
S
Meters
0
45
90
180
HA. Utheemu
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 23/09/2019
Map Number: Utheem/2019/10
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

3.8.3 Geophysical survey

The Resistivity tests were carried out in the locations as outlined in Figure below.

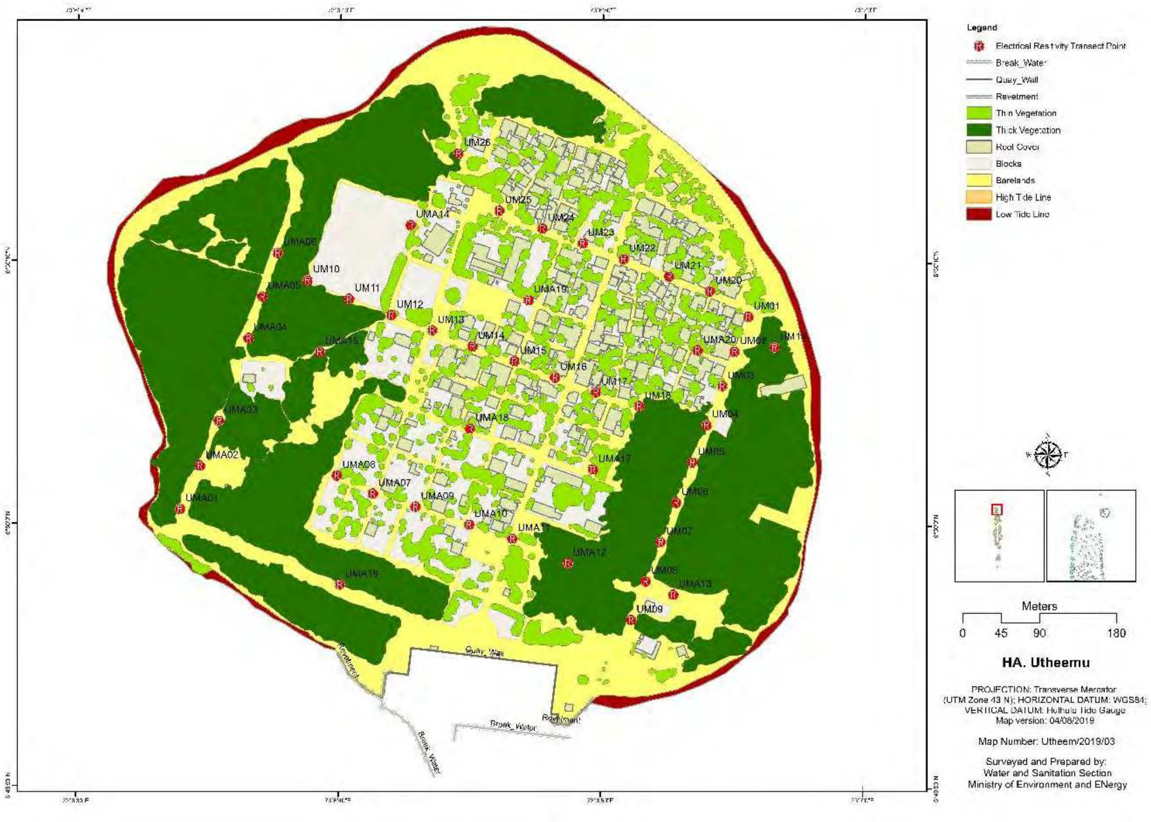


Figure 3.6: Location of ER points in Utheemu Island

3.8.4 Aerial surveys

Based on the aerial survey, a multiple dataset consisting of roof cover, thick vegetation area, thin vegetation area, bare lands and shoreline were extracted. This data is shown in Figure 3.7 and the table shows the different area distribution.

Figure 3.7: Area Distribution in Utheemu Island

Table 3.8: Area Distribution in Utheem

	Area (Square Meters)	% of total area
Roof cover	43,939	9%
Vegetation (Thick)	186,744	40%
Vegetation (Light)	62,948	13%
Bare lands	178,621	38%
Farm Lands	-	-
Wetlands (Inland)	-	-

3.8.5 Freshwater lens

Based on the ER survey, the depth to groundwater level and the freshwater-saline water interface was determined for a set of transverse transects as shown in Figure 3.8. Plots in the Figure 3.9 show the cross sections of each transect line. The dotted lines in the plots indicate a simple interpolation of levels to mean sea level in the island boundaries. These cross sections were used to identify the spatial extent and volume of the freshwater lens while they were also useful in deriving implications on the stress level of the aquifer based on the observed, localized drawdown effect in the groundwater table and up-coning in the freshwater-saline interface, defining the upper and lower boundaries of the freshwater lens in an island.

The Table 3.9 illustrates the freshwater volume calculation for the island. The area covered by freshwater for each transect line has been calculated. To estimate the total volume of available freshwater lens, the cross-section area of freshwater extent under each transect was multiplied by the distance between two transects. The sum of these lengths represents the cumulative length of the island

and thus, the above estimation could represent the total volume of the freshwater lens sandwiched between the groundwater table on top and freshwater-saline water interface in the bottom. Then the actual groundwater storage within this freshwater lens was calculated by multiplying the estimated total lens volume with the porosity of the topsoil in the island.

This estimation represents the total available freshwater volume within the freshwater lens at any given time (time of the measurement). The measurements were carried out towards the end of the dry period and the freshwater lens is presumed to be undergoing a 'stressed' condition due to continued groundwater abstractions despite reduced recharge in the dry period. Falkland (1994) method can be used to estimate the freshwater lend thickness under salient conditions using average annual rainfall, length and width of the island, and the comparison was used as a measure of stress level of the freshwater lens.

Table 3.9: Freshwater Volume Calculation for HA. Utheemu Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
	Start		0		0	0			
			33		0	0			
	UM25	ER	280	1.727	0.09	-3.85	486		
	UM24	ER	334	1.851	0.17	-4.54	236		
	UM23	ER	384	1.828	0.14	-4.7	237		
	UM22	ER	435	1.837	0.15	-3.74	225		
1	UM21	ER	493	1.96	0.16	-2.77	196		
	UM20	ER	544	1.881	0.13	-2.19	133		
	UM01	ER	593	2.091	0.12	-1.88	106		
			626		0	0	34		
	End		659		0	0	0		
	Total						1653	230	380,895
	Start		0		0	0			
			43		0	0			
	UM10	ER	224	1.571	0.19	-3.7	352		
	UM11	ER	278	1.707	0.23	-3.6	206		
	UM12	ER	330	1.501	0.25	-4.31	222		
	UM13	ER	382	1.44	0.32	-4.48	240		
2	UM14	ER	433	1.629	0.36	-4.84	256		
	UM15	ER	485	1.589	0.38	-5.4	285		
	UM16	ER	536	1.642	0.34	-5.26	288		
	UM17	ER	587	1.481	0.35	-5.55	294		
	UM18	ER	640	1.851	0.35	-4.15	276		
	UM04	ER	721	2.127	0.28	-2.32	290		
			823		0	0	132		
	End		866		0	0	0		

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
	Total						2840	131	372,047
3	Start		0		0	0			
			44		0	0			
	UMA04	ER	179	2.128	0.12	-2.4	170		
	UMA15	ER	263	1.726	0.25	-4.3	296		
	UMA18	ER	460	1.876	0.44	-3.36	822		
	UMA17	ER	611	1.52	0.4	-2.89	537		
	UM06	ER	718	2.245	0.26	-2.14	304		
			836		0	0	141		
	End		880		0	0	0		
	Total						2271	98	221,708
4	Start		0		0	0			
			39		0	0			
	UMA03	ER	82	2.443	0.09	-1.51	35		
	UMA08	ER	238	1.883	0.28	-2.42	334		
	UMA07	ER	285	1.75	0.3	-2.4	127		
	UMA09	ER	337	1.621	0.32	-2.08	132		
	UMA10	ER	403	1.453	0.32	-1.98	155		
	UMA11	ER	456	1.466	0.21	-2	120		
	UMA12	ER	527	1.065	0.16	-1.6	141		
	UM08	ER	620	1.881	0.16	-1.44	156		
	UMA13	ER	655	1.804	0.14	-1.06	49		
			738		0	0	50		
	End		777		0	0	0		
	Total						1299	213	276,502
									1,251,153

Volume of lens = 1,251,153m^3

Groundwater Storage = Porosity (20%) x Lens volume (m^3) = 250,231 m^3

Table 3.10: ER Survey Results of Longitudinal Sections for HA.Utheemu Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)
5	Start		0		0	0
			27		0	0
	UMA01	ER	50	2.959	0.09	0.09
	UMA02	ER	106	2.321	0.1	-1.1
	UMA03	ER	163	2.443	0.09	-1.51
	UMA04	ER	265	2.128	0.12	-2.4
	UMA05	ER	317	2.181	0.12	-2.8
	UMA06	ER	371	2.069	0.2	-2.62
			511		0	0
	End		538		0	0
	Total					
6	Start		0		0	0
			28		0	0
	UM09	ER	104	1.992	0.13	-0.87
	UM08	ER	154	1.881	0.16	-1.44
	UM07	ER	203	2.032	0.25	-2.07
	UM06	ER	252	2.245	0.26	-2.14
	UM05	ER	303	2.3	0.29	-2.21
	UM04	ER	350	2.127	0.28	-2.32
	UM03	ER	399	2.292	0.26	-2.14
	UM02	ER	442	2.352	0.24	-1.96
	UM01	ER	486	2.091	0.12	-1.88
			540		0	0
	End		569		0	0
	Total					

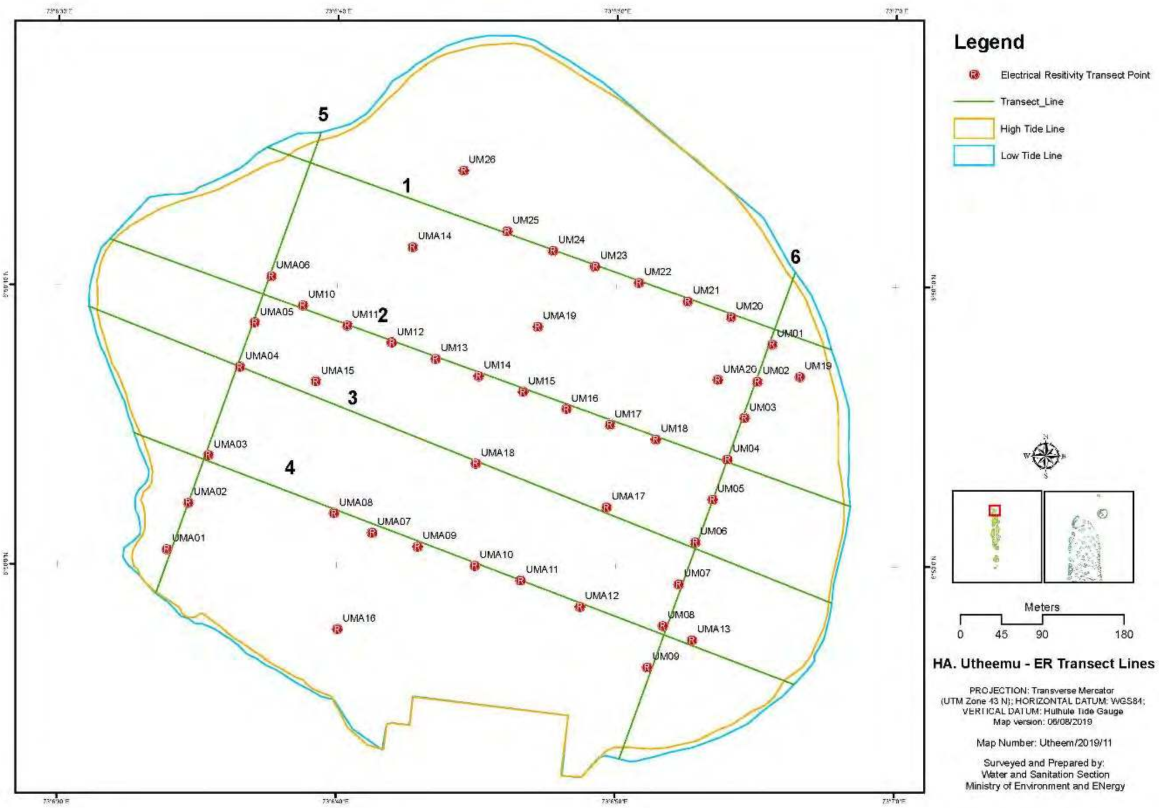
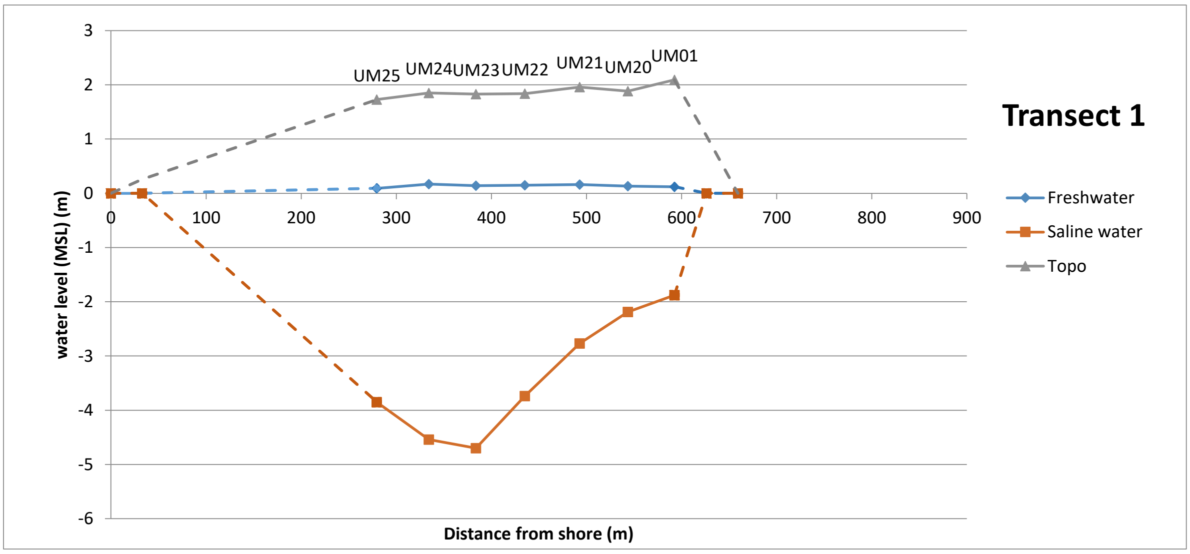
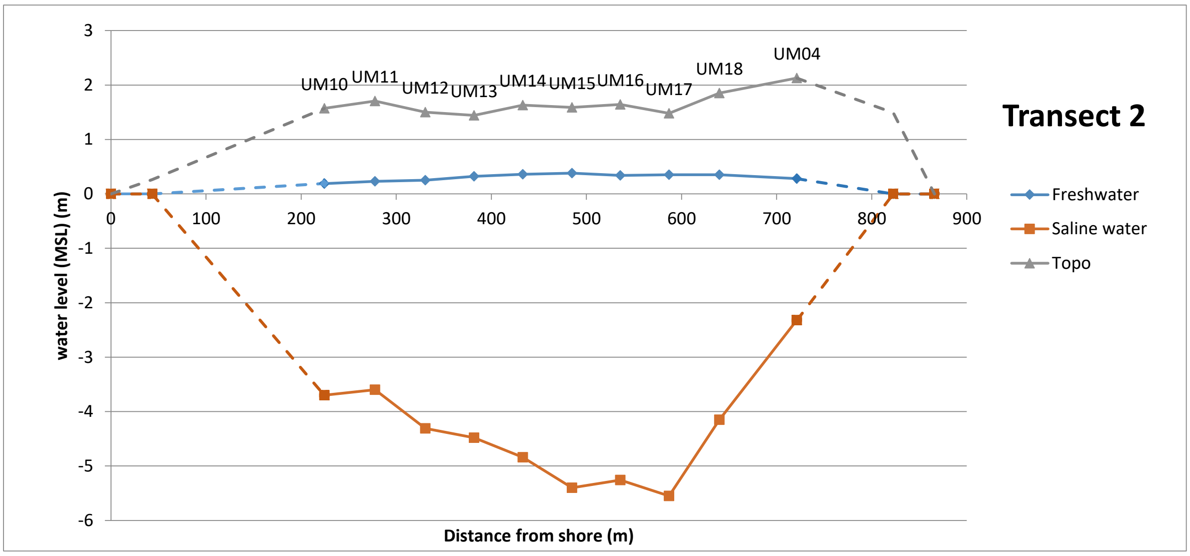
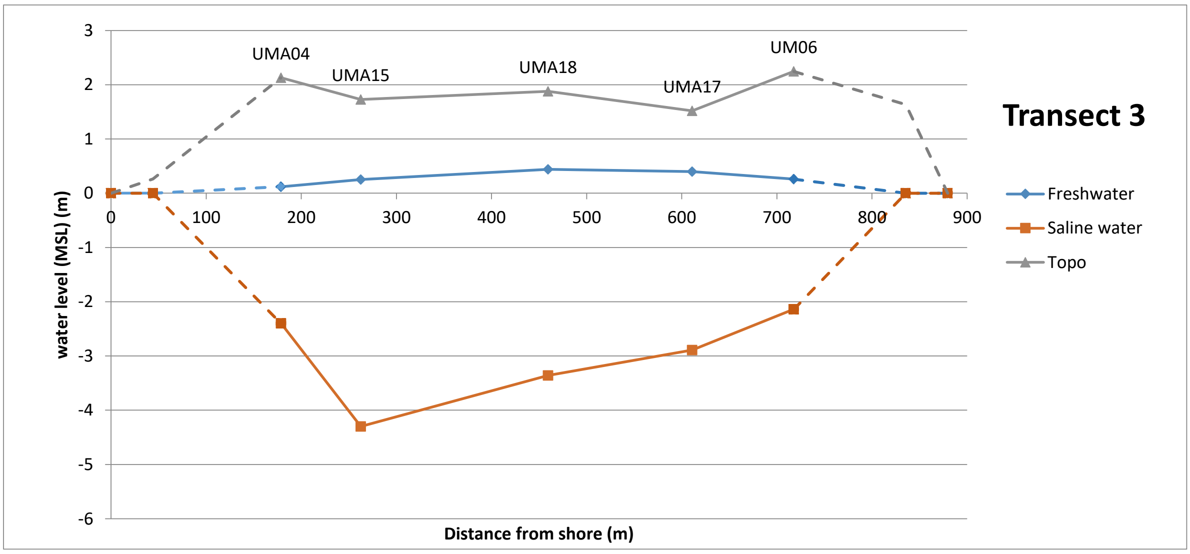
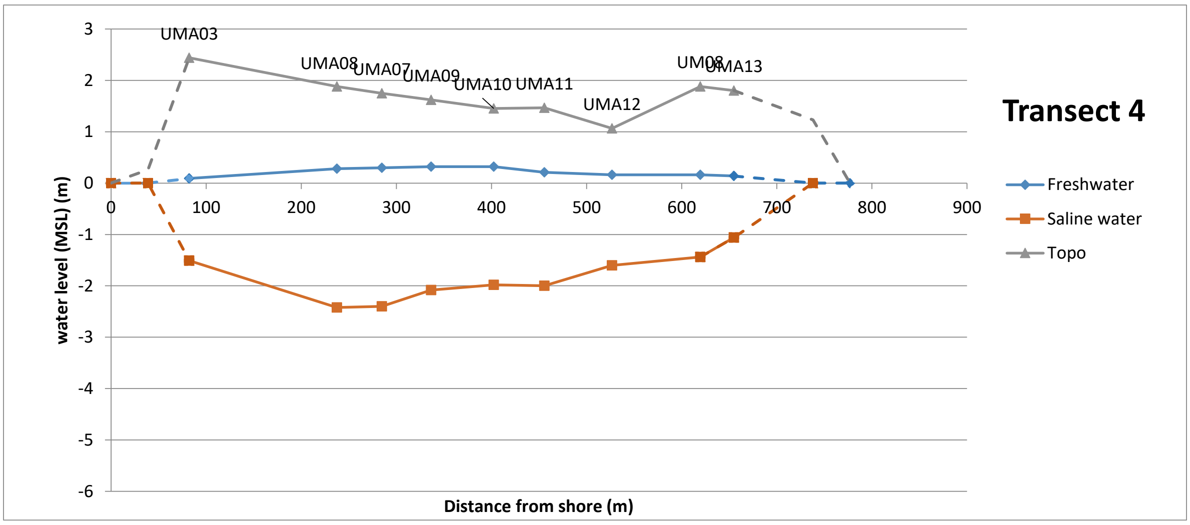


Figure 3.8: ER transect lines in Utheemu Island




Transect 2
water level (MSL) (m)
Distance from shore (m)
UM10
UM11
UM12
UM13
UM14
UM15
UM16
UM17
UM18
UM04
Freshwater
Saline water
Topo


Transect 3
water level (MSL) (m)
Distance from shore (m)
UMA04
UMA15
UMA18
UMA17
UM06
Freshwater
Saline water
Topo


Transect 4
water level (MSL) (m)
Distance from shore (m)
UMA03
UMA08
UMA07
UMA09
UMA10
UMA11
UMA12
UM08
UMA13
Freshwater
Saline water
Topo

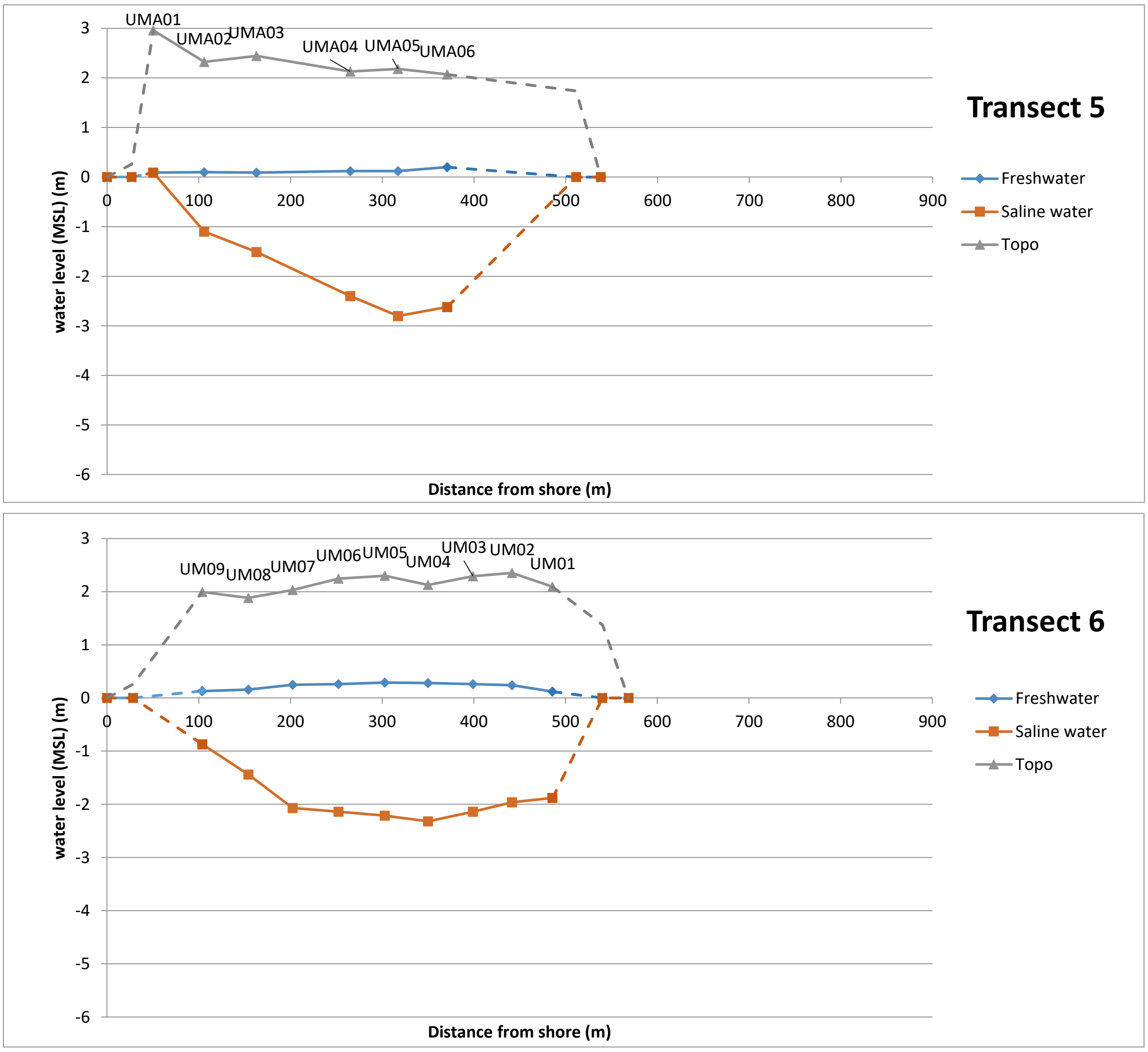


Figure 3.9: Cross-sections of transect lines in Utheemu Island

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented in the following pages:

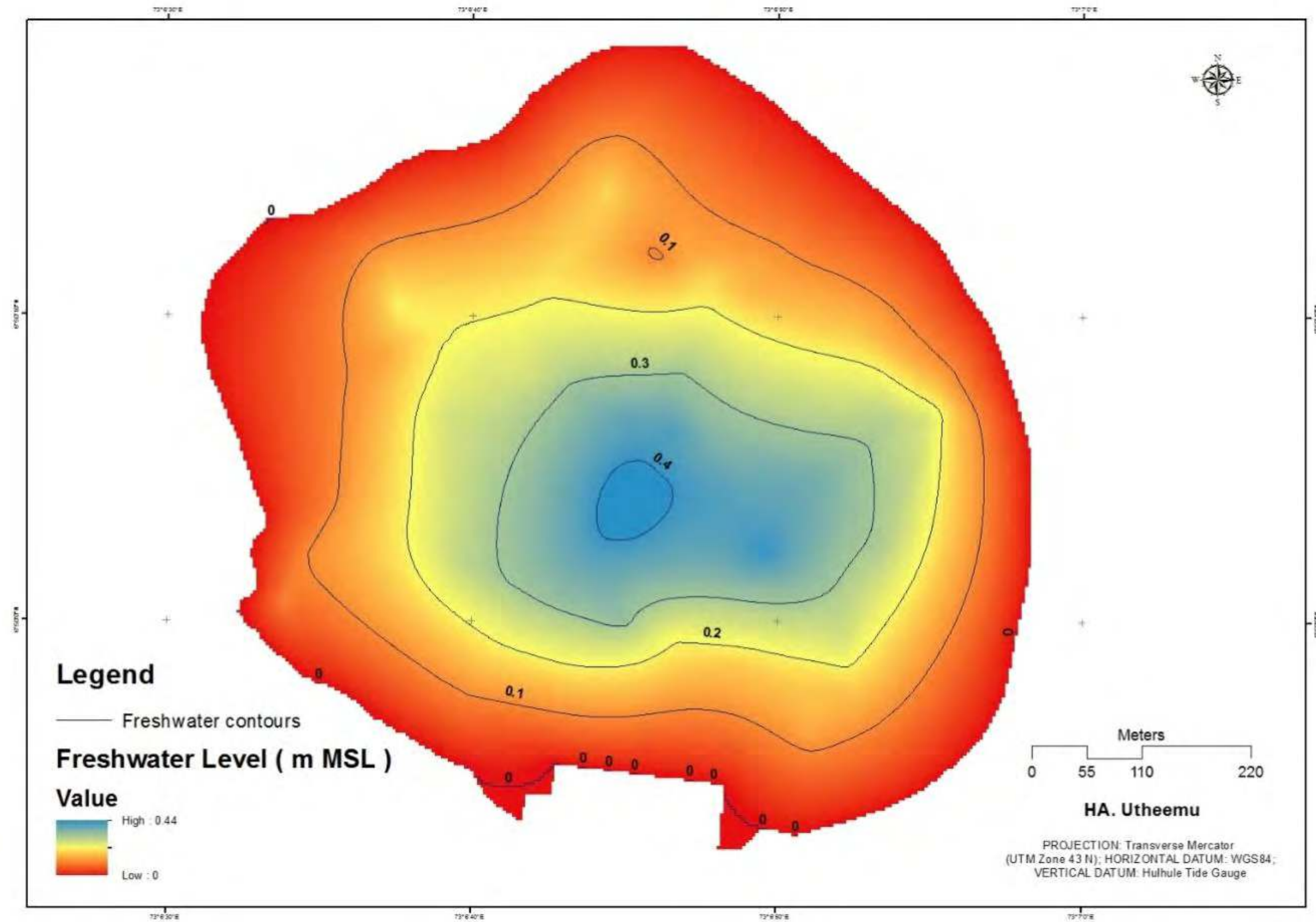


Figure 3.10: Freshwater Level in Utheemu Island

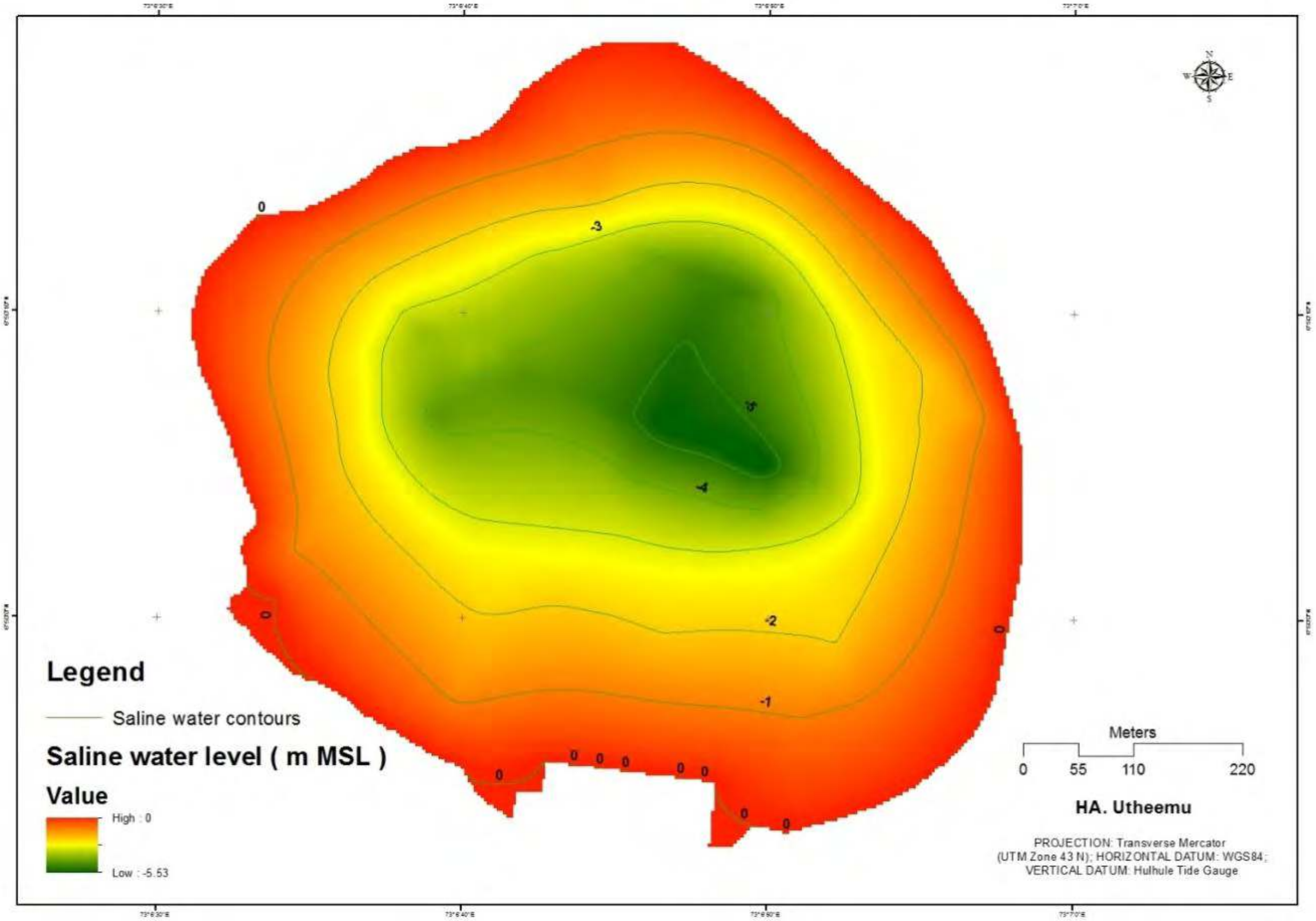


Figure 3.11: Saline water Level in Utheemu Island

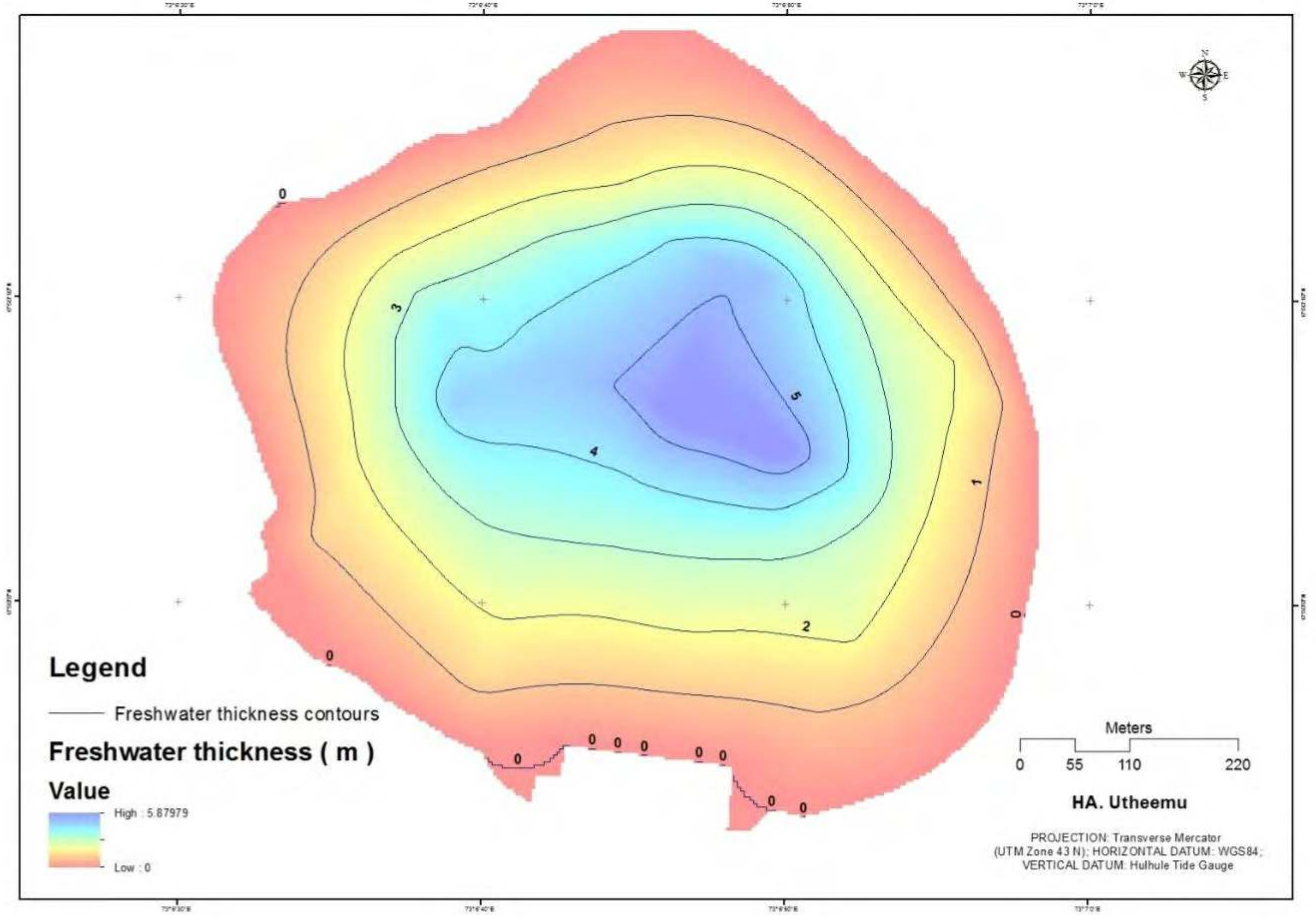


Figure 3.12: Freshwater thickness in Utheemu Island

The maximum freshwater thickness of the island is 5.9 m. According to Falkland, 1994, the freshwater level thickness of the island is 11 m. The relevant calculations are as follows;

Average Annual Rainfall = 1750 mm/yr

Width of the island = 880 m

Length of the island = 569 m

Freshwater lens Thickness (m)

= (6.94*log(width of the island)-14.38)*Average Annual Rainfall = 11 m

3.8.6 Water balance and recharge

An annual estimation is carried out based on water balance method. Rainwater harvesting is calculated using the number of rainwater harvesting units in the island. According to the spatial mean annual rainfall of Maldives, the island is reported as 1750 mm/year. Evapotranspiration was estimated using crop water requirement for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. The groundwater extractions were estimated from the amount of water usage in different sectors (residential, resorts, restaurants, agriculture and farming). The difference between recharge and groundwater extraction is taken to estimate different in storage.

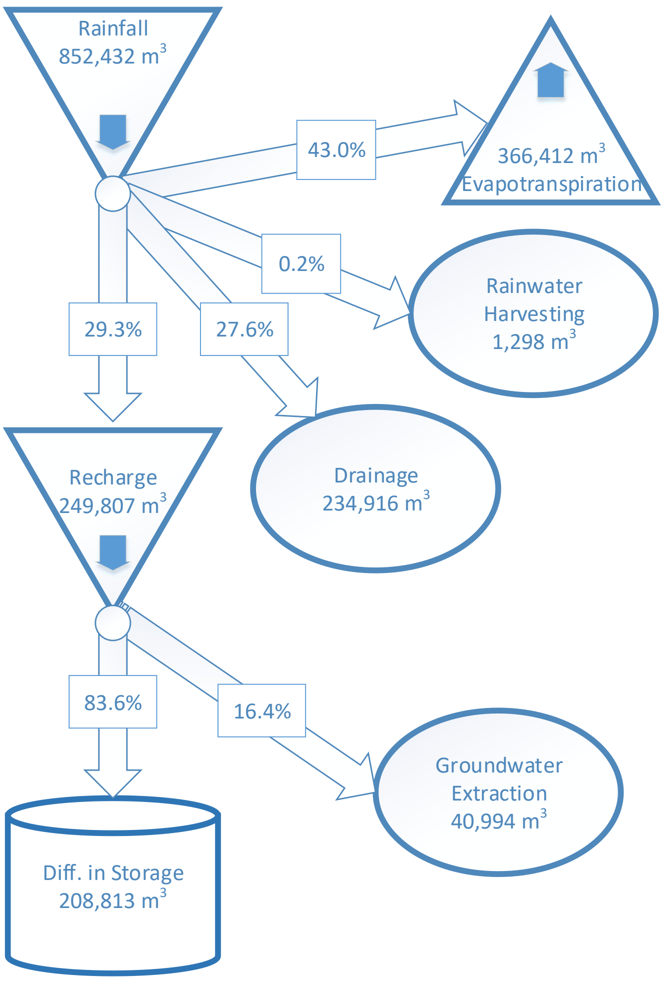


Figure 3.13: Schematic of water balance in Utheemu Island

3.8.7 Sustainable yield of the lens

Sustainable yield of the water lens refers to the safe extraction potential of a given groundwater aquifer without significantly affecting its quality or quantity. This parameter is an important factor in the sustainable development of islands as it allows planning and design of water and sanitation intervention in islands.

The island has a sustainable yield of 572 m^3 per day which was calculated subtracting groundwater extraction from recharge volume derived from water balance (Figure 3.13). According to Metai & Unit, n.d., based on geophysical investigations and drilling programme concluded that the safe sustainable yield was about 10% of mean annual rainfall. Accordingly, the expected sustainable yield for the island should be 234 m^3 per day while the present extraction is 112 m^3 per day (52%).

3.8.8 Permeability test

Permeability tests were carried out in the locations as outlined in Figure 3.14.

Figure 3.14: Locations of permeability tests in Utheemu Island

The estimated permeability values for the above test locations are presented below.

Table 3.11: The estimated permeability Values

r_e		0.0260
r_1		0.0285

Point	H	Tu	Cs	H/r_e	Q	K (m/s)	K (m/day)	Q (l/min)	Q (m^3/s)
UMPT1	0.7	1.2	50	26.9	1.2E-04	1.38E-04	11.88	7.0	0.00012
UMPT2	0.75	2.1	50	28.8	1.0E-04	6.74E-05	5.82	6.0	0.00010
UMPT3	0.75	1.7	50	28.8	2.9E-04	2.50E-04	21.60	17.5	0.00029
UMPT4	0.8	1.4	50	30.8	1.3E-04	1.26E-04	10.91	7.5	0.00013
UMPT5	0.6	1.4	43	23.1	8.3E-05	9.66E-05	8.35	5.0	0.00008

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m^3/s), H = Height of water in well (m), l = length of perforated section (m), r_1 = outside radius of casing (radius of hole in consolidated material) (m), r_e = effective radius of well = r_1 (area of perforations) / (outside area of perforated section of casing) : $r_1 = r_e$ in consolidated material that will stand open and is not cast, C_u and C_s =Conductivity Coefficients, and T_u = distance from water level in casing to water table (m).

3.8.9 Groundwater availability

1) The selected Utheem island has dimensions of width = 736 m and length = 865 m, with a total land area of 49.40 ha, a population of 569 persons, and a land use of built-up area 4.39 ha (9.3%), thick vegetation 18.67 ha (39.5%), light vegetation 6.29 ha (13.3%), and bare lands 17.86 ha (37.8%).

2) In order to recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of freshwater lens (FWL) and its associated recharge-discharge characteristics, 46 number of Electrical Resistivity (ER) location readings along 06 representatively selected transects were collected.

3) Soil overburden permeability tests (constant head) were carried out at 05 locations. In addition, groundwater level was also recorded at 05 locations where groundwater water quality samples were tested.

4) Permeability tests were carried out at representatively selected 05 number of locations. The measured permeability (K m/day) values ranged from a minimum of 5.82 m/day to a maximum of 21.60 m/day, with an average of 11.71 ± 6.01 m/day (Mean ± 1 Standard Deviation).

5) The ground elevation values ranged from a minimum of 0.06 m MSL to a maximum of 4.50 m MSL, with an average of 1.96 ± 0.58 m MSL (Mean ± 1 Standard Deviation).

6) The upper boundary of the freshwater lens (FWL) varied from a minimum of 0.09 m MSL to a maximum of 0.44 m MSL, with an average of 0.22 ± 0.10 m MSL (Mean ± 1 Standard Deviation).

7) The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -5.55 m MSL to a maximum of -0.87 m MSL, with an average of -2.89 ± 1.31 m MSL (Mean ± 1 Standard Deviation).

8) Accordingly, the freshwater lens (FWL) thickness values ranged from a minimum of 1.00 m to a maximum of 5.90 m, with an average of 3.11 ± 1.36 m (Mean ± 1 Standard Deviation).

9) The groundwater profile in the island is characterised by a relatively Low (0.15%) Rainwater Harvesting, relatively High (27.56%) Drainage, relatively Low (29.31%) Recharge, while the water use shows relatively Low (16.41%) Groundwater extraction, leading to relatively High (83.59%) Difference in Balance Storage.

10) The freshwater lens (FWL) volume calculated based on ER transect test data is 250,231 m^3 with a maximum FWL thickness of 5.90 m. The potential maximum FWL volume and thickness estimated based on Falkland (1994) method are 180,998 m^3 and 10.59 m.

3.8.10 Conclusive Comments and Recommendations

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 572 m^3 per day, while it is 234 m^3 per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 118 m^3 per day and this is about 50% of the allowable Safe Yield in the island with no up-coning and no drawdown in freshwater lens cross-sections. At present, there exists no island-wide sewerage network or water supply network. The water samples tested were found to be Moderately Odorous with 70.0% or 7/10 samples tested producing odour. The Hydrological condition of the freshwater lens aquifer can be categorised as Good based on above measurements and findings while Water quality aspects can be regarded as Contaminated with an Average Electrical Conductivity (EC) of 1,744.29 ± 2,683.09 µS/cm with measured values ranging from a minimum of 429.10 µS/cm to a maximum of 9,341.70 µS/cm, and an Average Ammonia Concentration of 2.93 ± 4.22 mg/L with measured values ranging from a minimum of 0.23 mg/L to a maximum of 13.36 mg/L.

The Availability of space for incorporating recharge measures and related infrastructure is Moderate while therefore the Potential for Recharging is considered to be high. Overall recommendation for groundwater recharging would be to use recharging trenches in roads & forest area and recharging pits in individual households and land blocks.

4 HDH. NOLHIVARANFARU ISLAND

4.1 General overview of the island

The island of Nolhivaranfaru is located at 6°41'50"N and 73°07'20"E in the Haa Dhaalu Administrative Atoll. It has a population of 1081 people, via the 2014 Census. The island is 3.55km long and 1.1km wide, giving it an area of 171 Hectares. The construction of the sewerage network in the island has been completed and will be operational soon. For now, septic tanks are still widely used. The island has a jetty on its western side. There is a harbor on the northern side of the island as of August 2018. The island has 2 mangroves. One measuring 280 x 20m and a smaller mangrove area with 65 x 22m. The island does not have a water supply network.

Table 4.1: Basic statistical information on Nolhivaranfaru island in Hdh Atoll.

Name of the island	HDh.Nolhivaranfaru
Longitude and Latitude	6°41'50"N, 73°07'20"E
Area	171 ha
Population (Census, 2014)	1081
Distance from Atoll Capital (HDh.Kulhudhuffushi**))**	10.2km
Distance from Male'	282.3 km
Harbour	Not Present
Island sewerage network	No
Water supply network	No
Other infrastructure	-

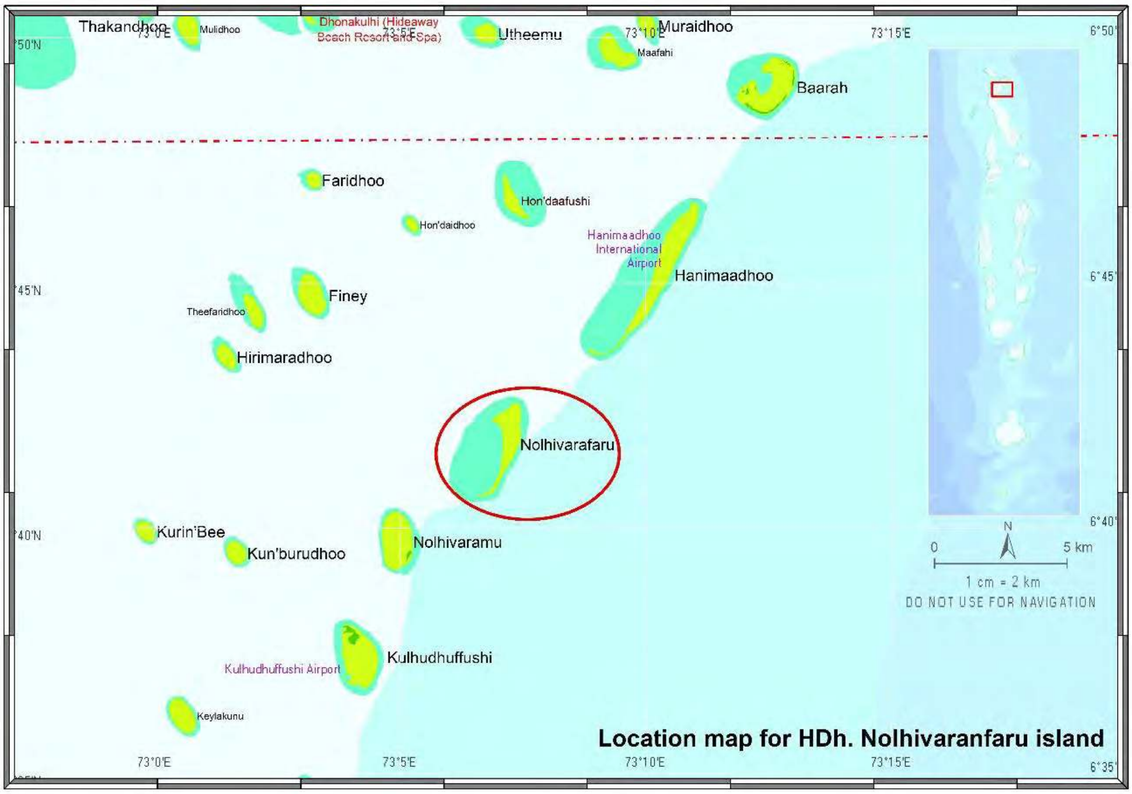


Figure 4.1: Location map for Nolhivaranfaru Island, Hdh Atoll.

4.2 Geology and vegetation

The island is about 3.55km long and 1.1km wide. The vegetation covers about 70% of the islands surface. The vegetation takes up most of the southern half of the islands and runs along the outside of the island as well. Around 4% of the land is being used for farming. The farms are located around the middle of the island, to the south of the habituated area of the island and to the north of most of the vegetation. The island has 2 mangroves where the bigger mangrove measures 280 x 20m and smaller mangrove measures 65 x 22m. Both the mangroves are located at the southern end of the island within the vegetation.

4.3 Topography

The island has a topography that ranges from an elevation of 0.27 meters to 1.73 meters above Mean Sea Level, with an average elevation of 0.95 meters above MSL.

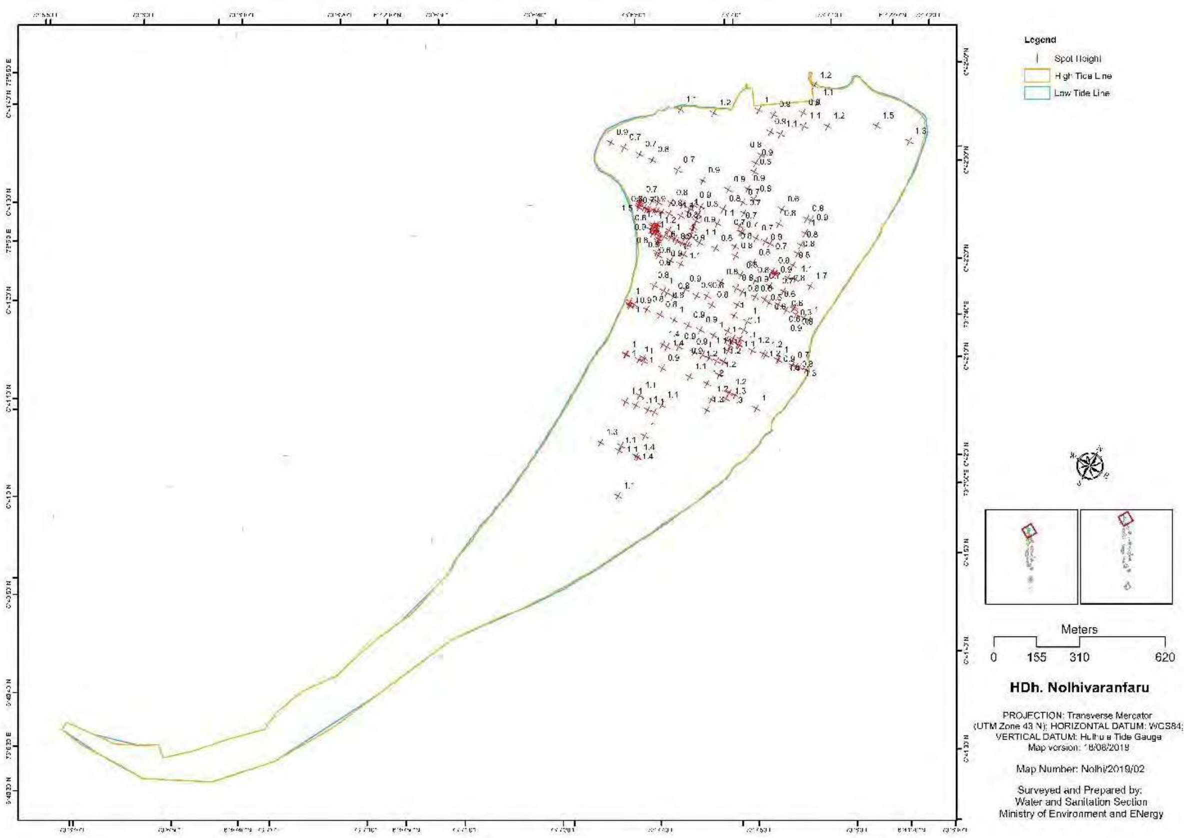


Figure 4.2: Map of Nolhivaranfaru Island showing spot heights

4.4 Climate

Nolhivaranfaru experiences the typical two monsoons namely, north east monsoon from November to April and South-west monsoons from April to November. There are no specific wind and rainfall data available for Nolhivaranfaru as there are no weather monitoring stations on the island.

4.5 Demography

The island has a population of 1081 people via the 2014 Census, of which 990 are locals and 91 are foreigners. However, this may not be accurate as the island council reports a larger population. When looking at the total population, Nolhivaranfaru has 73 more females than males (53:47 percent). This gap widens when only locals are considered, as then there are 136 more females than males (57:43

percent). This is because a significant majority of foreigners are male. The demographic breakdown is illustrated in the graphs and table below.

Table 4.2: Demographic Breakdown of Nolhivaranfaru Island

Atoll	locality	Resident population (Census, 2014)								
		Total			Maldivians			Foreigners		
		Both sexes	Male	Female	Both sexes	Male	Female	Both sexes	Male	Female
HDh	Nolhivaranfaru	1,081	504	577	990	427	563	91	77	14

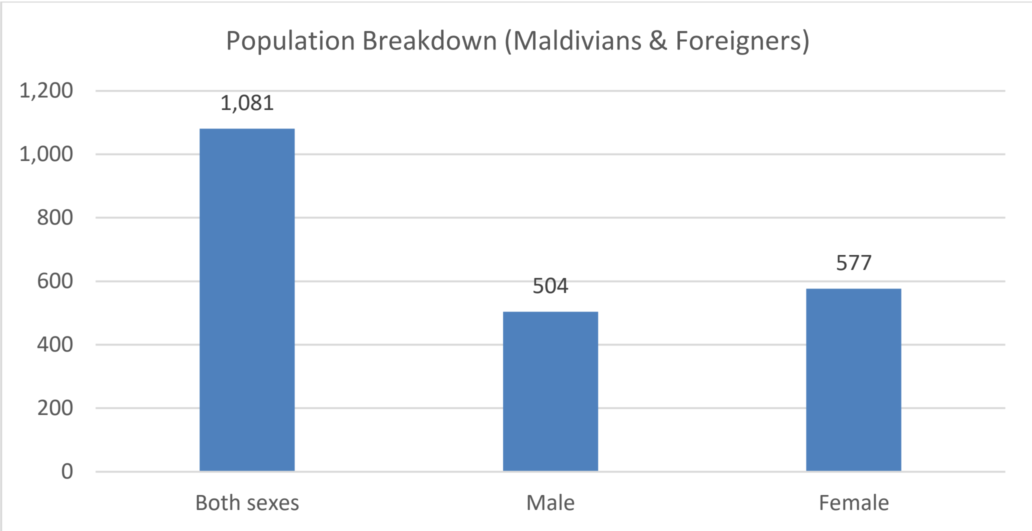


Figure 4.3: Population breakdown of Nolhivaranfaru (Maldivians & Foreigners)

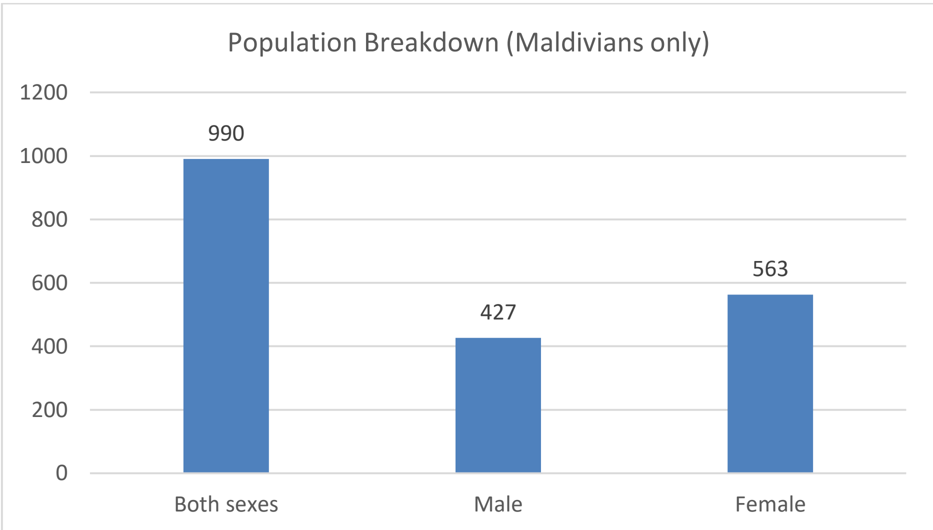


Figure 4.4: Population breakdown of Nolhivaranfaru (Maldivians)

4.6 Socio-economic condition

The island has around 6 hectares of land dedicated to farming.

4.7 Existing water and sanitation situation

The island does not have a water supply system. An under gravity sewerage system has been built and it is not operational yet, though it will be soon. The sewerage system includes a sea outfall pipe of 350 meters on the East side of the island. Until then septic tanks are still the main form of sanitation in the island. Each household has one or two septic tanks. Half of the surveyed households clean their septic tanks by periodically disposing the septic waste to sea, while 25% of households bury septic waste in other parts of the island and the remaining 25% of households have not cleaned their septic tanks. On average, there is an approximate distance of 3.82 meters between septic tanks and nearest well.

The main source of drinking water for residents of the island is rainwater collected in either community or household tanks. For cooking the main source of water is rainwater as well. When this runs out for many households during the dry season, rainwater from other houses or community wells are used. Some households resort to using well water from their own house or from a mosque.

4.8 Results

4.8.1 Water sources and water use

Based on domestic, commercial, institutional and industrial water usage, a total of 309,006 liters of groundwater are estimated to be used every day. Otherwise stated, 286 liters of groundwater are used per capita per day. The respective water use situations are detailed in the following sections.

4.8.1.1 Domestic water use situation

Based on the questionnaire to collect data on domestic water consumption, a summary of results are present in this section.

According to the survey, 100% of the households surveyed uses HDPE rainwater tanks as their main storage for water. A total of 95.65% households use rainwater for drinking while the remaining 4.35% use bottled water for drinking. 100% of the surveyed households use rainwater for cooking. None of the surveyed houses use rainwater for bathing or washing.

0% of the households use groundwater as drinking. Groundwater is mainly used for non-potable use in all the households surveyed.

The following table 4.3 summarizes the data for Nolhivaranfaru Island.

Table 4.3: Groundwater and rainwater use data for Nolhivaranfaru Island

Rainwater	
Households with rainwater tanks	100%
Rainwater use for drinking	95.65%
Rainwater use for cooking	100%
Rainwater use for bathing and washing	0%
Groundwater	
Groundwater as drinking source	0%
Groundwater for cooking	0%
Groundwater for non-potable use	100%
Total number of household wells surveyed	(10%)
Percentage of wells surveyed fitted with pumps	100%

Based on the survey questionnaire, average daily water demand per capita for domestic purposes has been estimated based on the average amount of water used per person for showering, toilet flushing, laundry and gardening, this data is shown in table 4.4. The total domestic water use is estimated to be 225 liters per capita per day.

Table 4.4: Domestic Water Usage in Nolhivaranfaru Island

Shower/ Liters per capita per day	Toilet/ Liters per capita per day	Laundry/ Liters per capita per day	Gardening/ Liters per capita per day	**Total/ Liters per capita per day**
116	35	28	46	**225**

4.8.1.2 Commercial water use situation

Based on the questionnaire to collect data on commercial water consumption, a summary of results is present in this section. A total of 1 restaurant and 1 guesthouse was surveyed.

For the guesthouse, the main use of groundwater was for showers, toilet flushing and gardening. The following table presents a summary. A total of 1271 liters per day of groundwater is used by 1 guesthouse in Nolhivaranfaru.

Table 4.5: Water Usage in Guesthouses in Nolhivaranfaru Island

Name of Guesthouse	**Number of rooms**	**Average occupancy throughout the year**	**Total Volume of water per day (Liters)**	**Total Volume of water per guest per day (Liters)**
Nolhi Escape	5	30%	1271	424
		Total:	1271	

For the restaurants, the main use of groundwater was for dishwashing and toilet use. 1 restaurant was surveyed and from this data, the total groundwater consumption for the 3 restaurants on this island was estimated to be 3405 liters.

4.8.1.3 Institutional water use situation

Based on the questionnaire to collect data on institutional water consumption, a summary of results is present in this section. Four institutions were surveyed for this study namely the powerhouse, council office, school and pre-school. Groundwater in the institutions in Nolhivaranfaru Island are mainly used for flushing toilets. A total of approximately 2094 liters of groundwater are estimated to be used per day by the institutions. Therefore, a total of approximately 1.94 liters of groundwater are estimated to be used per capita per day by the institutions of Nolhivaranfaru Island.

Table 4.6: Institutional Water Usage in Nolhivaranfaru

	Water Flushed (Liters per day)	Gardening (Liters per day)	Mopping (Liters per day)	Total Water Usage (Liters per day)	Total Water Usage by all institutions (Liters per day)	Institutional Groundwater Usage (Liters per capita per day)
Powerhouse	86		-	86	2094	1.94
Council	967	-	-	97		
School	758	1080	73	1911		

4.8.1.4 Industrial water use situation

There are approximately 103 plots registered at the island council to be used for farming purposes, each with an area of 5000 square feet. A total of 515,000 square feet is therefore designated on this island for farming purposes. Currently, 93 plots of land are being used for farming purposes. 19 plots of farming land were surveyed, which encompasses 20.4% of the total number of plots leased for farming. 4 out of 19 farming plots (21%) use water hose connected to the well through a pump for watering the plot, while the remaining 15 farming plots (79%) manually water their plots using watering cans. All of the farming plots use groundwater for irrigation.

On average, 630 liters of groundwater are used daily by each farming plot for irrigation. While the size of the plots given to all farmers are the same, farming is carried out at varying scales throughout Nolhivaranfaru. Small-scale farms which use the least amount of water use 16 liters daily and the farms which use the most amount of water use upto 2160 liters of groundwater daily. Therefore, for a total of 93 farming plots, it was estimated that 58,619 liters of groundwater are used daily by the farms of Nolhivaranfaru.

4.8.2 Groundwater quality

Groundwater quality measurements were made at selected wells in Nolhivaranfaru for both physical and microbiological testing.

The following table summarizes the water quality results.

Table 4.7: Summary of groundwater quality tests from Nolhivaranfaru, April 2019

Sample No	Odour	Physical Appearance
gw1	yes	Pale yellow with black particles
gw2	yes	Pale yellow with particles
gw3	yes	Clear with particles
gw4	yes	Clear with particles
gw5	yes	Clear with particles
gw6	yes	Pale yellow with particles
gw7	yes	Clear with particles
gw8	yes	Pale yellow with particles
gw9	yes	Clear with particles
gw10	yes	Pale yellow with particles

Sample No	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
gw1	1147	727	7.47	4.5	6.46	26.3	-	8.5	1.71	0.08		
gw2	1688	1077	7.84	0.74	7.89	26	-	91.4	2.22	0.25	1986	225
gw3	1202.2	705	7.62	0	1.32	30.6	0.53	8.8	5.85	0.24		
gw4	12225	7144	6.93	0.52	1.42	30.9	6.18	36.5	17.66	0.09		
gw5	742.9	436	7.98	0.11	5.81	30.6	0.32	57.7	0.68	0.14		
gw6	869.3	522	7.59	0.12	1.71	29.3	0.39	4.3	7.33	0.16	47	47
gw7	837.8	498	7.58	0.1	6.55	29.9	0.37	102.0	0.93	0.3		
gw8	1241	791	8.06	0.56	7.65	26.1	-	54.3	1.42	0.78	>2420	2420
gw9	1571.8	900	7.39	0.08	1.4	32.1	0.68	25.0	25.78	0.16		
gw10	877	520	7.65	0.1	4.13	30.1	0.39	3.8	3.59	<0.05	1390	291

	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)
WHO Standards	Suggested maximum limit of freshwater for potable purposes = 1500 µS/cm Suggested maximum limit of freshwater for non-potable purposes = 2500 µS/cm	-	-	-	-	-

	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
WHO Values	-	Guideline Value = 50 mg/L-NO3	Natural Level of Ammonia < 0.2 mg/L Threshold odour concentration = 1.5 mg/L Taste threshold = 35 mg/L	-	-	-

Figure 4.5: Location of groundwater sampling points in Nolhivaranfaru Island

Based on the full results and the summary shown in Table 7.5, the following observations are made:

- The Electrical Conductivity (EC) of the groundwater is generally low, apart from Sample GW4 which has an EC of 12,225 µS/cm. Sample GW4 has such a high EC because the sample was taken within 17m from the shoreline. The average EC is 2240 µS/cm including GW4, however, the average EC without GW4 is 1130.78 µS/cm which is below an acceptable limit for potable water of 1,500 µS/cm (refer section 2.2). Only three readings from the tested 10 readings are above the acceptable limit for potable water of 1,500 µS/cm (GW2, GW4 and GW9 with EC 1688, 12224.8 and 1571.8 µS/cm respectively.)

- Total dissolved solids (TDS) ranged from 436 mg/L to 7144 mg/L with an average of 1332 mg/L. It should be noted that the highest TDS of 7144 mg/L (GW4) is significantly higher than other samples, and the average TDS reading without GW4 is approximately half the average value including GW4 at a value of 686 mg/L.
- The pH ranged from 6.93 8.06 with an average pH of 7.61.
- Turbidity ranged from 0 NTU to 4.5 NTU with an average of 0.683 NTU. As a guide, "crystal-clear" water has a turbidity below 1 NTU, and water becomes visibly cloudy at 4 NTU and above. It should be noted that sample GW1 with turbidity of 4.5 NTU is the only sample with a higher turbidity than 0.8 NTU, and that the average turbidity without GW1 is 0.26 NTU.
- Dissolved oxygen levels ranged from 1.32 mg/L to 7.89 mg/L with an average of 4.43 mg/L.
- The salinity of groundwater ranged from 0.32 PSU to 6.18 PSU with an average of 1.27 PSU. Sample GW4 with salinity of 6.18 PSU is the only sample with a higher salinity than 0.68 PSU. Sample GW4 has a high salinity because the sample was taken within 17m from the shoreline.

- The average Nitrate concentration was 39.2 mg/L which does not exceeds the WHO guideline limit of 50 mg/L. The Nitrate concentrations ranged from lowest concentration of 3.8 mg/L to the highest concentration of 102 mg/L. Only 4 of 10 tested water samples exceeded the WHO guideline limit for Nitrate concentrations. Sample GW7 with the significantly highest Nitrate concentration was taken from the farming area. This high Nitrate concentration was expected as Nitrate can infiltrate groundwater as a consequence of agricultural activity involving application of inorganic nitrogenous fertilizers and manures.
- Ammonia concentrations were generally high. The average ammonia concentration was 6.72 mg/L. This exceeds the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. It was found that 7 of the 10 tested water samples exceeded the WHO guideline. Natural levels of ammonia are generally below 0.2 mg/L (WHO, 1993) and no tests showed concentrations below this level. There is no apparent correlation between increasing levels of ammonia and other nutrients.
- Phosphate concentrations ranged from 0.08 mg/L to 0.78 mg/L with an average concentration of 0.24 mg/L. There is no WHO drinking water guideline value for phosphate. However, it would normally be expected that phosphate concentrations in groundwater are less than 0.1 mg/L, where there are no impacts from human wastewater (e.g. effluent from septic tanks and 'greywater' from kitchens and bathrooms). Only 2 samples tested (20%) of samples tested were below 0.1 mg/L.
- Faecal Coliform levels were significant and ranged from lowest count of 47 MPN/100mL to the highest count of greater than 2420 MPN/100mL with an average of 746 MPN/100mL. Total coliform levels ranged from lowest count of 47 MPN/100 mL to the highest count of greater than 2420 MPN/100 mL with an estimated average of 1461 MPN/100mL. As expected, the groundwater layer is contaminated with effluent from septic tanks.

In conclusion, Nolhivaranfaru Island contains groundwater with moderate Electrical Conductivity with a higher average than WHO guidance value for potable water and high TDS. Nitrate concentration was lower than WHO maximum guidance value, average Ammonia concentration and average Phosphate concentration was higher than expected in natural, undisturbed groundwater. In terms of microbiological contamination, an island wide contamination is observed.

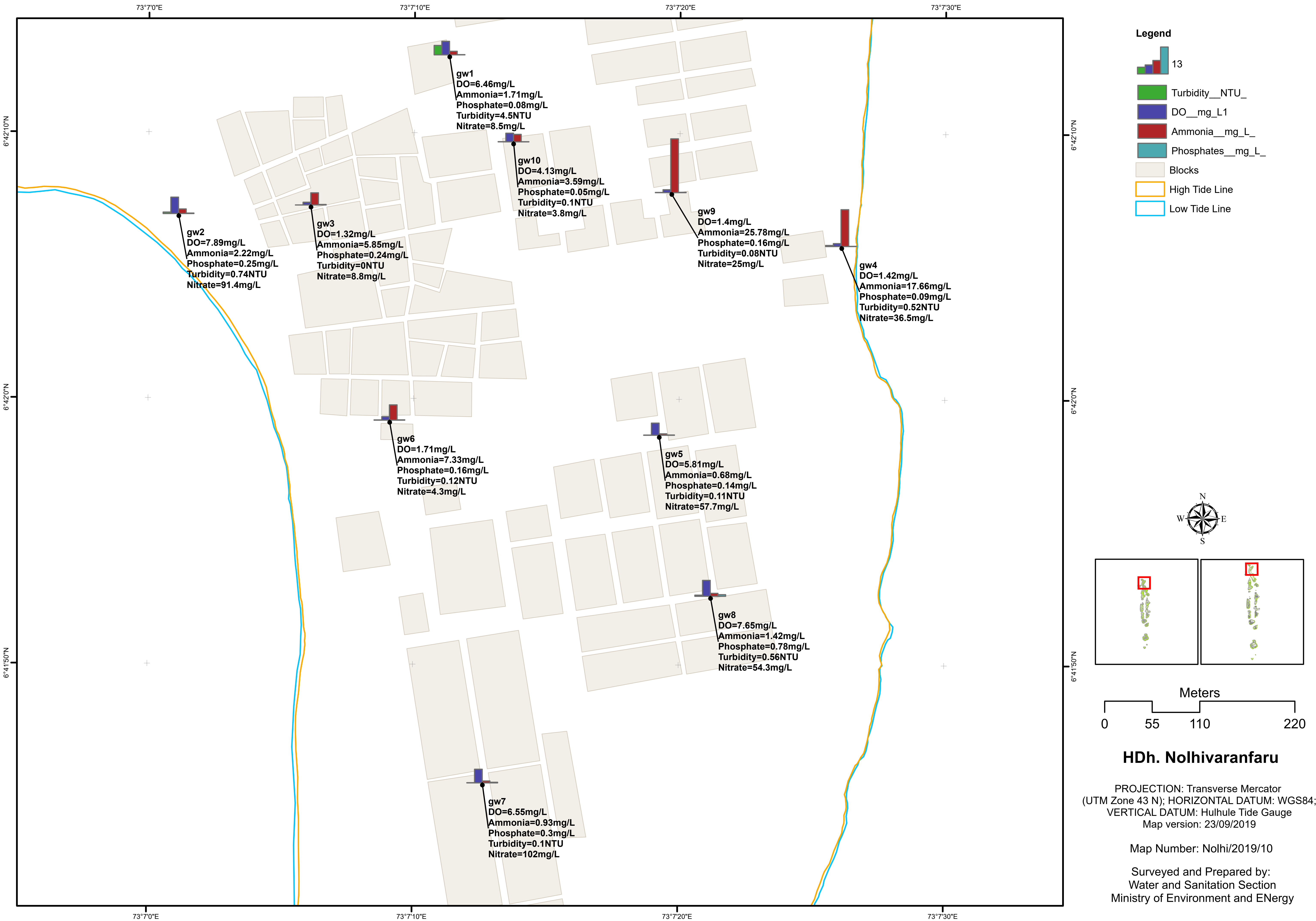
Additionally, the following pages contain maps which show the main physiochemical parameters displayed on map of the island.

HDh. Nolhivaranfaru

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 08/08/2019

Map Number: Nolhi/2019/09

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy



HDh. Nolhivaranfaru

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 23/09/2019

Map Number: Nolhi/2019/10

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

4.8.3 Geophysical survey

The Resistivity tests were carried out in the locations as outlined in Figure below.

Figure 4.6: Location of ER points in Nolhivaranfaru Island

4.8.4 Aerial surveys

Based on the aerial survey, a multiple dataset consisting of roof cover, thick vegetation area, thin vegetation area, bare lands and shorelines were extracted. This data is shown in Figure 4.7 below and the table 4.7 shows the different area distribution.

Figure 4.7: Area Distribution in Nolhivaranfaru Island

Table 4.8: Area Distribution in Nolhivaranfaru

	Area (Square Meters)	% of total area
Roof cover	80,941.19	5%
Vegetation (Thick)	1,029,354.70	61%
Vegetation (Light)	169,240.10	10%
Bare lands	358,027.93	21%
Farm Lands	47,845.07	3%
Wetlands (Inland)	-	-

4.8.5 Freshwater lens

Based on the ER survey the depth to groundwater level and the freshwater-saline water interface was determined for a set of transverse transects as shown in Figure 4.8. Plots in the Figure 4.9 show the cross sections of each transect line. The dotted lines in the plots indicate a simple interpolation of levels to mean sea level in the island boundaries. These cross sections were used to identify the spatial extent and volume of the freshwater lens while they were also useful in deriving implications on the stress level of the aquifer based on the observed, localized drawdown effect in the groundwater table and up-coning in the freshwater-saline interface, defining the upper and lower boundaries of the freshwater lens in an island.

The Table 4.9 illustrates the freshwater volume calculation for the island. The area covered by freshwater for each transect line has been calculated. To estimate the total volume of available freshwater lens, the cross-section area of freshwater extent under each transect was multiplied by the distance between two transects. The sum of these lengths represents the cumulative length of the island and thus, the above estimation could represent the total volume of the freshwater lens sandwiched between the groundwater table on top and freshwater-saline water interface in the bottom. Then the actual groundwater storage within this freshwater lens was calculated by multiplying the estimated total lens volume with the porosity of the topsoil in the island.

This estimation represents the total available freshwater volume within the freshwater lens at any given time (time of the measurement). The measurements were carried out towards the end of the dry period and the freshwater lens is presumed to be undergoing a 'stressed' condition due to continued groundwater abstractions despite reduced recharge in the dry period. Falkland (1994) method can be used to estimate the freshwater lend thickness under salient conditions using average annual rainfall, length and width of the island, and the comparison was used as a measure of stress level of the freshwater lens.

Table 4.9: Freshwater Volume Calculation for HDH. Nolvivaranfaru Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
1	Start		0	0	0	0			
	NF01	ER	40	0.260	0.056	-0.274	7		
	NF02	ER	90	0.715	0.015	-0.495	21		
	NF03	ER	152	0.72	0.02	-0.48	31		
	NF04	ER	202	0.754	0.044	-0.766	32		
	NF05	ER	302	0.718	0.068	-2.122	151		
	NF06	ER	399	0.886	0.116	-1.834	202		
	NF07	ER	498	0.916	0.166	-1.264	167		
	NF08	ER	598	0.79	0.11	-1.61	158		
	NF09	ER	706	0.636	0.07	-1.764	191		
	NF10	ER	801	0.845	0.045	-1.635	168		
			1010	0.673	0	0	175		
	End		1063	0	0	0	0		
	Total						1302	345	449159
2	Start		0	0	0	0			

			40	0.260	0	0	0		
	NFA01	ER	77	1.1	0.19	-0.28	9		
	NFA02	ER	138	1.168	0.13	-2.09	82		
	NFA03	ER	201	1.016	0.116	-2.464	151		
	NFA04	ER	257	1.053	0.11	-2.69	150		
	NFA05	ER	319	0.848	-0.012	-3.262	186		
	NFA06	ER	396	0.814	0.01	-3.29	254		
	NFA07	ER	465	0.845	0.12	-3.28	230		
	NFA08	ER	541	0.793	0.2	-1.6	199		
	NFA09	ER	630	1.074	0.234	-0.876	128		
	NFA10	ER	688	1.729	0.24	-0.56	56		
			759	1.106	0	0	28		
	End		799	0	0	0	0		
	Total						1474	245	360609
3	Start		0	0	0	0			
			36	0.260	0	0	0		
	NF23	ER	38	0.863	0.183	-0.227	0		
	NF22	ER	86	0.789	0.129	-3.171	90		
	NF21	ER	139	0.809	0.119	-2.911	165		
	NF20	ER	191	0.987	0.237	-2.673	156		
	NF19	ER	245	0.858	0.118	-2.942	161		
	NF18	ER	293	0.87	0.08	-3.64	164		
	NF17	ER	345	0.984	0.184	-3.896	200		
	NF16	ER	394	1.016	0.166	-3.724	197		
	NF15	ER	445	1.148	0.208	-3.952	204		
	NF14	ER	496	1.18	0.26	-2.5	176		
	NF13	ER	546	1.169	0.249	-1.211	106		

	NF12	ER	597	0.964	0.144	-1.416	76		
	NF11	ER	650	0.731	0.031	0.031	41		
			679	0.330	0	0	0		
	End		715	0	0	0	0		
	Total						1738	242	420569
4	Start		0	0	0	0	0		
			34	0.260	0	0	0		
	NFA11	ER	90	1.043	0.12	-3.68	106		
	NFA12	ER	157	1.01	0.13	-4.23	275		
	NFA13	ER	230	0.87	0.16	-4.04	311		
	NFA14	ER	334	1.054	0.194	-3.866	430		
	NFA15	ER	401	1.178	0.278	-3.272	257		
	NFA16	ER	490	1.19	0.22	-0.99	211		
	NFA17	ER	599	1.03	0.07	-1.34	143		
			647	0.604	0	0	34		
	End		682	0	0	0	0		
	Total						1766	167	295336
5	Start		0	0	0	0	0		
			33	0.260	0	0	0		
	NFA20	ER	180	1.073	0.233	-4.287	332		
	NFA19	ER	266	1.035	0.005	-4.365	382		
	NFA18	ER	311	1.07	0.23	-2.83	168		
			635	0.970	0	0	495		
	End		668	0	0	0	0		
	Total						1376	175	241275
6	Start		0	0	0	0	0		
			30	0.260	0	0	0		
	NF26	ER	177	1.261	0.221	-2.659	212		

	NF25	ER	251	1.059	0.149	-2.481	202		
	NF24	ER	324	1.397	0.367	-1.083	149		
			573	1.246	0	0	180		
	End		603	0	0	0	0		
	Total						744	629	467561
									2,234,510

Volume of lens = 2,234,510 m^3

Groundwater Storage = Porosity (15%) x Lens volume (m^3) = 335,176 m^3

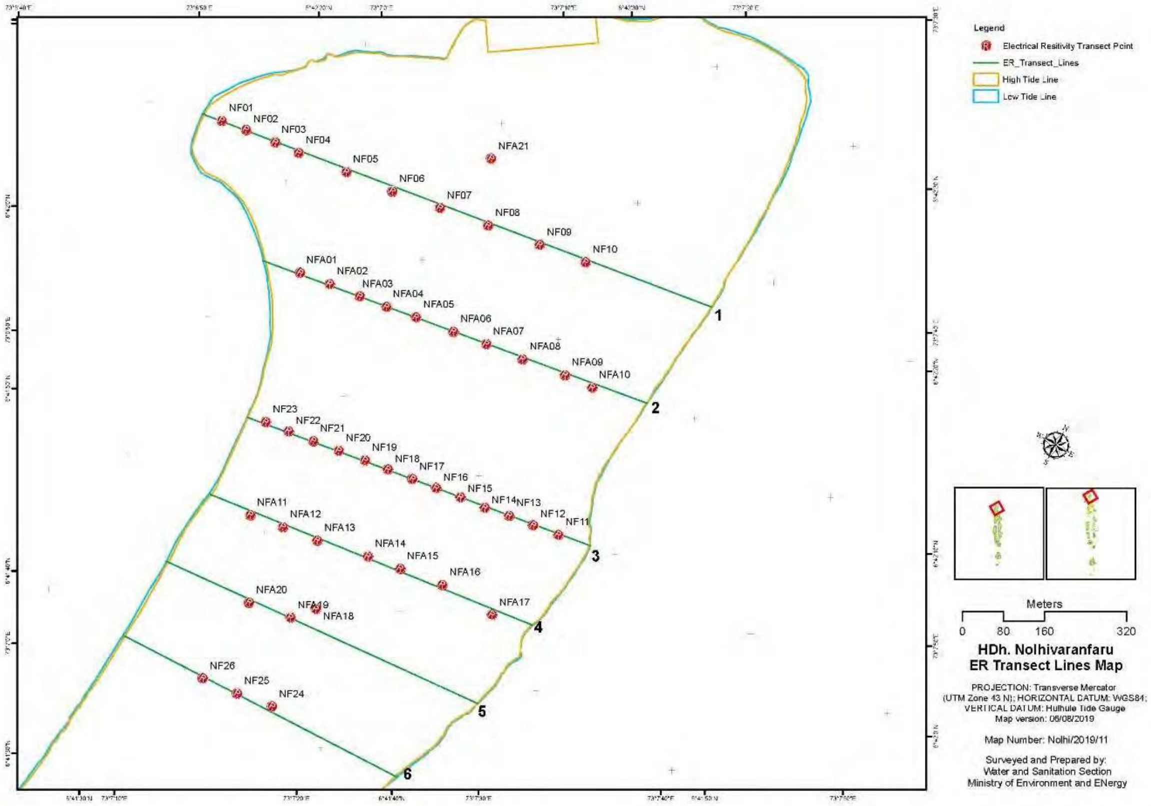
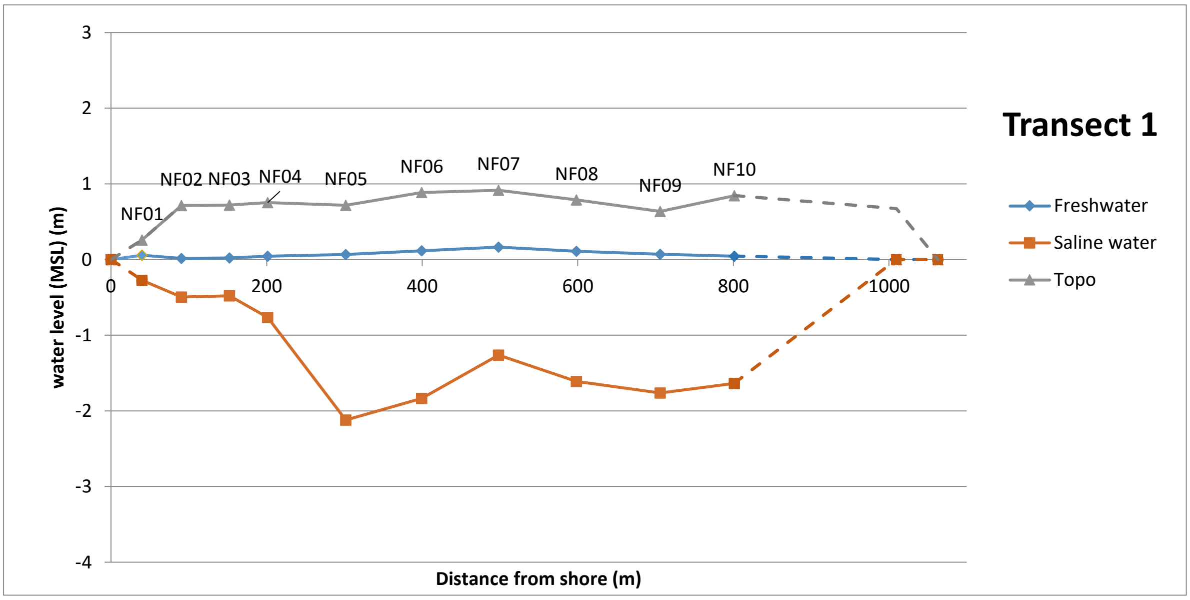
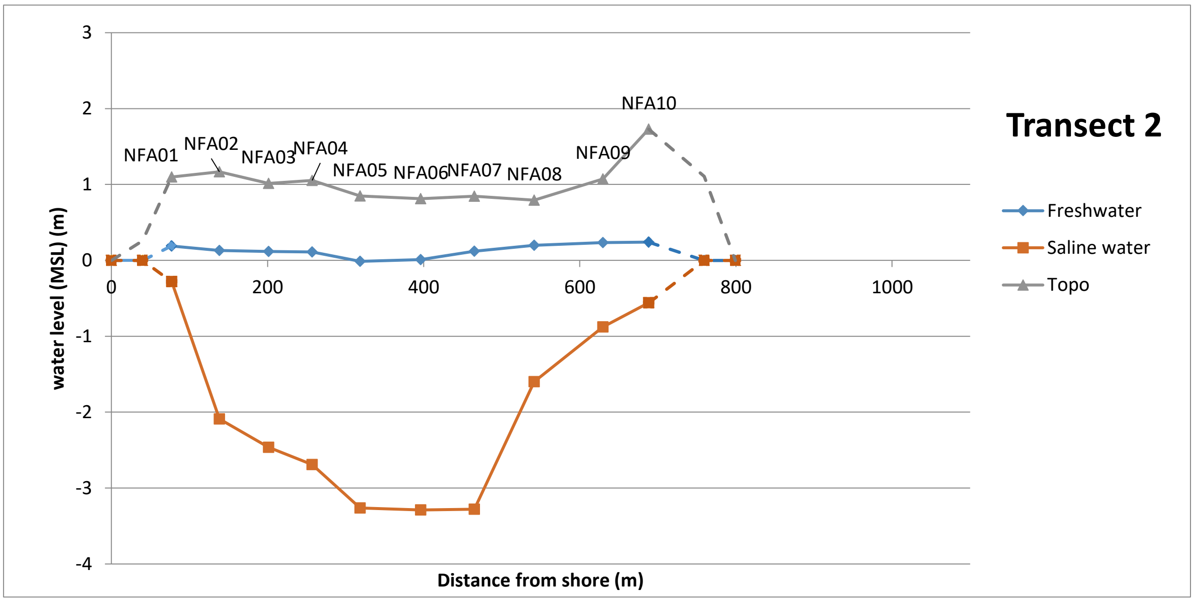
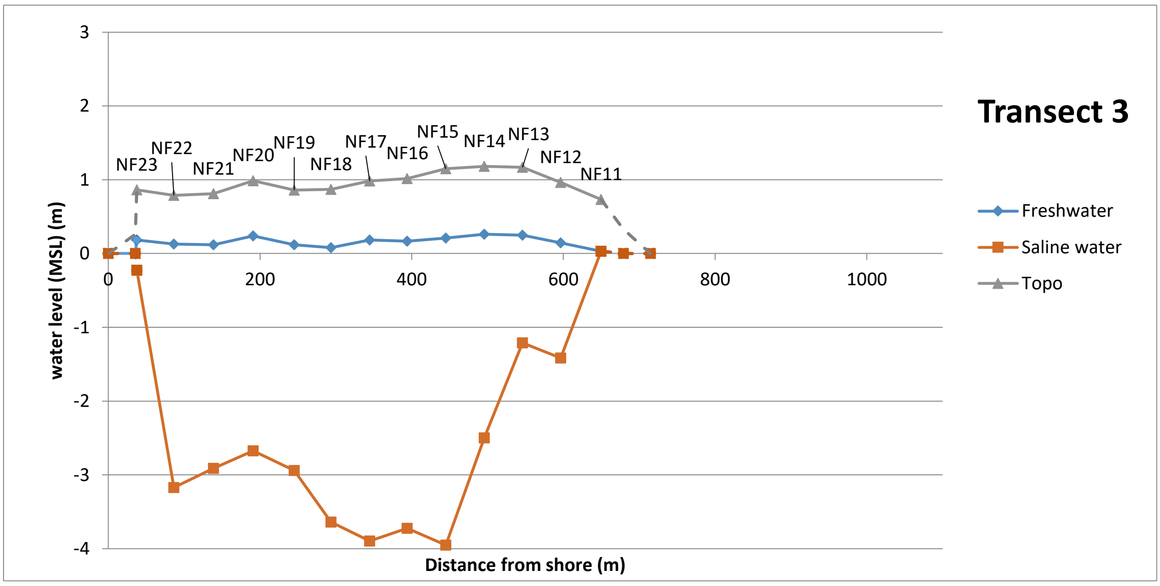
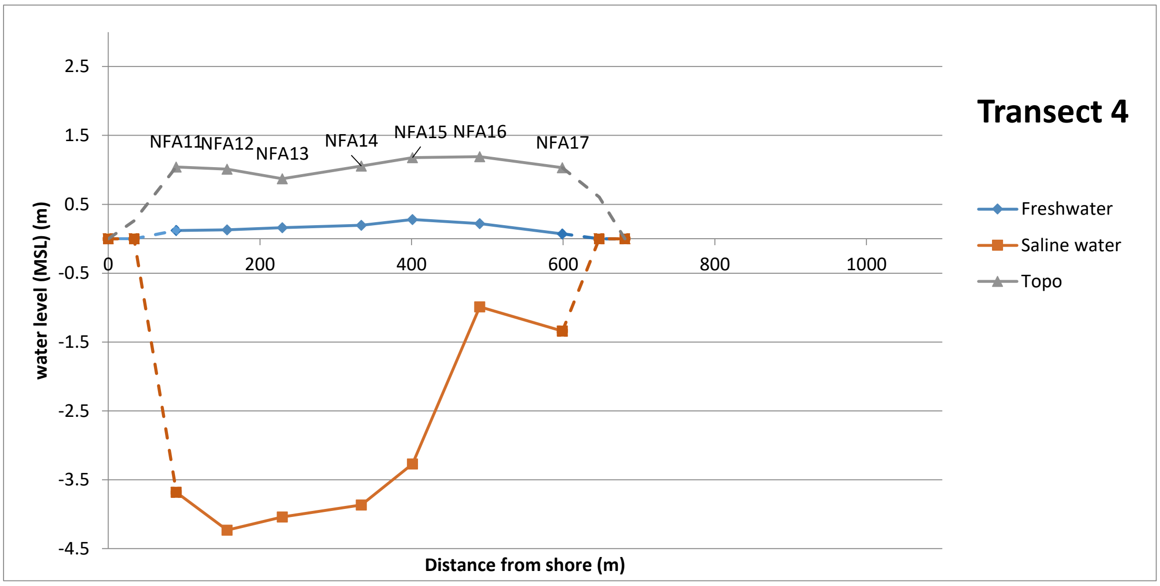


Figure 4.8: ER transect lines in Nolhivaranfaru Island




Transect 2
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo
NFA01
NFA02
NFA03
NFA04
NFA05
NFA06
NFA07
NFA08
NFA09
NFA10
3
2
1
0
-1
-2
-3
-4
0
200
400
600
800
1000


Transect 3
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo
NF23
NF22
NF21
NF20
NF19
NF18
NF17
NF16
NF15
NF14
NF13
NF12
NF11
3
2
1
0
-1
-2
-3
-4
0
200
400
600
800
1000



The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented in the following pages:

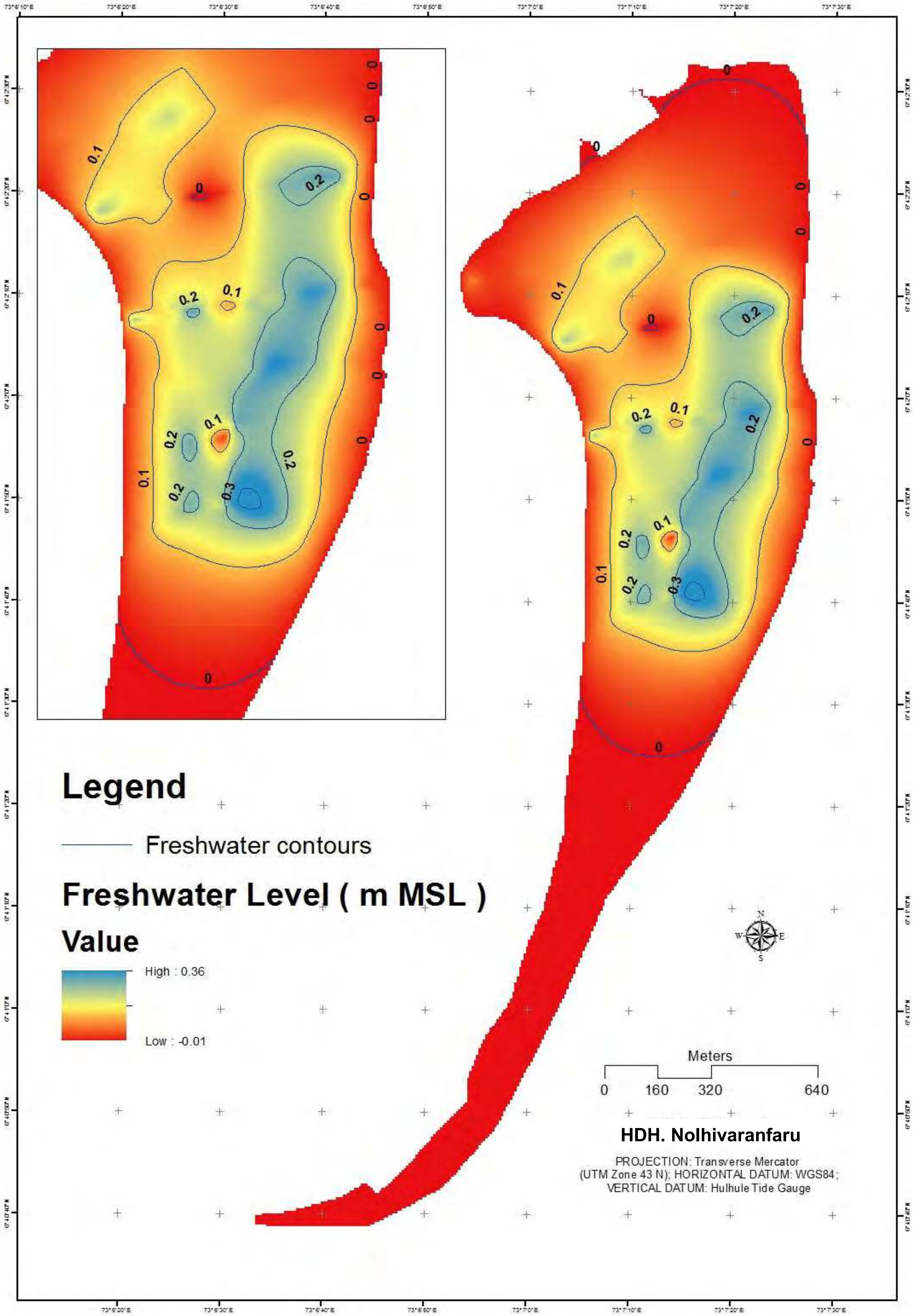


Figure 4.9: Freshwater Level in Nolhivaranfaru Island

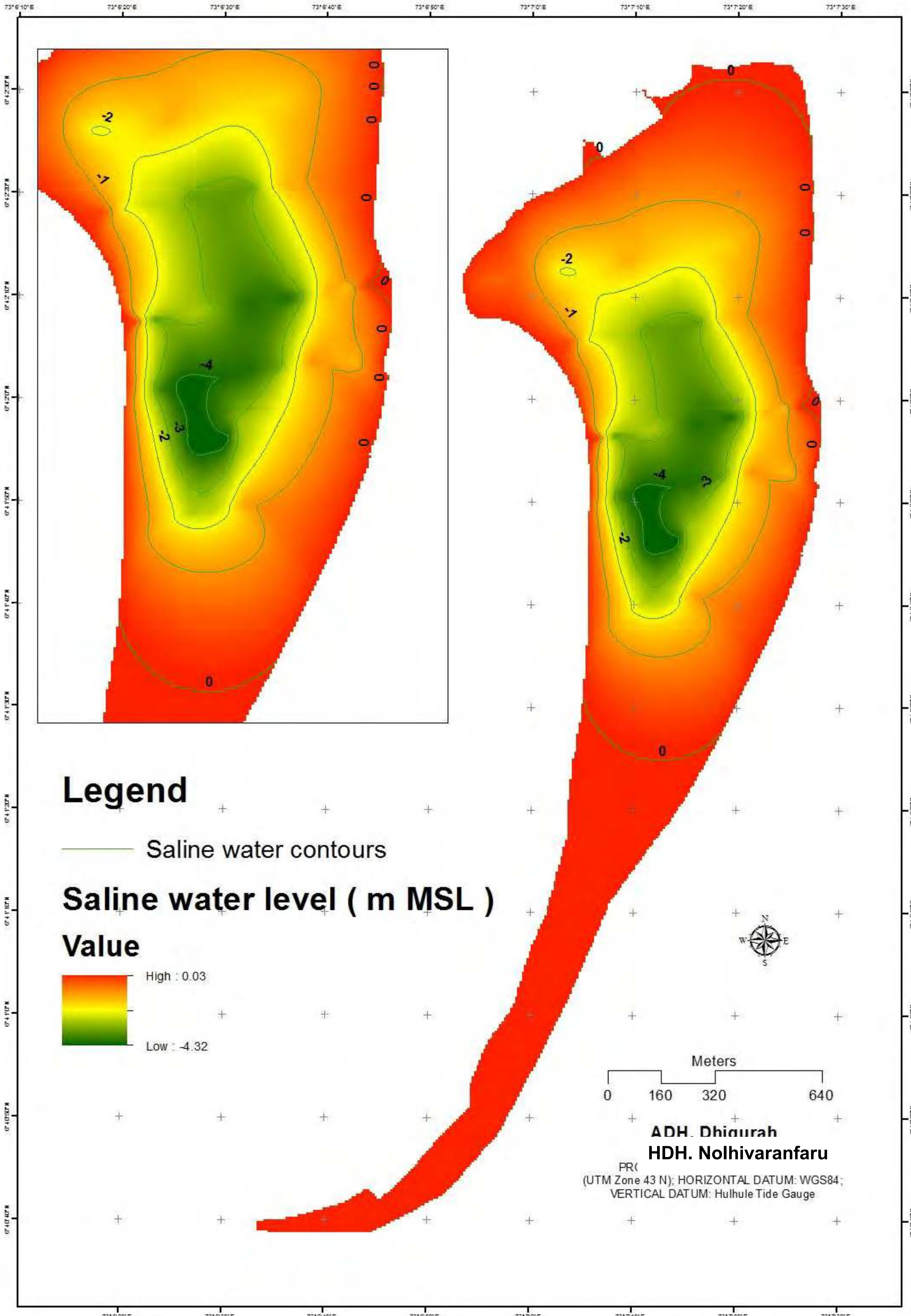


Figure 4.10: Saline water Level in Nolhivaranfaru Island

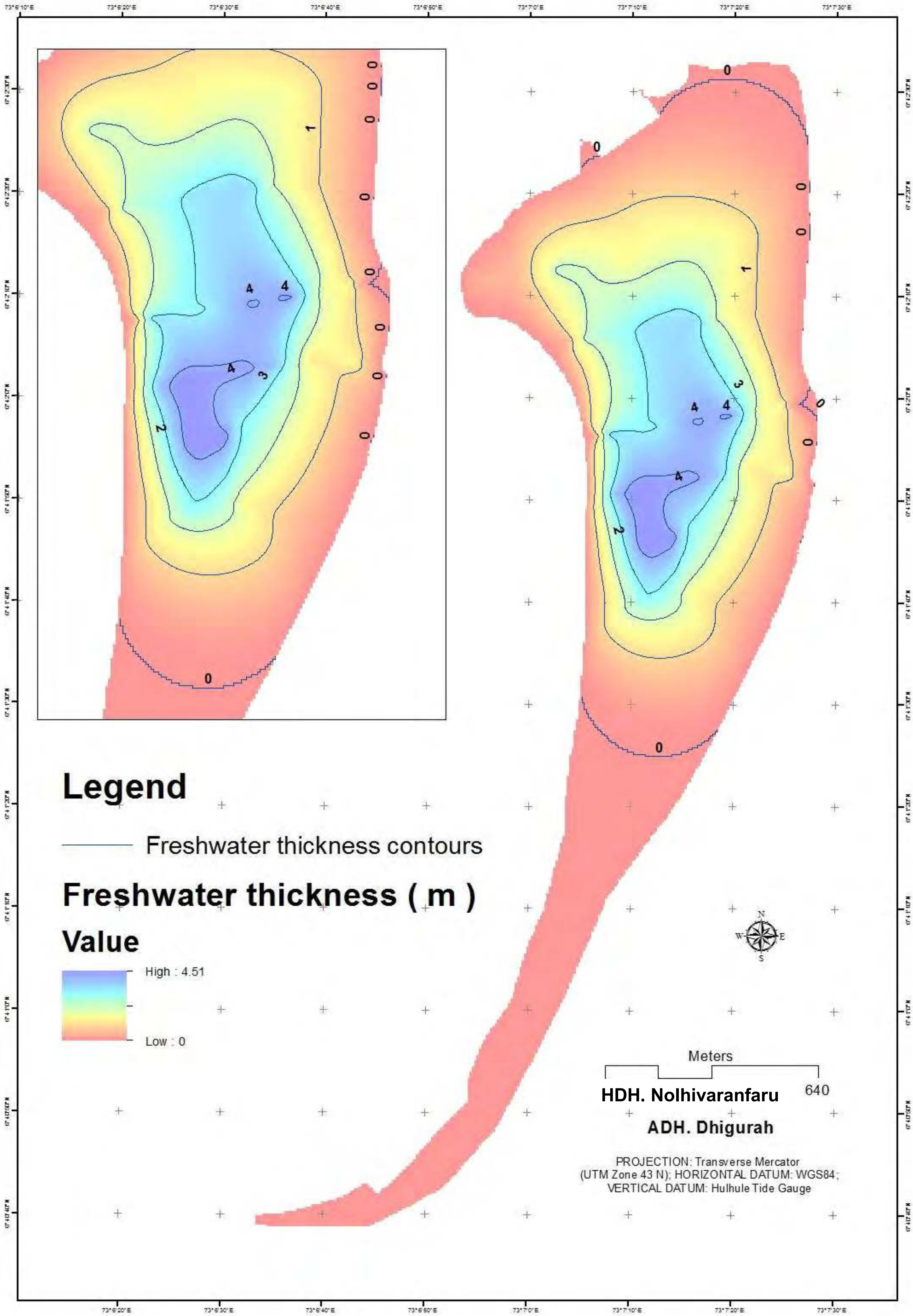


Figure 4.11: Freshwater thickness in Nolhivaranfaru Island

The maximum freshwater thickness of the island is 5.2 m. According to Falkland, 1994, the freshwater level thickness of the island is 9m. The relevant calculations are as follows;

Average Annual Rainfall = 1775 mm/yr

Width of the island = 715 m

Length of the island = 2003 m

Freshwater lens Thickness (m)

= (6.94*log(width of the island)-14.38)*Average Annual Rainfall = 10 m

4.8.6 Water balance and recharge

An annual estimation is carried out based on water balance method. Rainwater harvesting is calculated using number of rainwater harvesting units in the island. According to the spatial mean annual rainfall of Maldives, the island is reported as 1775 mm/year. Evapotranspiration was estimated using crop water requirement for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. The groundwater extractions were estimated from amount of water usage in different sectors (residential, resorts, restaurants, agriculture and farming).The difference between recharge and groundwater extraction is taken to estimate different in storage.

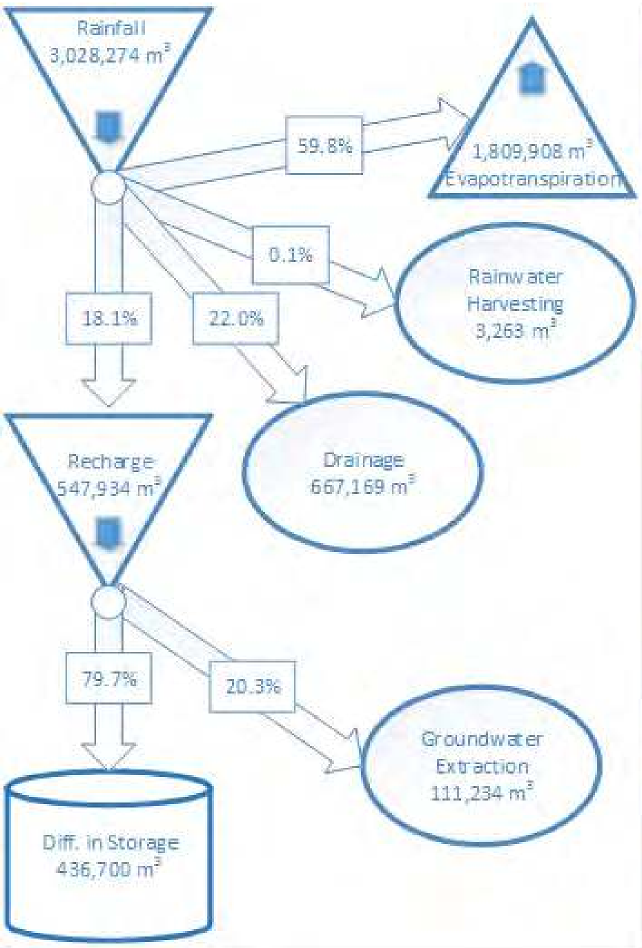


Figure 4.12: Schematic of water balance in Nolhivaranfaru Island

4.8.7 Sustainable yield of the lens

Sustainable yield of the water lens refers to the safe extraction potential of a given groundwater aquifer without significantly affecting its quality or quantity. This parameter is an important factor in the sustainable development of islands as it allows planning and design of water and sanitation intervention in islands.

The island has a sustainable yield of 1196 m^3 per day which was calculated subtracting groundwater extraction from recharge volume derived from water balance (Figure 9.13). According to Metai & Unit, n.d., based on geophysical investigations and drilling programme concluded that the safe sustainable yield was about 10% of mean annual rainfall. Such that the expected sustainable yield for the island should be 830 m^3 per day.

4.8.8 Permeability test

Permeability tests were carried out in the locations as outlined in Figure 4.13.

Figure 4.13: Locations of permeability tests in Nolhivaranfaru Island

The estimated permeability values for the above test locations are presented below.

Table 4.10: The estimated permeability Values

r_e		0.0260
r_1		0.0285

Point	H	Tu	Cs	H/r_e	Q	K (m/s)	K (m/day)	Q (l/min)	Q (m^3/s)
NFPT1	0.5	0.7	40	19.2	2.5E-05	6.19E-05	5.35	1.5	0.00003
NFPT2	0.65	0.6	45	25.0	6.7E-05	1.73E-04	14.95	4.0	0.00007
NFPT3	0.6	1.1	43	23.1	3.3E-05	4.92E-05	4.25	2.0	0.00003
NFPT4	0.7	0.9	50	26.9	8.3E-05	1.31E-04	11.32	5.0	0.00008
NFPT5	0.4	0.5	32	15.4	6.3E-06	2.64E-05	2.28	0.4	0.00001
NFPT6	0.6	0.8	43	23.1	5.0E-05	1.08E-04	9.35	3.0	0.00005

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m^3/s), H = Height of water in well (m), l = length of perforated section (m), r_1 = outside radius of casing (radius of hole in consolidated material) (m), r_e = effective radius of well = r_1 (area of perforations) / (outside area of perforated section of casing) : $r_1 = r_e$ in consolidated material that will stand open and is not cast, C_u and C_s =Conductivity Coefficients, and T_u = distance from water level in casing to water table (m).

4.8.9 Groundwater availability

1) The selected Nolhivaranfaru island has dimensions of width = 715 m and length = 2003 m, with a total land area of 171.00 ha, a population of 1081 persons, and a land use of built-up area 8.09 ha (4.8%), thick vegetation 102.93 ha (61.1%), light vegetation 16.92 ha (10.0%), and farmlands 4.78 ha (2.8%).

2) In order to recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of freshwater lens (FWL) and its associated recharge-discharge characteristics, 47 number of Electrical Resistivity (ER) location readings along 06 representatively selected transects were collected.

3) Soil overburden permeability tests (constant head) were carried out at 06 locations. In addition, groundwater level was also recorded at 07 locations where groundwater water quality samples were tested.

4) Permeability tests were carried out at representatively selected 05 number of locations. The measured permeability (K m/day) values ranged from a minimum of 2.28 m/day to a maximum of 14.95 m/day, with an average of 7.92 ± 4.79 m/day (Mean ± 1 Standard Deviation).

5) The ground elevation values ranged from a minimum of 0.27 m MSL to a maximum of 1.73 m MSL, with an average of 0.95 ± 0.23 m MSL (Mean ± 1 Standard Deviation).

6) The upper boundary of the freshwater lens (FWL) varied from a minimum of -0.01 m MSL to a maximum of 0.37 m MSL, with an average of 0.14 ± 0.08 m MSL (Mean ± 1 Standard Deviation).

7) The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -4.37 m MSL to a maximum of 0.03 m MSL, with an average of -2.24 ± 1.29 m MSL (Mean ± 1 Standard Deviation).

8) Accordingly, the freshwater lens (FWL) thickness values ranged from a minimum of 0.33 m to a maximum of 4.52 m, with an average of 2.43 ± 1.26 m (Mean ± 1 Standard Deviation).

9) The groundwater profile in the island is characterised by a relatively Low (0.11%) Rainwater Harvesting, relatively Low (22.03%) Drainage, relatively Very Low (18.09%) Recharge, while the water use shows relatively High (20.30%) Groundwater extraction, leading to relatively High (79.70%) Difference in Balance Storage.

10) The freshwater lens (FWL) volume calculated based on ER transect test data is 335,176 m^3 with a maximum FWL thickness of 4.52 m. The potential maximum FWL volume and thickness estimated based on Falkland (1994) method are 239,274 m^3 and 9.63 m.

4.8.10 Conclusive Comments and Recommendations

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 1,196 m^3 per day, while it is 830 m^3 per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 309 m^3 per day and this is about 37% of the allowable Safe Yield in the island with minor up-coning and slight drawdown in freshwater lens cross-sections. At present, there exists no island-wide sewerage network or water supply network. The water samples tested were found to be Highly Odorous with 100.0% or 10/10 samples tested producing odour. The Hydrological condition of the freshwater lens aquifer can be categorised as Moderate to Low based on above measurements and findings while Water quality aspects can be regarded as Contaminated with an Average Electrical Conductivity (EC) of 2,240.18 ± 3,522.33 µS/cm with measured values ranging from a minimum of 742.90 µS/cm to a maximum of 12,224.80 µS/cm, and an Average Ammonia Concentration of 6.72 ± 8.42 mg/L with measured values ranging from a minimum of 0.68 mg/L to a maximum of 25.78 mg/L.

The Availability of space for incorporating recharge measures and related infrastructure is High while therefore the Potential for Recharging is considered to be Moderate. Overall recommendation for groundwater recharging would be to use recharging ponds in low lying areas and recharging trenches in other areas.

5 SH. FUNADHOO ISLAND

5.1 General overview of the island

The island of Funadhoo is located at 6°08'54"N and 73°17'24"E in the Shaviyani Administrative Atoll. It is the atolls capital island. It is 3373 m long and 415 m wide, leading it to have an area of 118 Hectares. The population of the island, via the 2014 Census, is 2104. A harbor has been built on the western side of the island. The island has 2 mangroves. One is approximately 1km in length and the other is 75x50 m. The island does not have an existing water supply network. For waste disposal most houses are connected to the island sewerage network. Work to construct an airport on the northern side of the island has been completed as of March 2019.

Table 5.1: Basic statistical information on Funadhoo island in Shaviyani Atoll.

Name of the island	Sh.Funadhoo
Longitude and Latitude	6°08'54"N, 73°17'24"E
Area	100 ha
Population (Census, 2014)	2104
Distance from Atoll Capital (Sh. Funadhoo)	0
Distance from Male'	Approx. 219.52 km
Harbour	Present
Island sewerage network	Yes
Water supply network	No
Other infrastructure	

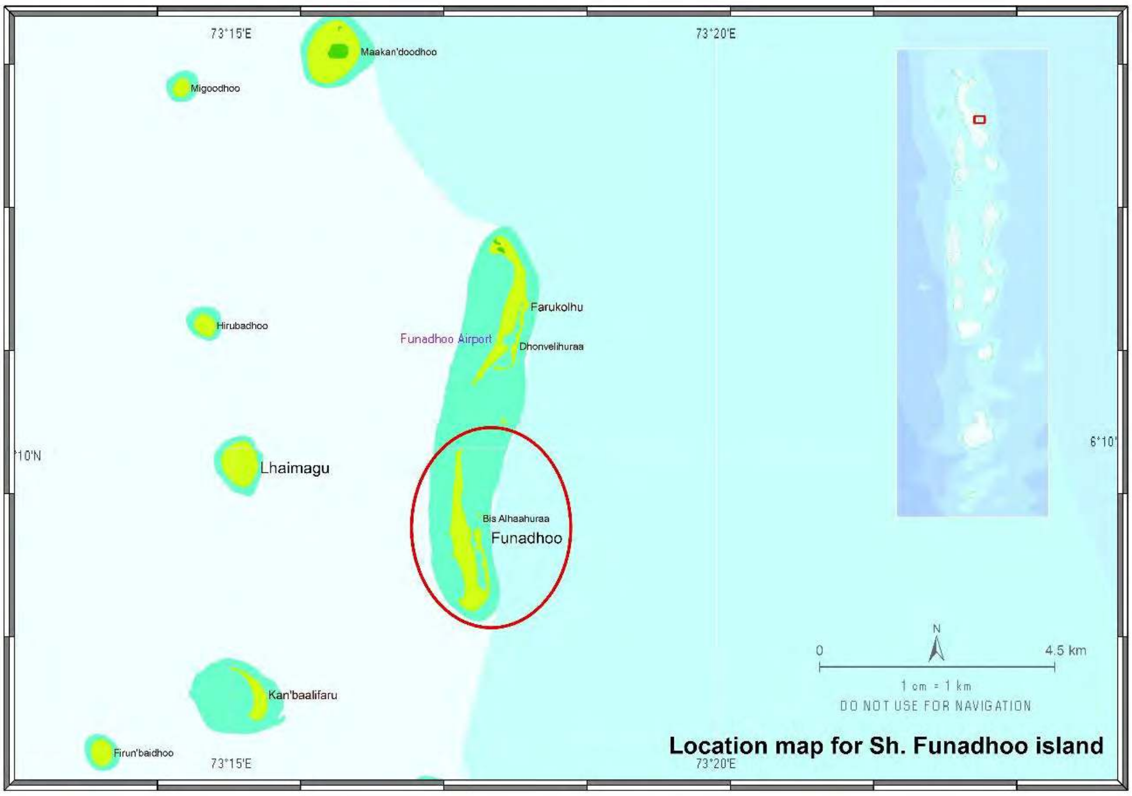


Figure 5.1: Location map for Funadhoo Island, Shaviyani Atoll.

5.2 Geology and vegetation

The island is approximately 3373 m long and 415 m wide. Approximately 25% of the island is taken up by the newly constructed airport, which was built on top of mostly reclaimed land on the northern side of the island. The island has 2 mangroves. One is approximately 1km in length and the other is 75x50 m. The larger one covers about 10% of the island and is on the eastern side of the island. The smaller one is at the northern side of the island, next to the airport. The vegetation covers about 30% of the island, which is primarily located at the northern and southern sides of the island, and on the eastern side to the right of the mangrove. No farming takes place on the island with the exception of home gardens.

5.3 Topography

The island has a topography that ranges from an elevation of 0.29 meters to 1.79 meters above Mean Sea Level, with an average elevation of 1.07 meters above MSL. Figure 5.2 shows digital surface model of Funadhoo Island showing spot heights.

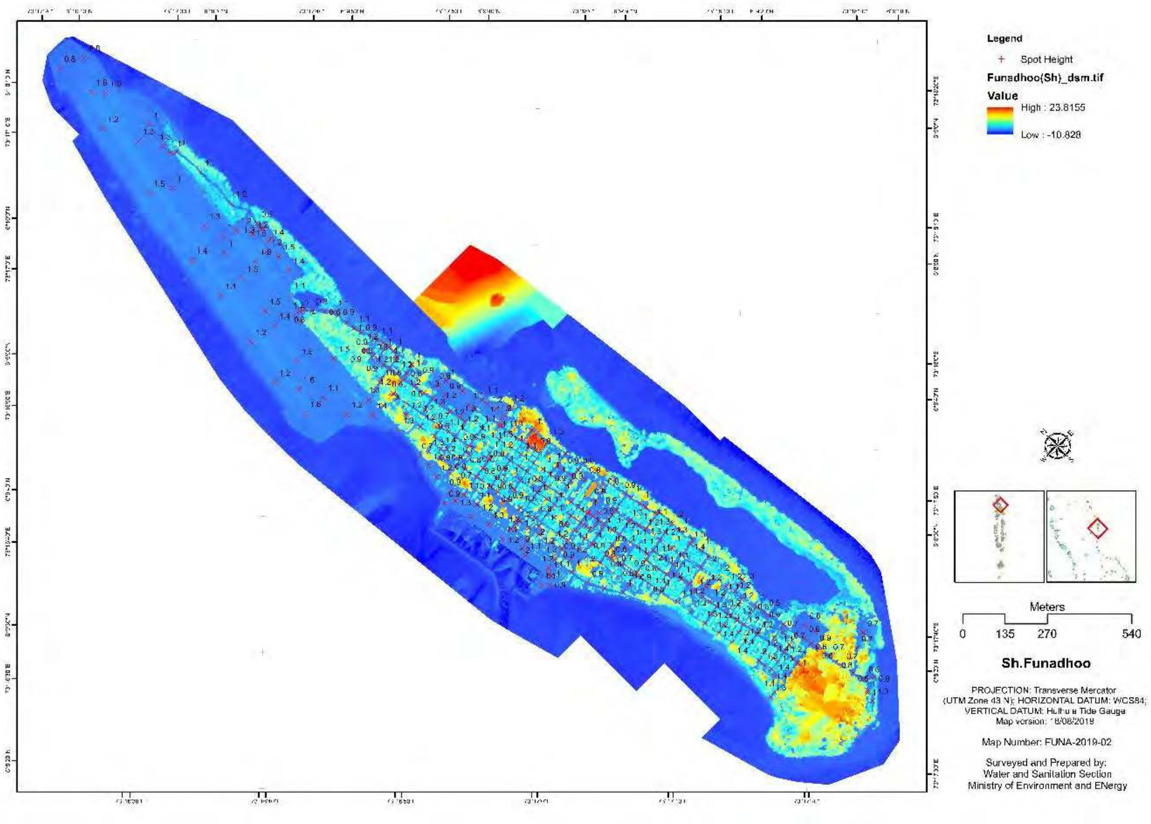


Figure 5.2: Digital surface model of Funadhoo Island

5.4 Climate

Funadhoo experiences the typical two monsoons namely, north east monsoon from November to April and South-west monsoons from April to November. There are no specific wind and rainfall data available for Funadhoo as there are no weather monitoring stations on the island.

5.5 Demography

The island has a population of 2104 people via the 2014 Census, of which 2015 of those are locals and 89 are foreigners. However, this figure may not be accurate as there is a larger population being reported by the island council. For the total population there are 106 more females than males (52:48 percent). This difference is found to be slightly more when only locals are considered with a difference of 141 more females than males (53:47 percent). Among the foreigners there are significantly more males than females, with 62 males and 27 females. The following graphs and tables illustrate the demographic breakdown.

Table 5.2: Demographic Breakdown of Funadhoo Island

Atoll	locality	Resident population (Census, 2014)								
		Total			Maldivians			Foreigners		
		Both sexes	Male	Female	Both sexes	Male	Female	Both sexes	Male	Female
Sh	Funadhoo	2,104	999	1,105	2,015	937	1,078	89	62	27

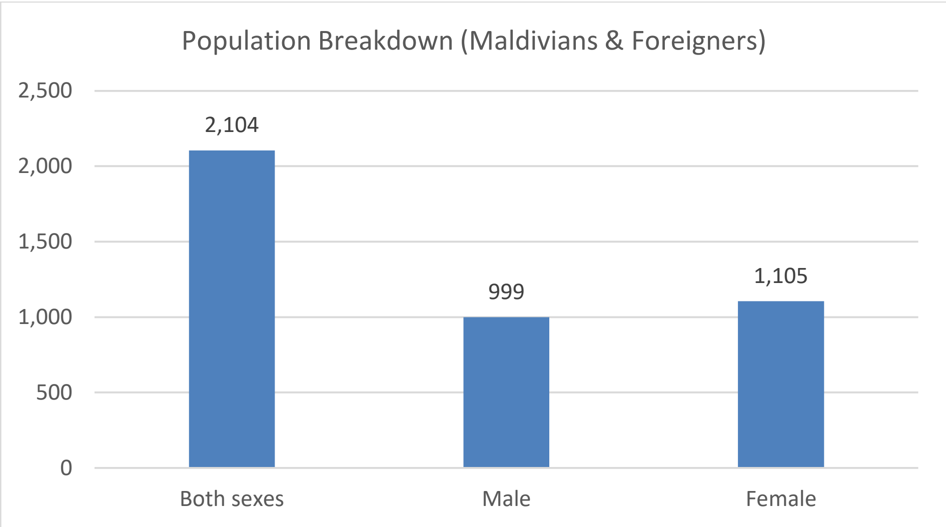


Figure 5.3: Population breakdown of Funadhoo (Maldivians & Foreigners)

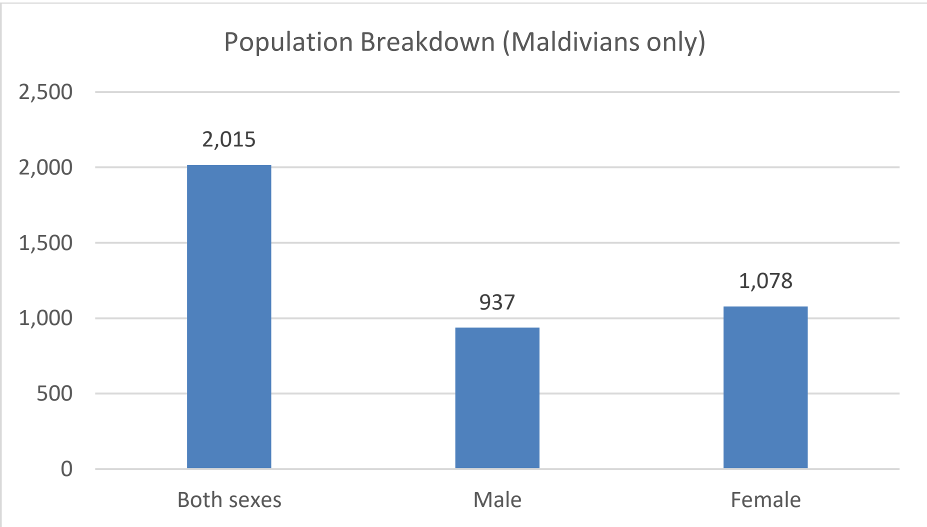


Figure 5.4: Population breakdown of Funadhoo (Maldivians)

5.6 Socio-economic condition

Construction of an airport on the northern end of the island has just recently concluded.

5.7 Existing water and sanitation situation

The Island does not have an existing water supply network but does have a sewerage network to which almost all the households are connected to. Out of the 30 houses surveyed, only one house was not connected to the island sewerage network and still used septic tanks for sanitation purposes. This house claims a distance of 6 meters between their septic tank and nearest well.

Their primary source of both cooking and drinking water is rainwater which is collected in either household or community rainwater tanks. This has a tendency of running out in many households during the dry season. As a result, some use water from community or neighbouring households' tanks, some use well water and others use bottled water instead.

5.8 Results

5.8.1 Water sources and water use

Based on domestic, commercial and institutional water usage, a total of 510,313 liters of groundwater are estimated to be used every day. Otherwise stated, 243 liters of groundwater are used per capita per day. From all the islands surveyed, the highest total groundwater usage per day is observed in Sh. Funadhoo. This is as expected as Funadhoo has the highest population from the 13 islands. The respective water use situations are detailed in the following sections. There is no industrial water usage on this island.

5.8.1.1 Domestic water use situation

Based on the questionnaire to collect data on domestic water consumption, a summary of results are present in this section.

According to the survey, 96.67% of the households surveyed uses HDPE rainwater tanks as their main storage for water. A total of 100% households use rainwater for drinking and 100% use it for cooking. None of the surveyed houses use rainwater for bathing or washing.

0% of the households use groundwater as drinking. Groundwater is mainly used for non-potable use in all the households surveyed.

The following table 5.3 summarizes the data for Funadhoo island.

Table 5.3: Groundwater and rainwater use data for Funadhoo Island

Rainwater	
Households with rainwater tanks	100%
Rainwater use for drinking	96.67%
Rainwater use for cooking	100%
Rainwater use for bathing and washing	0%
Groundwater	
Groundwater as drinking source	3.33%
Groundwater for cooking	0%
Groundwater for non-potable use	100%
Total number of household wells surveyed	(10%)
Percentage of wells surveyed fitted with pumps	100%

Based on the survey questionnaire, average daily water demand per capita for domestic purposes has been estimated based on the average amount of water used per person for showering, toilet flushing, laundry and gardening, this data is shown in table 5.4. The total domestic water use is estimated to be 237 liters per capita per day.

Table 5.4: Domestic Water Usage in Funadhoo Island

Shower/ Liters per capita per day	Toilet/ Liters per capita per day	Laundry/ Liters per capita per day	Gardening/ Liters per capita per day	Total/ Liters per capita per day
142	30	16	40	**237**

5.8.1.2 Commercial water use situation

Based on the questionnaire to collect data on commercial water consumption, a summary of results is present in this section. A total of 2 restaurants were surveyed. Funadhoo Island does not have any guesthouses.

For the restaurants, the main use of groundwater was for dishwashing and toilet use. A total of 2 restaurants (50%) were surveyed and from this data, the water consumption for the total 4 restaurants on Funadhoo Island were estimated to be 6698 liters per day.

5.8.1.3 Institutional water use situation

Based on the questionnaire to collect data on institutional water consumption, a summary of results is present in this section. The institutions surveyed for this study were atoll office, island office, health center and the school. Groundwater in the institutions in Funadhoo Island are mainly used for gardening, mopping floors and flushing toilets. A total of approximately 5675 liters of groundwater are estimated to be used per day by the institutions. Therefore, a total of approximately 2.70 liters of groundwater are estimated to be used per capita per day by the institutions of Funadhoo Island.

Table 5.5: Water Usage in Institutions in Funadhoo Island

<table>
<tr><th></th><th>Water Flushed (Liters per day)</th><th>Gardening (Liters per day)</th><th>Mopping (Liters per day)</th><th>Shower (Liters per day)</th><th>Total Water Usage (Liters per day)</th><th>Total Water Usage by all institutions (Liters per day)</th><th>Institutional Groundwater Usage (Liters per capita per day)</th></tr>
<tr><td>Health Center</td><td>399</td><td>-</td><td>-</td><td>143</td><td>542</td><td rowspan="4">5675</td><td rowspan="4">2.70</td></tr>
<tr><td>Atoll Office</td><td>157</td><td>1080</td><td>-</td><td>-</td><td>1237</td></tr>
<tr><td>Island Office</td><td>109</td><td>360</td><td>-</td><td>-</td><td>469</td></tr>
<tr><td>School</td><td>1558</td><td>1620</td><td>250</td><td>-</td><td>3428</td></tr>
</table>

5.8.2 Groundwater quality

Groundwater quality measurements were made at selected wells in Funadhoo for both physical and microbiological testing.

The following table summarizes the water quality results.

Table 5.6: Summary of groundwater quality tests from Funadhoo, April 2019

Sample No	Odour	Physical Appearance
gw1	yes	Clear with particles
gw2	yes	Clear with green particles
gw3	yes	Clear with particles
gw4	yes	Clear
gw5	yes	Clear
gw6	yes	Clear with particles
gw7	yes	Clear with particles
gw8	yes	Clear
gw9	yes	Pale yellow with particles
gw10	yes	Pale yellow with particles
gw11	yes	Pale yellow with particles
gw12	yes	Pale yellow with particles
gw13	yes	Pale yellow with particles

Sample No	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
gw1	1,950.8	1127	7.46	0.11	6.05	31.5	0.87	15.2	2.5	0.08		
gw2	3,581.6	2115	7.41	0.13	5.63	30.3	1.69	34.9	3.72	0.14	411	313
gw3	2,532.2	1502	7.9	0.02	7.71	30.0	1.17	17.3	1.95	0.26		
gw4	2,065.4	1226	7.35	0.29	7.25	30.0	0.95	15.1	1.69	0.34		
gw5	3,095.2	1804	7.29	1.60	6.73	31.0	1.42	30.4	3.11	0.13	54	37
gw6	1,191.6	698	7.47	0.44	6.81	30.8	0.52	21.4	1.03	0.74		
gw7	1,414.5	833	7.62	0.00	6.86	30.5	0.63	48.4	1.34	0.14		
gw8	5,245.8	3047	7.22	0.03	6.39	31.2	2.48	23.0	6.35	0.07		
gw9	8,869.9	5216	7.27	0.1	6.39	30.5	4.41	40.8	7.86	0.2	153	
gw10	3,720.6	2150	7.42	0.03	6.19	31.5	1.71	39.8	5.98	0.13		
gw11	9,505	5524	7.79	0.05	7.17	31.2	4.68	46.9	8.15	0.2	>2420	>2420
gw12	19,985.6	11138	7.53	0.13	7.08	33.7	9.96	88.8	15.79	0.09		
gw13	34,964.5	20439	7.36	0.11	7.16	30.9	19.44	115.9	37.92	0.17	>2420	727

	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)
WHO Standards	Suggested maximum limit of freshwater for potable purposes = 1500 µS/cm Suggested maximum limit of freshwater for non-potable purposes = 2500 µS/cm	-	-	-	-	-

	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
WHO Values	-	Guideline Value = 50 mg/L-NO3	Natural Level of Ammonia < 0.2 mg/L Threshold odour concentration = 1.5 mg/L Taste threshold = 35 mg/L	-	-	-

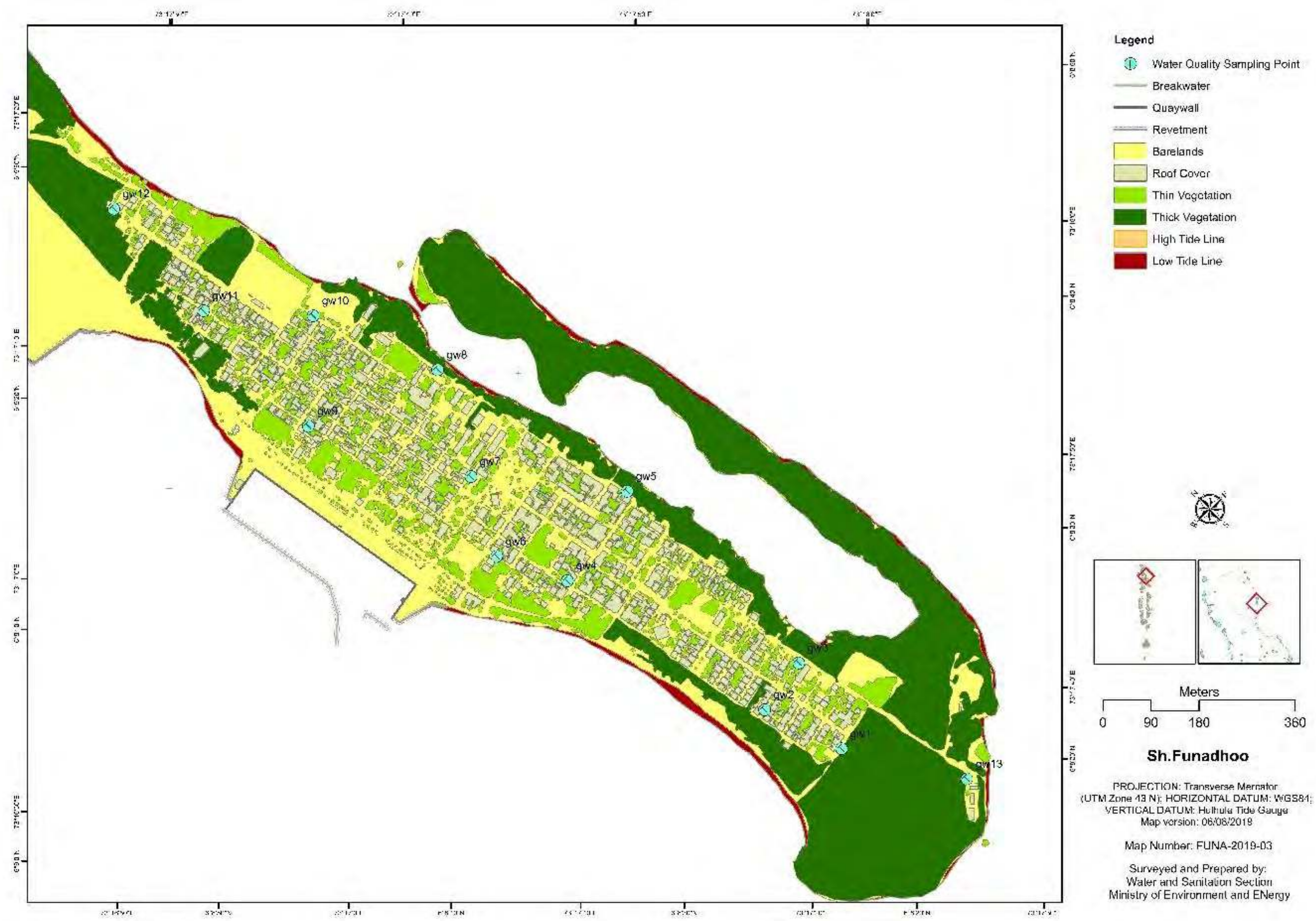


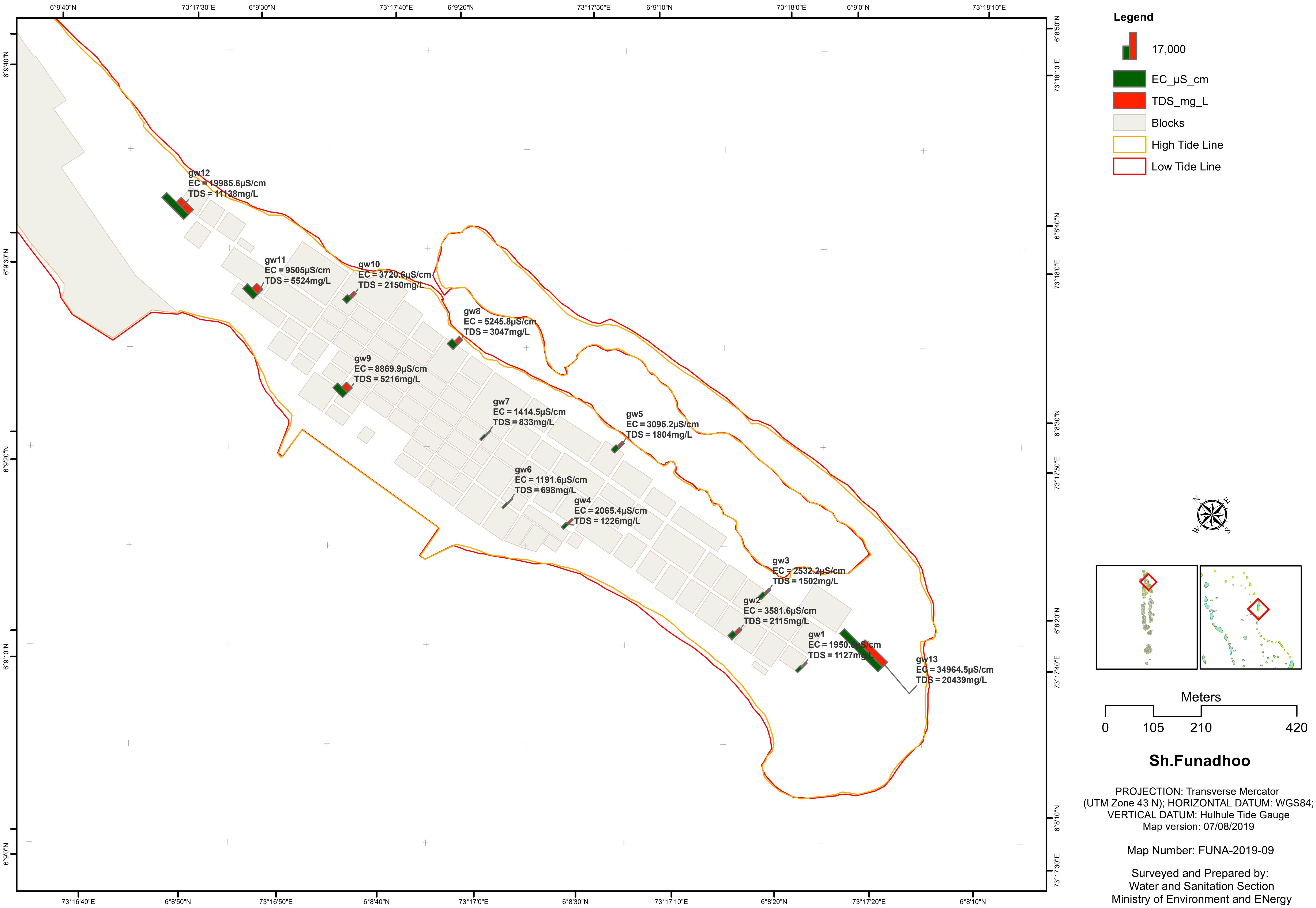
Figure 5.5: Location of groundwater sampling points in Sh. Funadhoo Island

Based on the full results and the summary shown in Table 9.6, the following observations are made:

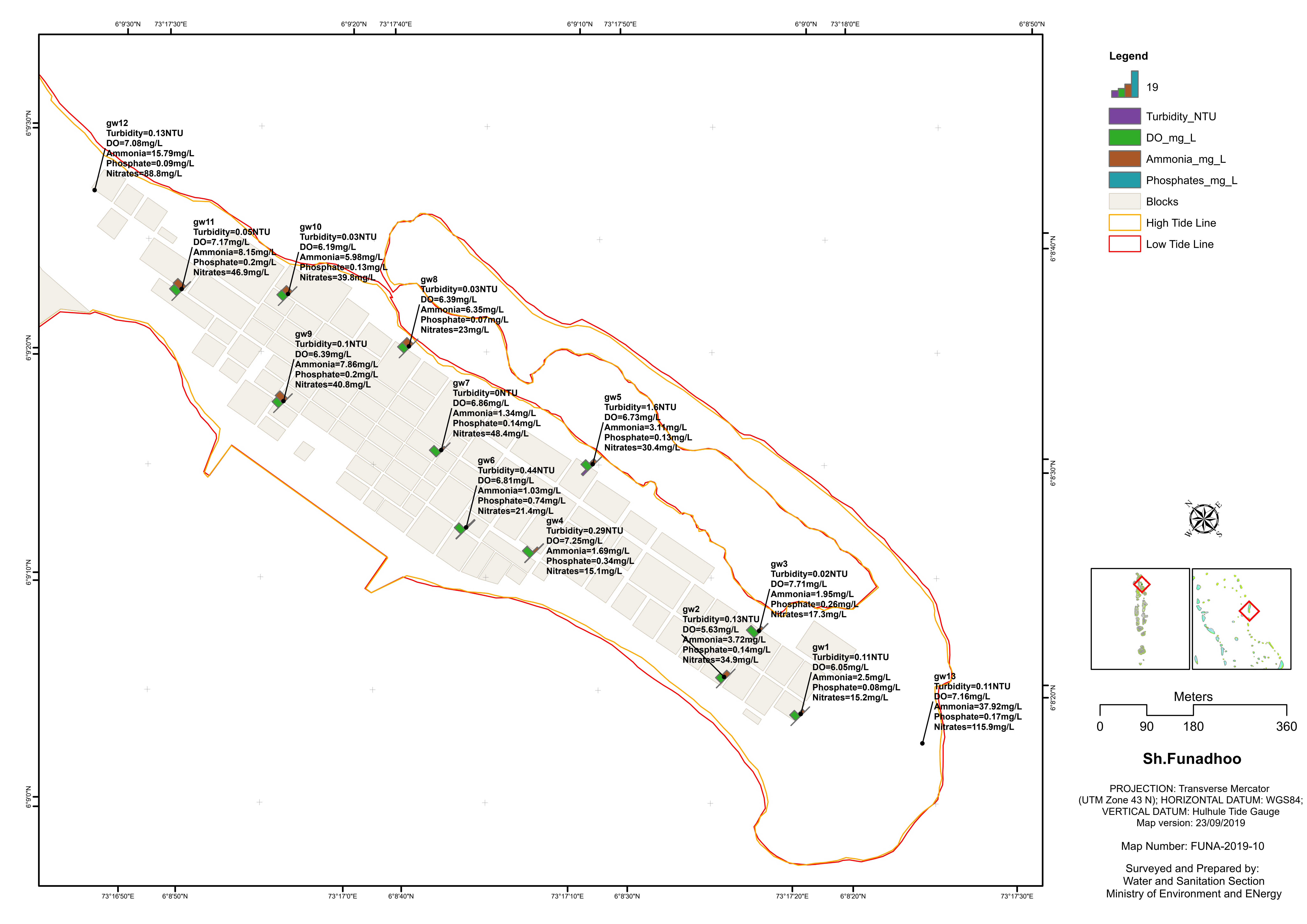
- The salinity (EC) of the groundwater is very high. The average EC reading of approximately 7547.9 µS/cm considerably exceeds the acceptable limit for potable water of 1,500 µS/cm (refer section 2.2). 11 of 13 tested water samples exceeded this limit, which is a high percentage of 84.6%. It should be noted that from all the islands surveyed so far, Sh. Funadhoo shows the highest average EC reading as well as the highest single EC reading of 34,964.50 µS/cm (gw13). The EC readings range from 1192 µS/cm to 34965 µS/cm. Sample gw13 which has the highest EC was taken from Fenaka which is located within 35m from the shoreline. Sample gw12 which has the second highest EC was also taken in close proximity to the sea, within 73m from the shoreline. Samples gw9 and gw11 which also have higher EC were taken closer to the seaside of the island compared to most other samples which were taken closer to the mangrove shoreline.
- Total dissolved solids were high and ranged from 698 mg/L to 20,439 mg/L with an average of 4371 mg/L. From all the islands surveyed, samples from Sh. Funadhoo had the highest average TDS reading as well as gw13 had the highest TDS reading recorded (20,439 mg/L).
- The pH ranged from 7.22 to 7.9 with an average pH of 7.31. As TDS readings are calculated from Specific Conductance and Conductivity, the trends shown in TDS readings are similar to EC.
- Turbidity ranged from 0 NTU to 1.6 NTU with an average of 0.23 NTU. As a guide, "crystal-clear" water has a turbidity below 1 NTU, and water becomes visibly cloudy at 4 NTU and above. All the samples had turbidity within the WHO acceptable limit.
- Dissolved oxygen levels ranged from 5.63 to 7.71 mg/L with an average of 6.72 mg/L.
- The salinity of groundwater ranged from 0.52 PSU to 19.44 PSU with an average of 3.84 PSU. Sample gw13 which has the highest salinity of 19.44 PSU is the only sample with a higher salinity than 10 PSU. The average salinity excluding gw13 is 2.54PSU. From all the islands surveyed, Sh. Funadhoo has the highest average salinity as well as the highest single salinity reading of 19.44 PSU (gw13.)
- The average Nitrate concentration was 41.4 mg/L which does not exceed the WHO guideline limit of 50 mg/L. The Nitrate concentrations ranged from 15.1 mg/L to 115.9 mg/L. 2 of 13 tested water samples (15%) exceeded the WHO guideline limit for Nitrate concentrations.
- Ammonia concentrations were generally high. The average ammonia concentration was 7.49 mg/L. This exceeds the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. It was found that 11 of the 13 tested water samples (84.62%) exceeded the WHO guideline. Natural levels of ammonia are generally below 0.2 mg/L (WHO, 1993) and no tests showed concentrations below this level. There is no apparent correlation between increasing levels of ammonia and other nutrients.
- Phosphate concentrations ranged from 0.07 mg/L to 0.74 mg/L with an average concentration of 0.21 mg/L. There is no WHO drinking water guideline value for phosphate. However, it would normally be expected that phosphate concentrations in groundwater are less than 0.1 mg/L, where there are no impacts from human wastewater (e.g. effluent from septic tanks and 'greywater' from kitchens and bathrooms). Only 3 of 13 the tested water samples (23%) had concentrations below 0.1 mg/L.
- Total Coliform levels were high and ranged from lowest count of 37 MPN/100mL to the highest count of more than 2420 MPN/100mL with an average estimated to be greater than 874.25 MPN/100mL. Faecal coliform levels were high, and showed concentrations ranging from 54 MPN/100mL to concentrations greater than 2420 MPN/100mL with an average concentration of 1091.6 MPN/100mL. As expected, the groundwater layer is contaminated with effluent from septic tanks.

Overall, the groundwater condition on the island in terms of salinity is not desirable. Funadhoo Island contains groundwater with generally high Electrical Conductivity with a higher average than WHO guidance value for potable and non-potable water and high TDS. Out of the samples tested from all the islands, the maximum EC, salinity and TDS was recorded on Sh. Funadhoo (gw13). Nitrate concentration was lower than WHO maximum guidance value, average Ammonia concentration and average Phosphate concentration was higher than expected in natural, undisturbed groundwater. In terms of microbiological contamination, an island wide contamination is observed.

The following pages contain maps which show the main physiochemical parameters displayed on map of the island.



Legend
17,000
EC_µS_cm
TDS_mg_L
Blocks
High Tide Line
Low Tide Line
gw12
EC = 19985.6µS/cm
TDS = 11138mg/L
gw11
EC = 9505µS/cm
TDS = 5524mg/L
gw10
EC = 3720.6µS/cm
TDS = 2150mg/L
gw8
EC = 5245.8µS/cm
TDS = 3047mg/L
gw9
EC = 8869.9µS/cm
TDS = 5216mg/L
gw7
EC = 1414.5µS/cm
TDS = 833mg/L
gw5
EC = 3095.2µS/cm
TDS = 1804mg/L
gw6
EC = 1191.6µS/cm
TDS = 698mg/L
gw4
EC = 2065.4µS/cm
TDS = 1226mg/L
gw3
EC = 2532.2µS/cm
TDS = 1502mg/L
gw2
EC = 3581.6µS/cm
TDS = 2115mg/L
gw1
gw13
EC = 34964.5µS/cm
TDS = 20439mg/L
Meters
0 105 210 420
Sh.Funadhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 07/08/2019
Map Number: FUNA-2019-09
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy



Legend
19
Turbidity_NTU
DO_mg_L
Ammonia_mg_L
Phosphates_mg_L
Blocks
High Tide Line
Low Tide Line
gw12
Turbidity=0.13NTU
DO=7.08mg/L
Ammonia=15.79mg/L
Phosphate=0.09mg/L
Nitrates=88.8mg/L
gw11
Turbidity=0.05NTU
DO=7.17mg/L
Ammonia=8.15mg/L
Phosphate=0.2mg/L
Nitrates=46.9mg/L
gw10
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DO=6.19mg/L
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Phosphate=0.07mg/L
Nitrates=23mg/L
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DO=6.39mg/L
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Phosphate=0.2mg/L
Nitrates=40.8mg/L
gw7
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Phosphate=0.14mg/L
Nitrates=48.4mg/L
gw5
Turbidity=1.6NTU
DO=6.73mg/L
Ammonia=3.11mg/L
Phosphate=0.13mg/L
Nitrates=30.4mg/L
gw6
Turbidity=0.44NTU
DO=6.81mg/L
Ammonia=1.03mg/L
Phosphate=0.74mg/L
Nitrates=21.4mg/L
gw4
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Ammonia=1.69mg/L
Phosphate=0.34mg/L
Nitrates=15.1mg/L
gw3
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Phosphate=0.26mg/L
Nitrates=17.3mg/L
gw2
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Ammonia=3.72mg/L
Phosphate=0.14mg/L
Nitrates=34.9mg/L
gw1
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Ammonia=2.5mg/L
Phosphate=0.08mg/L
Nitrates=15.2mg/L
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DO=7.16mg/L
Ammonia=37.92mg/L
Phosphate=0.17mg/L
Nitrates=115.9mg/L
6°9'30"N
73°17'30"E
6°9'20"N
73°17'40"E
6°9'10"N
73°17'50"E
6°9'0"N
73°18'0"E
6°8'50"N
6°9'30"N
6°9'20"N
6°9'10"N
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6°8'40"N
73°17'10"E
6°8'30"N
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73°17'30"E
N
E
W
S
Meters
0
90
180
360
Sh.Funadhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 23/09/2019
Map Number: FUNA-2019-10
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

5.8.3 Geophysical survey

The Resistivity tests were carried out in the locations as outlined in Figure 5.6 below.

Figure 5.6: Location of ER points in Funadhoo Island

5.8.4 Aerial surveys

Based on the aerial survey, a multiple dataset consisting of roof cover, thick vegetation area, thin vegetation area, bare lands and shorelines were extracted. This data is shown in Figure 5.7 and the table 5.7 shows the different area distribution.

Figure 5.7: Area Distribution in Funadhoo Island

Table 5.7: Area Distribution in Funadhoo

	Area (Square Meters)	% of total area
Roof cover	107,788	9.2%
Vegetation (Thick)	376,006	32.1%
Vegetation (Light)	128,282	10.9%
Bare lands	560,231	47.8%
Farm Lands	-	-
Wetlands (Inland)	-	-

5.8.5 Freshwater lens

Based on the ER survey the depth to groundwater level and the freshwater-saline water interface was determined for a set of transverse transects as shown in Figure 5.8. Plots in the Figure 5.9 shows the cross sections of each transect line. The dotted lines in the plots indicating a simple interpolation of levels to mean sea level in the island boundaries. These cross sections were used to identify the spatial extent and volume of the freshwater lens while they were also useful in deriving implications on the stress level of the aquifer based on the observed, localized drawdown effect in the groundwater table and up-coning in the freshwater-saline interface, defining the upper and lower boundaries of the freshwater lens in an island.

The Table 5.8 illustrate the freshwater volume calculation for the island. The area covered by freshwater for each transect line has been calculated. To estimate the total volume of available freshwater lens, the cross-section area of freshwater extent under each transect was multiplied by the distance between two transects. The sum of these lengths represents the cumulative length of the island and thus, the above estimation could represent the total volume of the freshwater lens sandwiched between the groundwater table on top and freshwater-saline water interface in the bottom. Then the actual groundwater storage within this freshwater lens was calculated by multiplying the estimated total lens volume with the porosity of the topsoil in the island.

This estimation represents the total available freshwater volume within the freshwater lens at any given time (time of the measurement). The measurements were carried out towards the end of the dry period and the freshwater lens is presumed to be undergoing a ‘stressed’ condition due to continued groundwater abstractions despite reduced recharge in the dry period. Falkland (1994) method can be used to estimate the freshwater lend thickness under salient conditions using average annual rainfall, length and width of the island, and the comparison was used as a measure of stress level of the freshwater lens.

Table 5.8: Freshwater Volume Calculation for Funadhoo Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
1	Start		0	0	0	0			
			24	0.219	0	0			
	FDA04	ER	104	0.934	0.02	0.02	0		
	FDA05	ER	157	0.984	0.04	0.04	0		
	FDA07	ER	254	0.642	0.03	0.03	0		
	FDA09	ER	302	1.067	0.02	-0.26	7		
	FDA10	ER	350	1.146	0.07	-0.8	27		
	FDA11	ER	397	1.31	0.06	-0.54	35		
			463	0.958	0	0	20		
	End		488	0	0	0	0		
	Total						89	277	24647
2	Start		0	0	0	0			
			12	0.281	0	0			
	FD13	ER	28	0.662	0.13	-0.25	3		
	FD14	ER	79	0.769	0	-1.48	47		
	FD15	ER	129	1.257	0.15	-1.51	78		
	FD16	ER	176	1.183	0.23	-1.01	67		
			229	0.966	0	0	33		
	End		241	0	0	0	0		
	Total						229	166	38017
3	Start		0	0	0	0			
			14	0.503	0	0			
	FD20	ER	39	1.391	0.15	-0.22	5		
	FD19	ER	90	1.234	0.17	-1.42	50		
	FD18	ER	138	1.176	0.17	-1.68	83		
	FD17	ER	204	1.235	0.25	-0.61	90		
			267	1.009	0	0	27		
	End		281	0	0	0	0		
	Total						254	205	52201

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
4	Start		0	0	0	0			
			16	0.521	0	0			
	FD21	ER	38	1.244	0	-0.39	4		
	FD22	ER	92	1.252	0.06	-2.13	69		
			305	1.164	0	0	234		
	End		321	0	0	0	0		
	Total						307	168	51635
5	Start		0	0	0	0			
			21	0.285	0	0			
	FDA13	ER	91	1.247	0.04	-2.18	78		
	FDA12	ER	144	1.279	0.07	-2.5	128		
			394	1.181	0	0	321		
	End		415	0	0	0	0		
	Total						527	254	133934
6	Start		0	0	0	0			
			19	0.372	0	0			
	FD05	ER	52	1.024	0.12	-1.42	25		
	FD04	ER	184	0.991	0.15	-2.55	280		
	FD03	ER	228	0.953	0.11	-2.13	110		
	FD02	ER	284	1.054	0.12	-1.9	119		
	FD01	ER	327	1.204	0.01	-0.37	51		
			356	0.738	0	0	6		
	End		375	0	0	0	0		
	Total						591	179	105748
7	Start		0	0	0	0			
			19	0.345	0	0			
	FD09	ER	66	1.188	0.23	-1.04	30		
	FD10	ER	119	1.009	0.09	-1.9	86		
	FD11	ER	208	0.802	-0.03	-2.04	178		
	FD12	ER	298	0.913	0.01	-1.84	173		
			366	0.712	0	0	63		
	End		385	0	0	0	0		
	Total						530	161	85190
8	Start		0	0	0	0			
			14	0.206	0	0			
	FDA03	ER	58	0.869	0.06	-0.81	19		
	FDA02	ER	96	0.785	0.11	-1.59	50		
	FDA01	ER	178	0.809	0.06	-1.5	133		
			261	0.694	0	0	65		
	End		274	0	0	0	0		

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
	Total						266	206	54794
9	Start		0	0	0	0			
			21	0.537	0	0			
	FD08	ER	39	1.009	0.04	0.04	0		
	FD07	ER	61	0.707	0.07	-0.06	1		
	FD06	ER	85	1.037	0.07	-0.08	3		
			390	0.972	0	0	23		
	End		411	0	0	0	0		
	Total						28	40	1098
									27,363

Volume of lens = 27363 m^3

Groundwater Storage = Porosity (20%) x Lens volume (m^3) = 5473 m^3

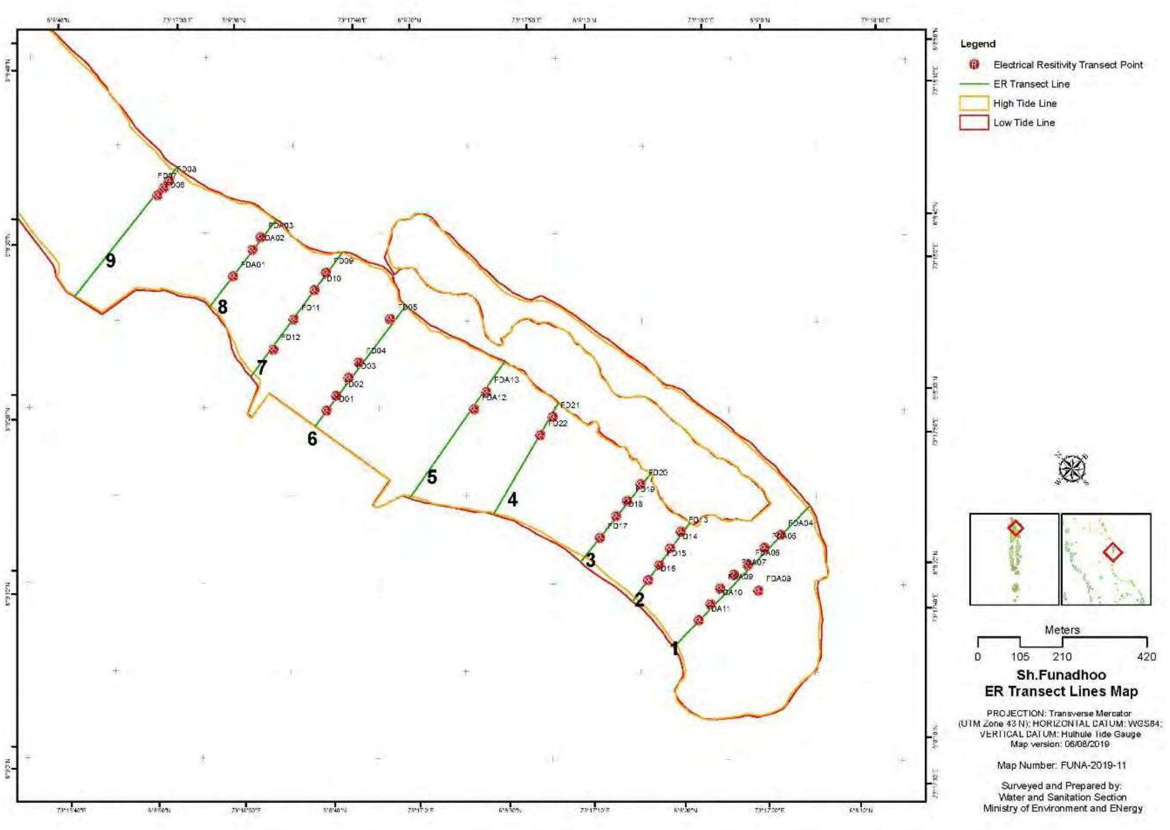
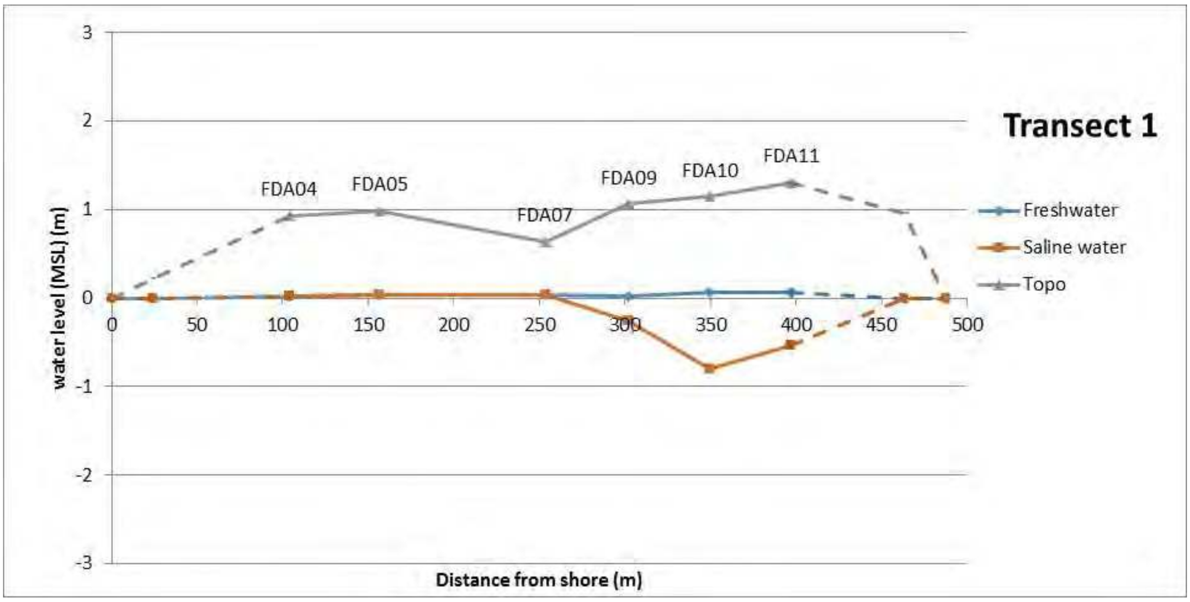
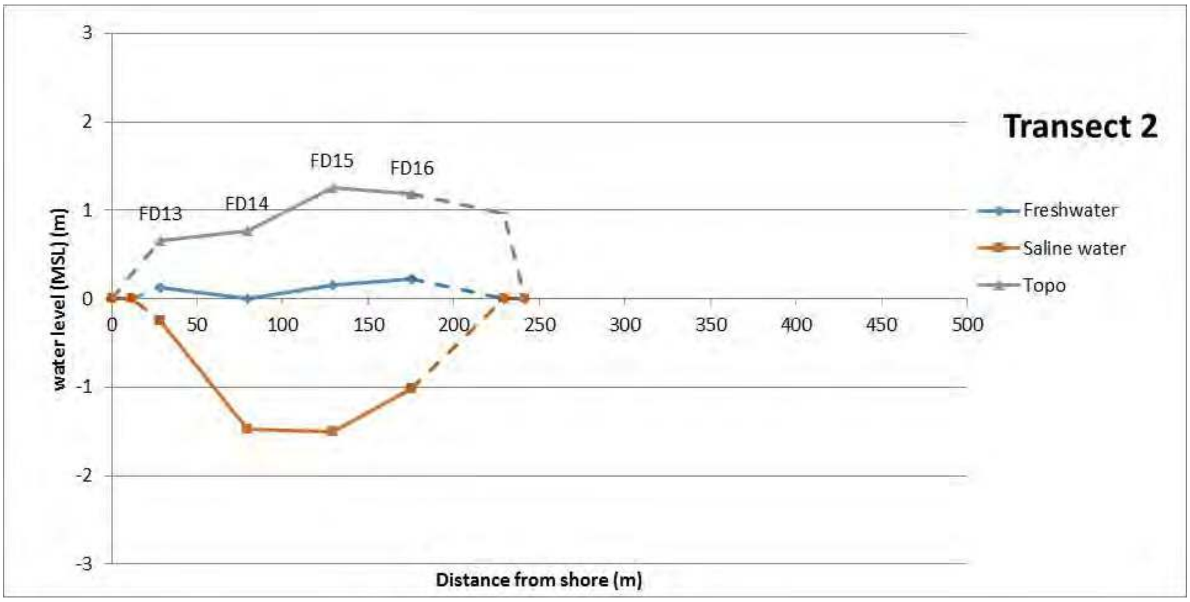
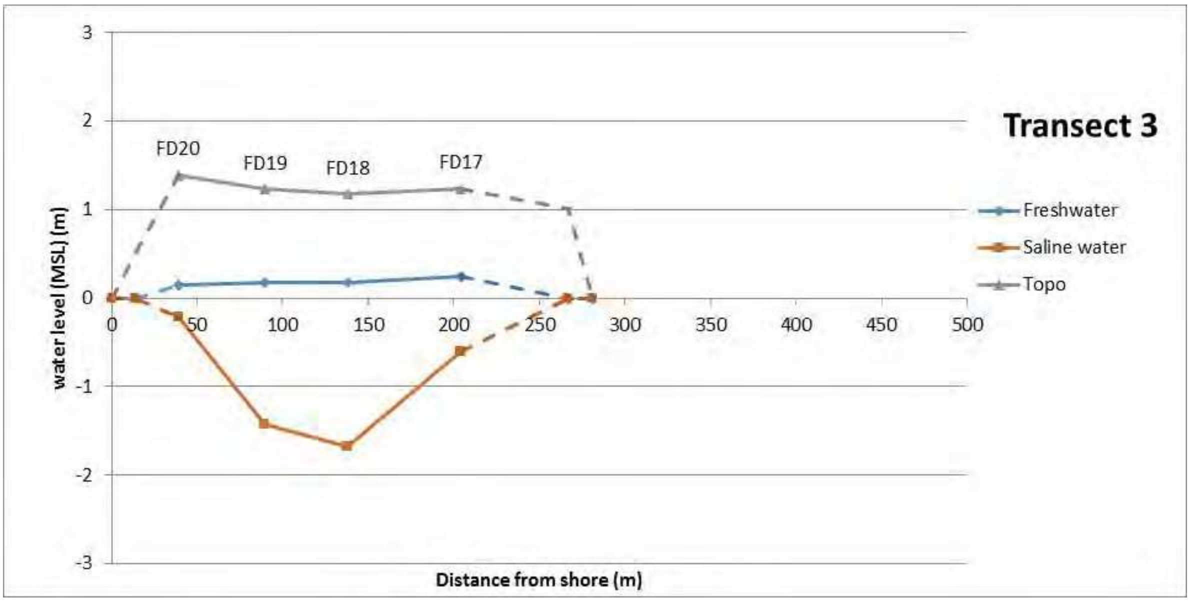
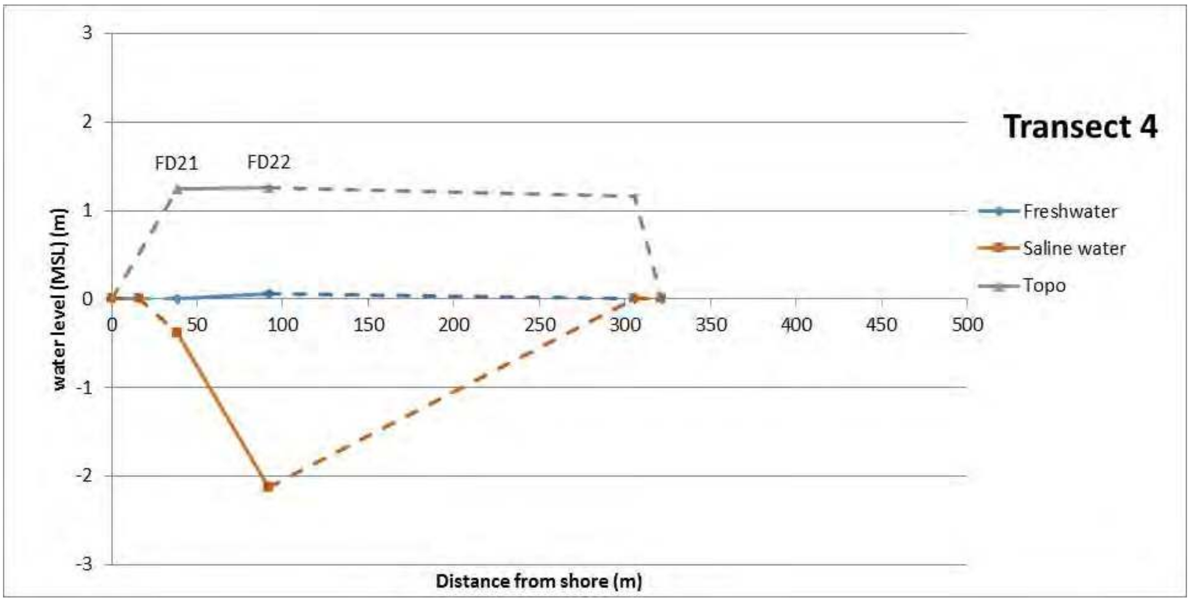


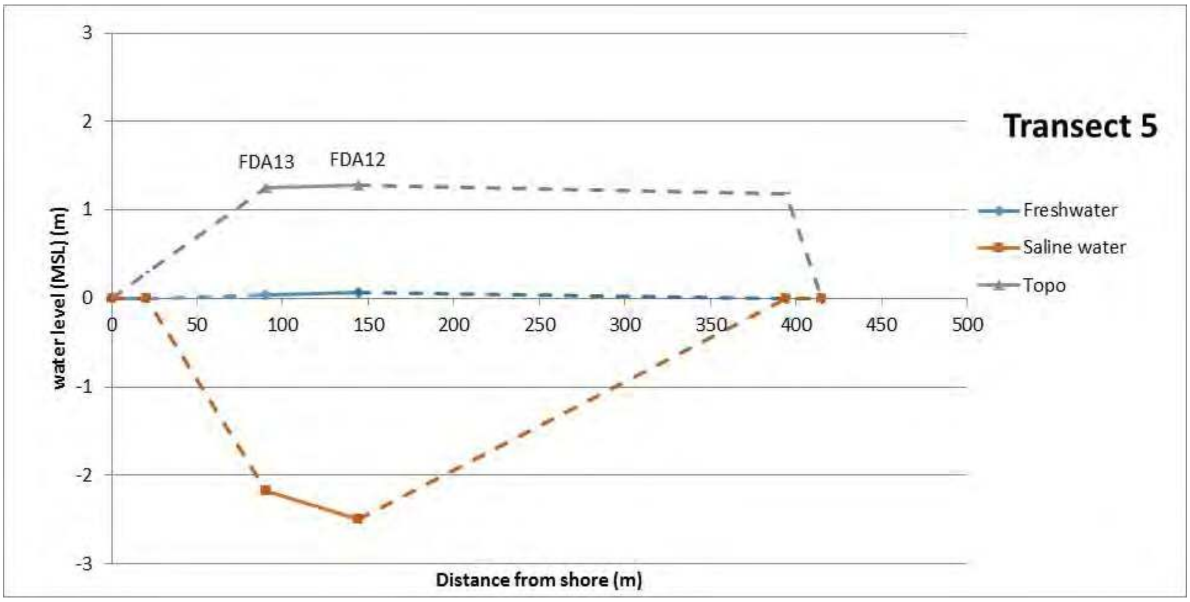
Figure 5.8: ER transect lines in Funadhoo Island

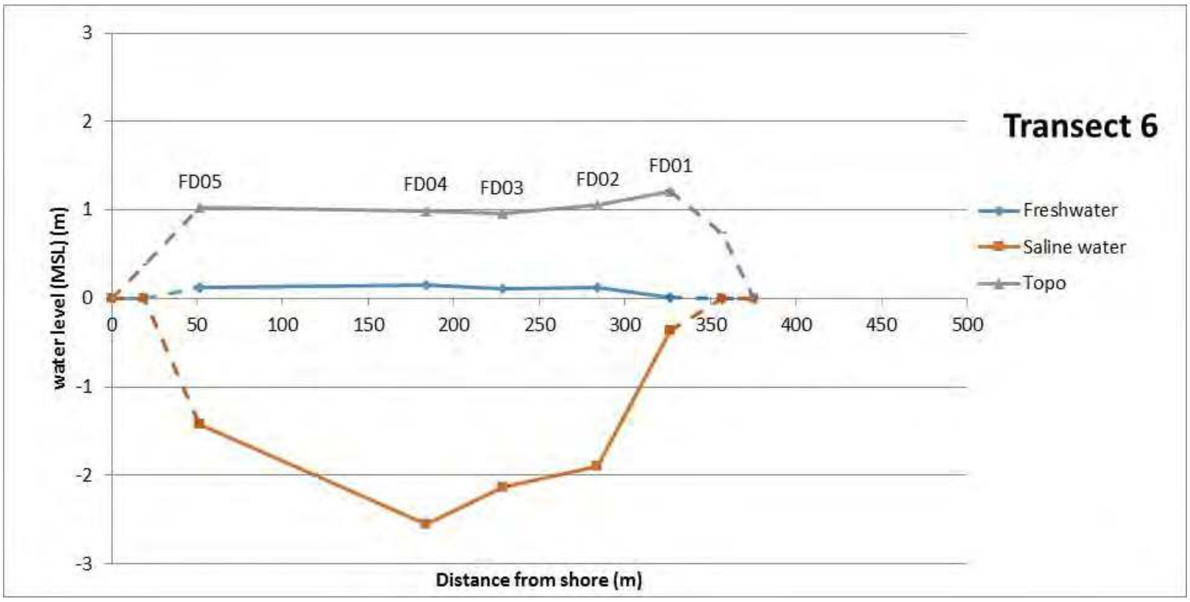

Transect 1
FDA04
FDA05
FDA07
FDA09
FDA10
FDA11
Freshwater
Saline water
Topo
water level (MSL) (m)
Distance from shore (m)

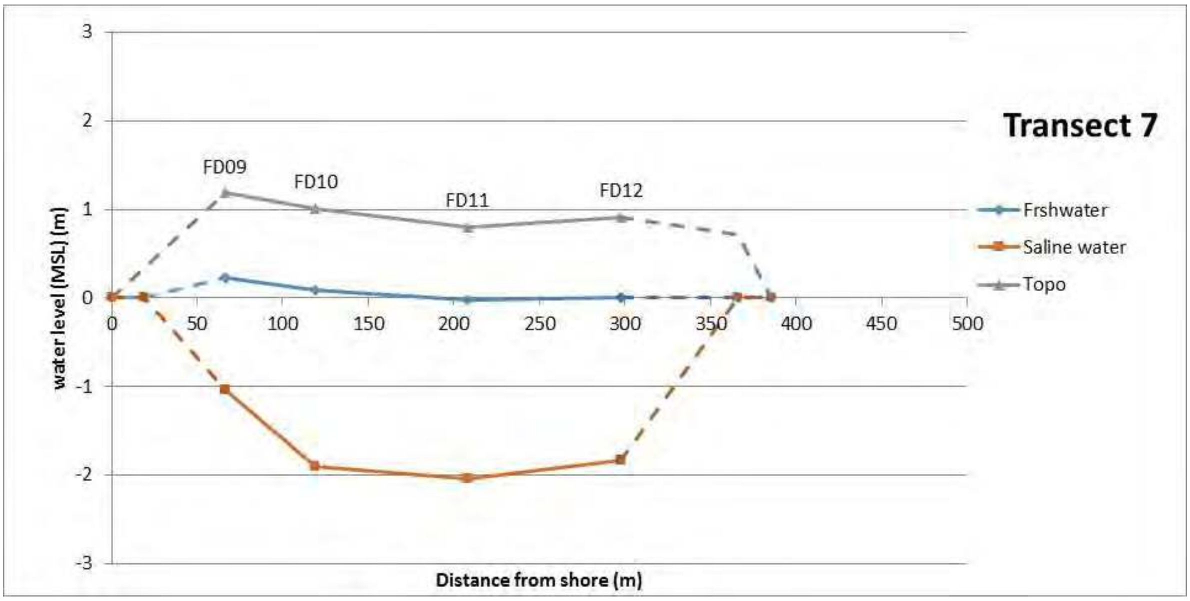

Transect 2
FD13
FD14
FD15
FD16
Freshwater
Saline water
Topo
water level (MSL) (m)
Distance from shore (m)


Transect 3
FD20
FD19
FD18
FD17
Freshwater
Saline water
Topo
water level (MSL) (m)
Distance from shore (m)


Transcect 4
FD21
FD22
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo
3
2
1
0
-1
-2
-3
0
50
100
150
200
250
300
350
400
450
500


Transcect 5
FDA13
FDA12
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo
3
2
1
0
-1
-2
-3
0
50
100
150
200
250
300
350
400
450
500


Transect 6
FD05
FD04
FD03
FD02
FD01
Freshwater
Saline water
Topo
water level (MSL) (m)
Distance from shore (m)
3
2
1
0
-1
-2
-3
0
50
100
150
200
250
300
350
400
450
500


Transect 7
FD09
FD10
FD11
FD12
Frshwater
Saline water
Topo
water level (MSL) (m)
Distance from shore (m)
3
2
1
0
-1
-2
-3
0
50
100
150
200
250
300
350
400
450
500

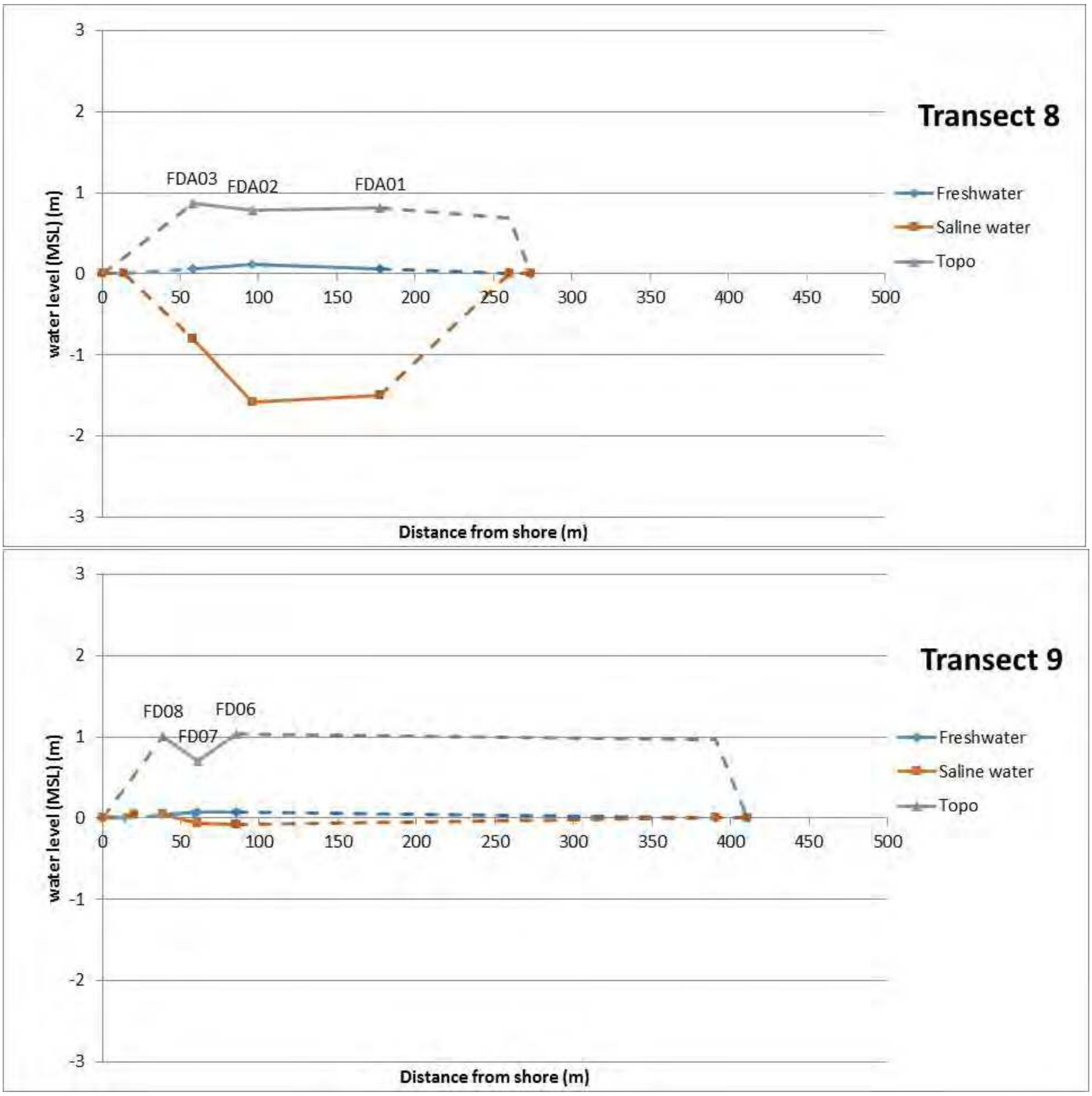


Figure 5.9: Cross-sections of transect lines in Funadhoo Island

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented in the following pages.

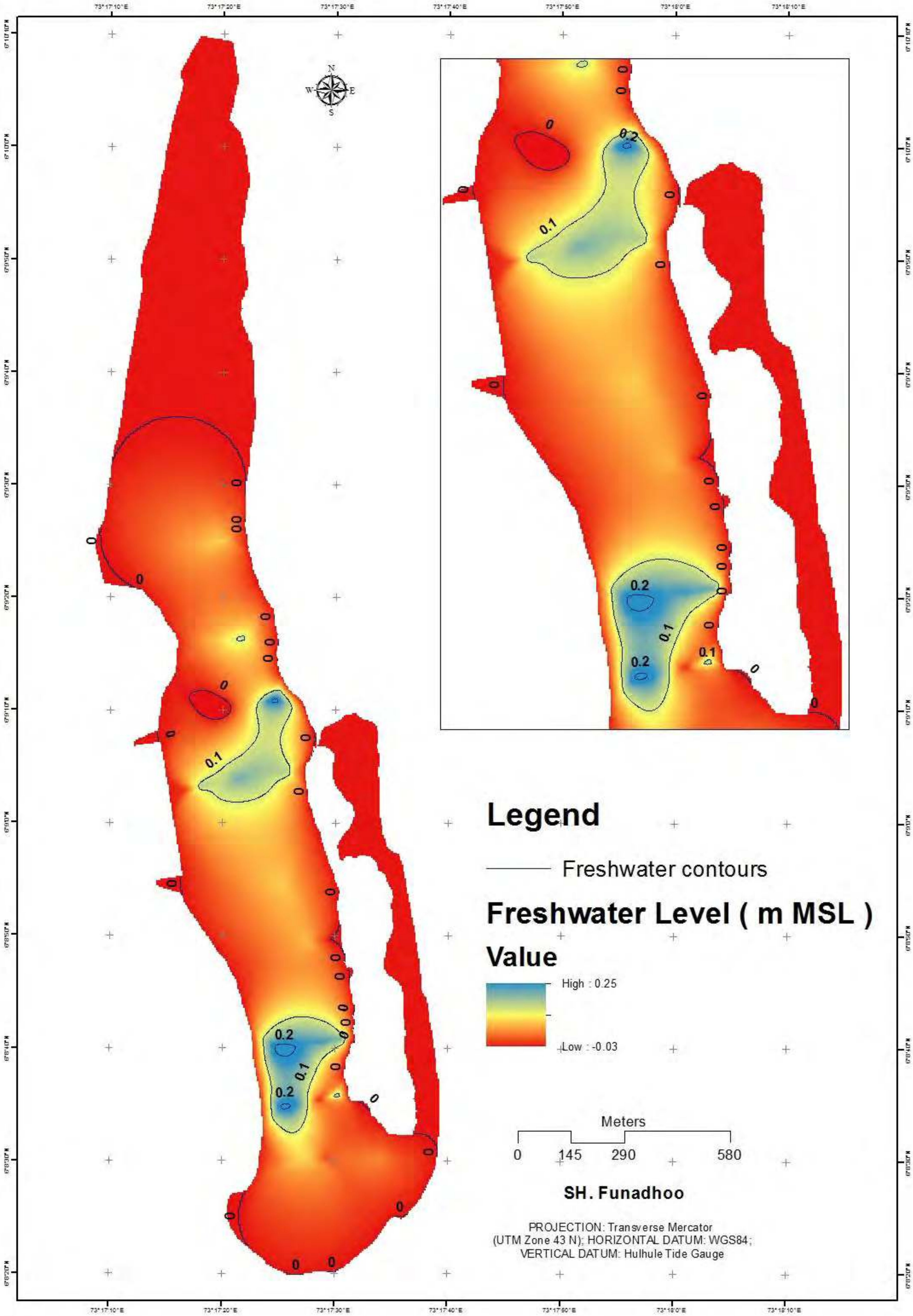


Figure 5.10: Freshwater Level in Funadhoo Island

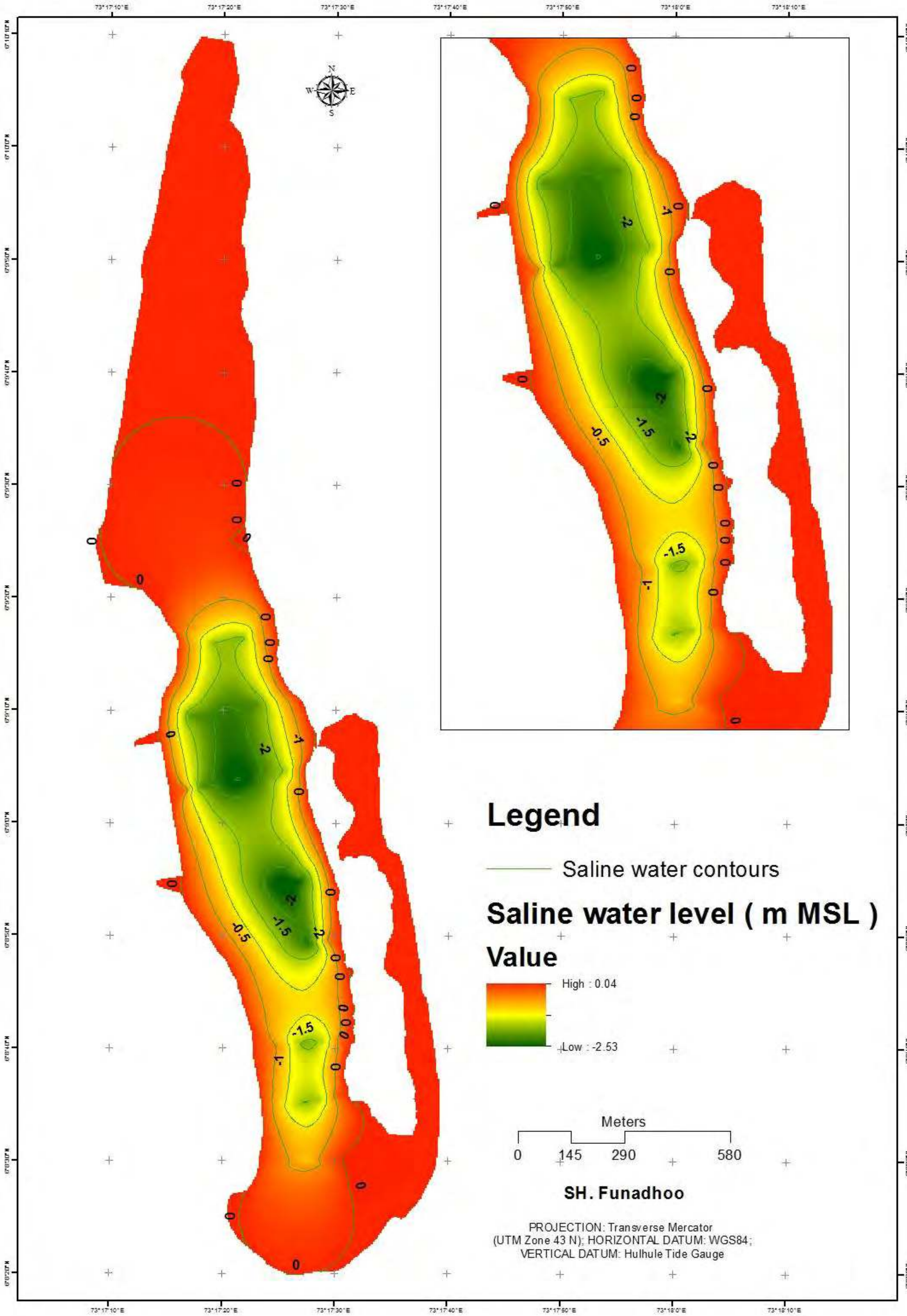


Figure 5.11: Saline water Level in Funadhoo Island

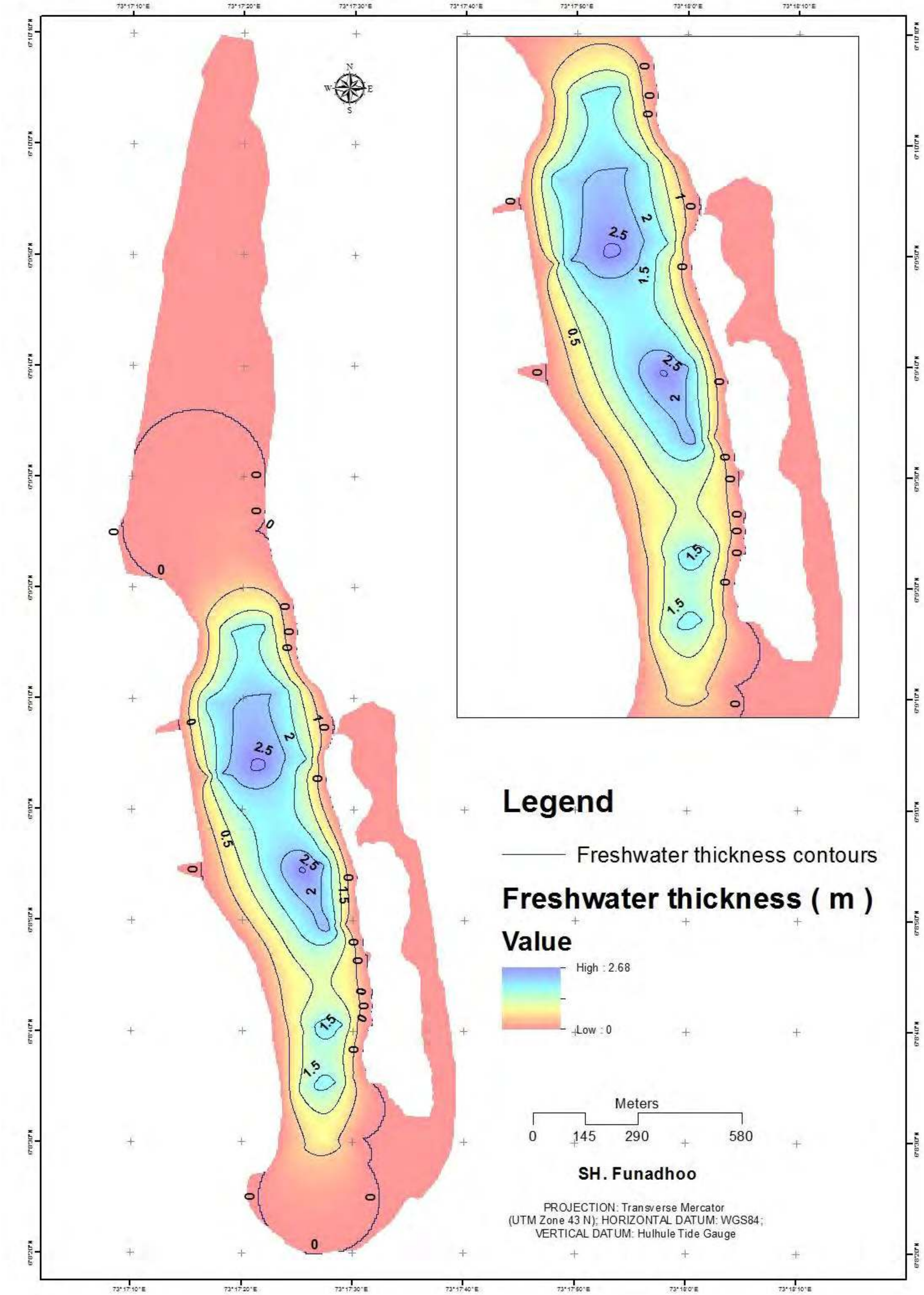


Figure 5.12: Freshwater thickness in Funadhoo Island

The maximum freshwater thickness of the island is 2.68 m. According to Falkland, 1994, the freshwater level thickness of the island is 9m. The relevant calculations are as follows;

Average Annual Ranfall =	1800	mm/yr
Width of the island =	415	m
Length of the island =	2023	m

Freshwater lens Thickness (m)

= (6.94*log(width of the island)-14.38)*Average Annual Rainfall = 7 m

5.8.6 Water balance and recharge

An annual estimation is carried out based on water balance method. Rainwater harvesting is calculated using number of rainwater harvesting units in the island. According to the spatial mean annual rainfall of Maldives, the island is reported as 1800 mm/year. Evapotranspiration was estimated using crop water requirement for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. The groundwater extractions were estimated from amount of water usage in different sectors (residential, resorts, restaurants, agriculture and farming). The difference between recharge and groundwater extraction is taken to estimate different in storage.

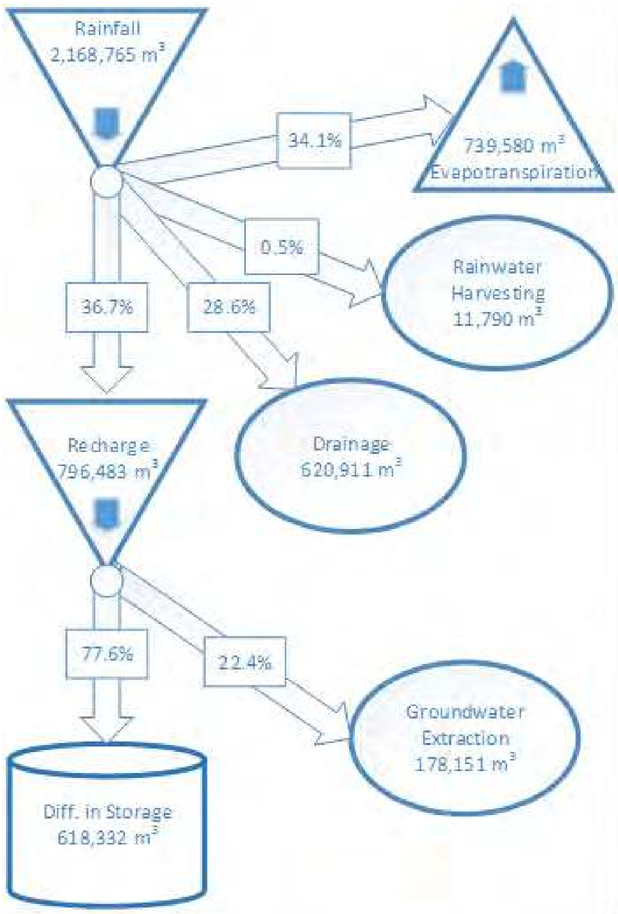


Figure 5.13: Schematic of water balance in Funadhoo Island

5.8.7 Sustainable yield of the lens

Sustainable yield of the water lens refers to the safe extraction potential of a given groundwater aquifer without significantly affecting its quality or quantity. This parameter is an important factor in the

sustainable development of islands as it allows planning and design of water and sanitation intervention in islands.

The island has a sustainable yield of 1694 m^3 per day which was calculated subtracting groundwater extraction from recharge volume derived from water balance (

Figure 5.13). According to Metai & Unit, n.d., based on geophysical investigations and drilling programme concluded that the safe sustainable yield was about 10% of mean annual rainfall. Such that the expected sustainable yield for the island should be 594 m^3 per day.

5.8.8 Permeability test

Permeability tests were carried out in the locations as outlined in Figure 5.14.

Figure 5.14: Locations of permeability tests in Funadhoo Island

The estimated permeability values for the above test locations are presented below.

Table 5.9: The estimated permeability Values

r_e		0.0260
r_l		0.0285

Point	H	Tu	Cs	H/r_e	Q	K (m/s)	K (m/day)	Q (l/min)	Q (m^3/s)
FDPT1	0.5	0.5	40	19.2	5.0E-05	1.73E-04	14.97	3.0	0.00005
FDPT2	0.7	1.0	50	26.9	8.3E-05	1.18E-04	10.18	5.0	0.00008
FDPT3	0.6	1.0	43	23.1	1.7E-04	2.71E-04	23.38	10.0	0.00017
FDPT4	0.7	1.1	50	26.9	1.1E-04	1.37E-04	11.85	6.4	0.00011
FDPT5	0.6	0.9	43	23.1	1.3E-05	2.25E-05	1.95	0.8	0.00001

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m^3/s), H = Height of water in well (m), l = length of perforated section (m), r_l = outside radius of casing (radius of hole in consolidated material) (m), r_e = effective radius of well = r_l (area of perforations) / (outside area of perforated section of casing) : $r_l = r_e$ in consolidated material that will stand open and is not cast, C_u and C_s =Conductivity Coefficients, and T_u = distance from water level in casing to water table (m).

5.8.9 Groundwater availability

1) The selected Funadhoo island has dimensions of width = 415 m and length = 3373 m, with a total land area of 118 ha, a population of 2104 persons, and a land use of built-up area 1.07 ha (9.2%), thick vegetation 37.60 ha (32.1%), light vegetation 12.82 ha (10.9%), and bare lands 56.02 ha (47.8%).

2) In order to recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of freshwater lens (FWL) and its associated recharge-discharge characteristics, 35 number of Electrical Resistivity (ER) location readings along 09 representatively selected transects were collected.

3) Soil overburden permeability tests (constant head) were carried out at 05 locations. In addition, groundwater level was also recorded at 06 locations where groundwater water quality samples were tested.

4) Permeability tests were carried out at representatively selected 05 number of locations. The measured permeability (K m/day) values ranged from a minimum of 1.95 m/day to a maximum of 23.38 m/day, with an average of 12.47 ± 7.77 m/day (Mean ± 1 Standard Deviation).

5) The ground elevation values ranged from a minimum of 0.29 m MSL to a maximum of 1.79 m MSL, with an average of 1.07 ± 0.22 m MSL (Mean ± 1 Standard Deviation).

6) The upper boundary of the freshwater lens (FWL) varied from a minimum of -0.03 m MSL to a maximum of 0.25 m MSL, with an average of 0.09 ± 0.07 m MSL (Mean ± 1 Standard Deviation).

7) The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -2.55 m MSL to a maximum of 0.04 m MSL, with an average of -1.06 ± 0.85 m MSL (Mean ± 1 Standard Deviation).

8) Accordingly, the freshwater lens (FWL) thickness values ranged from a minimum of 0.00 m to a maximum of 2.70 m, with an average of 1.15 ± 0.86 m (Mean ± 1 Standard Deviation).

9) The groundwater profile in the island is characterised by a relatively Low (0.54%) Rainwater Harvesting, relatively High (28.63%) Drainage, relatively High (36.73%) Recharge, while the water use shows relatively high (22.37%) Groundwater extraction, leading to relatively Low (77.63%) Difference in Balance Storage.

10) The freshwater lens (FWL) volume calculated based on ER transect test data is 5,473 m^3 with a maximum FWL thickness of 2.70 m. The potential maximum FWL volume and thickness estimated based on Falkland (1994) method are 83,403 m^3 and 6.82 m.

5.8.10 Conclusive Comments and Recommendations

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 1,694 m^3 per day, while it is 594 m^3 per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 510 m^3 per day and this is about 86% of the allowable Safe Yield in the island with minor up-coning and slight drawdown in freshwater lens cross-sections. At present, there exists an island-wide sewerage network but no water supply network. The water samples tested were found to be Highly Odorous with 100% or 13/13 samples tested producing odour. The Hydrological condition of the freshwater lens aquifer can be categorised as Moderate to Low based on above measurements and findings while Water quality aspects can be regarded as Contaminated with an Average Electrical Conductivity (EC) of 7,547.90 ± 9,712.59 µS/cm with measured values ranging from a minimum of 1,191.60 µS/cm to a maximum of 34,964.50 µS/cm, and an Average Ammonia Concentration of 7.49 ± 10.01 mg/L with measured values ranging from a minimum of 1.03 mg/L to a maximum of 37.92 mg/L.

The Availability of space for incorporating recharge measures and related infrastructure is Low while therefore the Potential for Recharging is considered to be Low. Overall recommendation for groundwater recharging would be to use recharging pits within individual land blocks.

6 N. HENBADHOO ISLAND

6.1 General overview of the island

The island of Henbadhoo is located at 5°58'03"N and 73°23'26"E and is part of the Noonu Administrative Atoll. It is 463 m long and 360 m wide, giving it an area of 13.6 Hectares. According to the 2014 Census the population of the island is 491. The island does not have a harbor but it has two jetties, one on the eastern side and one on the western side. The island does not have a sewerage network so the main method of waste disposal used is septic tanks. In addition to this the island does not have a water supply network.

Table 6.1: Basic statistical information on Henbadhoo island in Noonu Atoll.

Name of the island	N.Henbadhoo
Longitude and Latitude	5°58'03"N, 73°23'26"E
Area	13.6 ha
Population (Census, 2014)	491
Distance from Atoll Capital (N. Manadhoo)	22.5km
Distance from Male'	198.6km
Harbour	Not Present
Island sewerage network	No
Water supply network	No
Other infrastructure	-

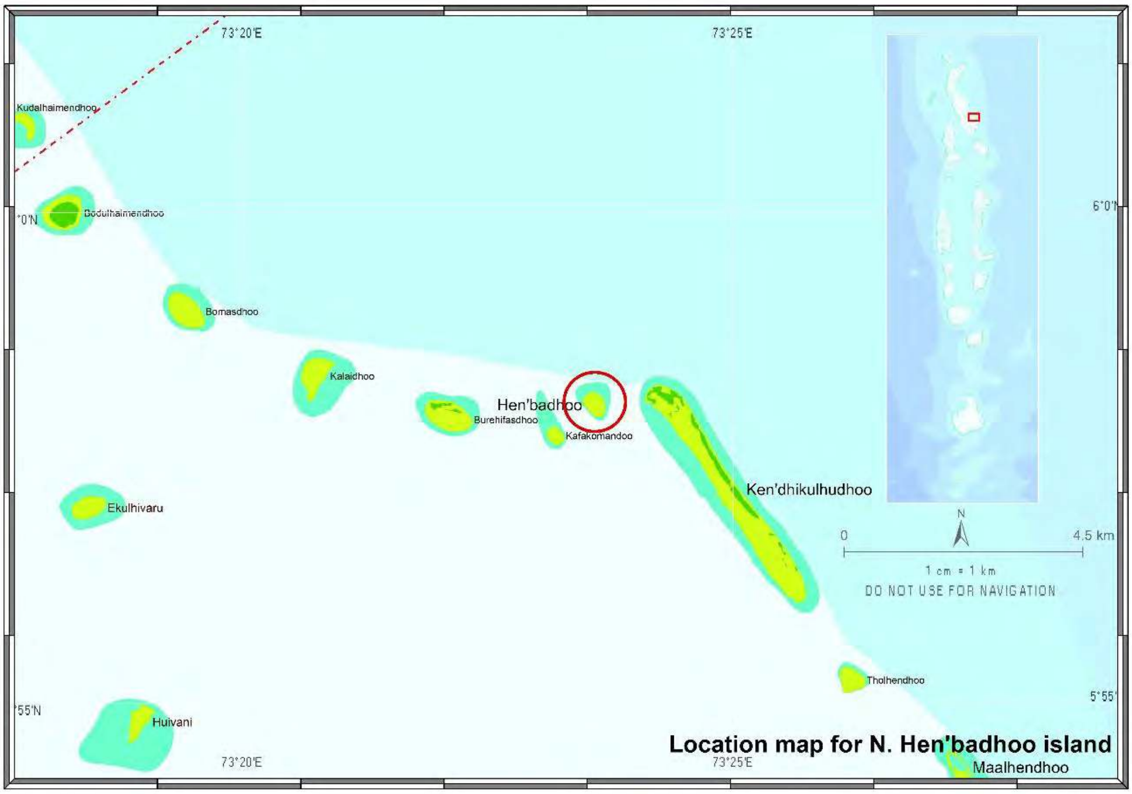


Figure 6.1: Location map for Henbadhoo Island, Noonu Atoll.

6.2 Geology and vegetation

The island is approximately 463 m long and 360 m wide, giving it a total area of about 13.6 Hectares. About 1/3 of the island surface is vegetation. This vegetation is mostly located at the outer edges around the island, though there are a few dense patches of vegetation in the middle of the island too. With the exception of home gardens, farming does not take place on this island.

6.3 Topography

The island has a topography that ranges from an elevation of 0.92 meters to 1.84 meters above Mean Sea Level, with an average elevation of 1.38 meters above MSL. Figure 5.2 shows digital surface model of Henbadhoo Island showing spot heights.

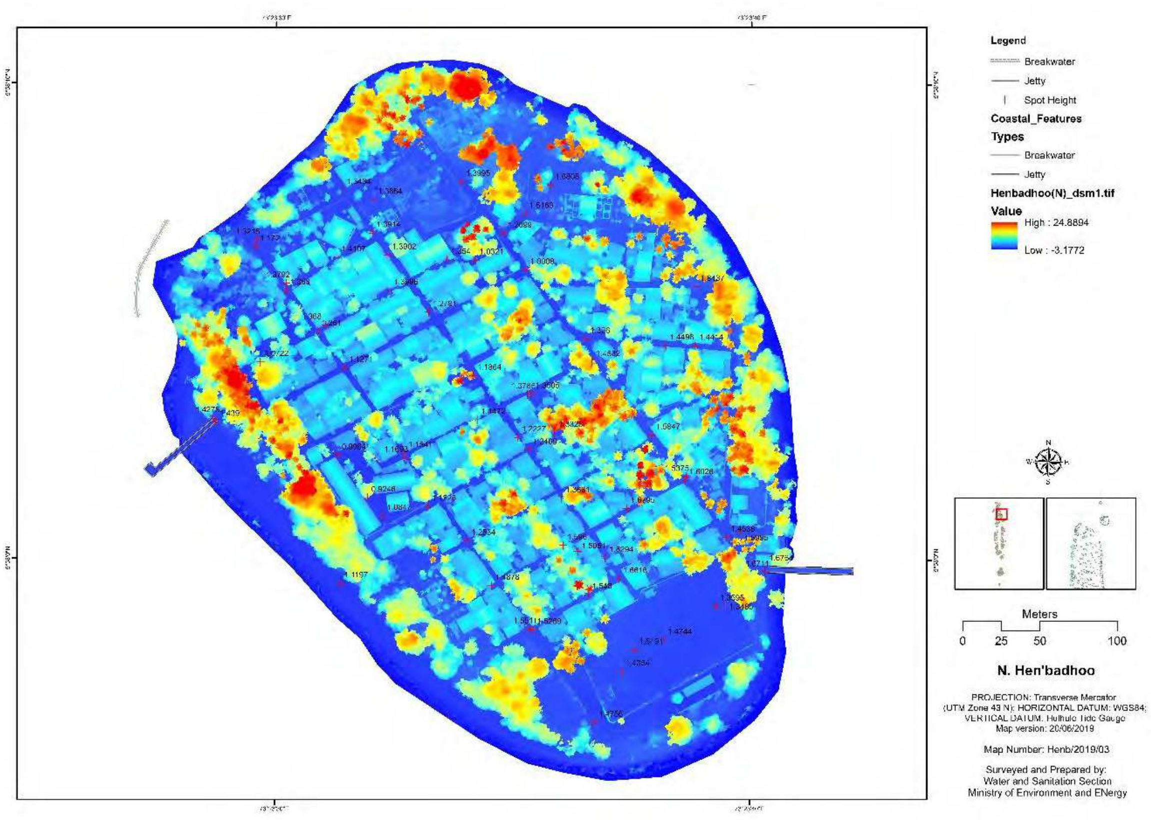


Figure 6.2: Map of Henbadhoo Island showing spot heights and digital surface model (DSM)

6.4 Climate

Henbadhoo experiences the typical two monsoons namely, north east monsoon from November to April and South-west monsoons from April to November. There are no specific wind and rainfall data available for Henbadhoo as there are no weather monitoring stations on the island.

6.5 Demography

According to the 2014 Census, the island has a registered population of 491 people, of which 475 are locals and 16 are foreigners. There are 117 more females than males when looking at the total population (62:38 ratio). When only locals are considered there are 113 more females than males (62:38 ratio). Overall the island has significantly more females than males. When only the foreign population is taken into account there are also more females than males. The following graphs and table illustrate the demographic breakdown.

Table 6.2: Demographic Breakdown of Henbadhoo Island

Atoll	locality	Resident population								
		Total			Maldivians			Foreigners		
		Both sexes	Male	Female	Both sexes	Male	Female	Both sexes	Male	Female
N	Henbadhoo	491	187	304	475	181	294	16	6	10

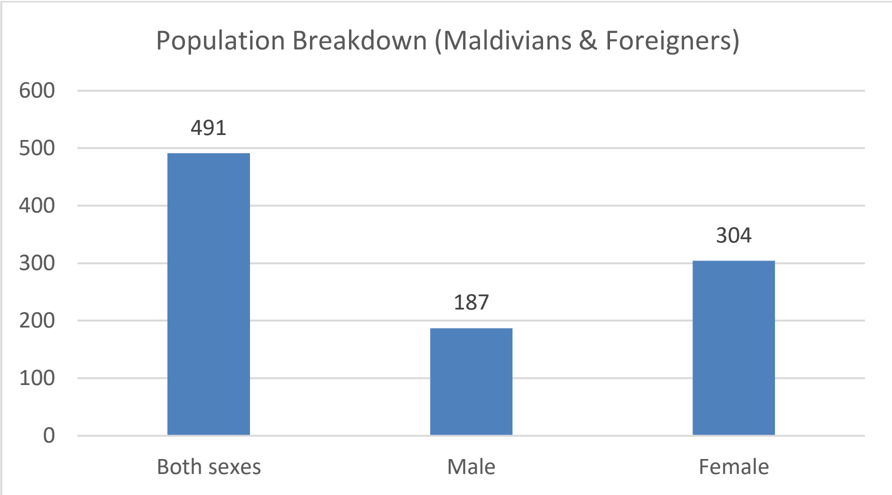


Figure 6.3: Population breakdown of Henbadhoo (Maldivians & Foreigners)

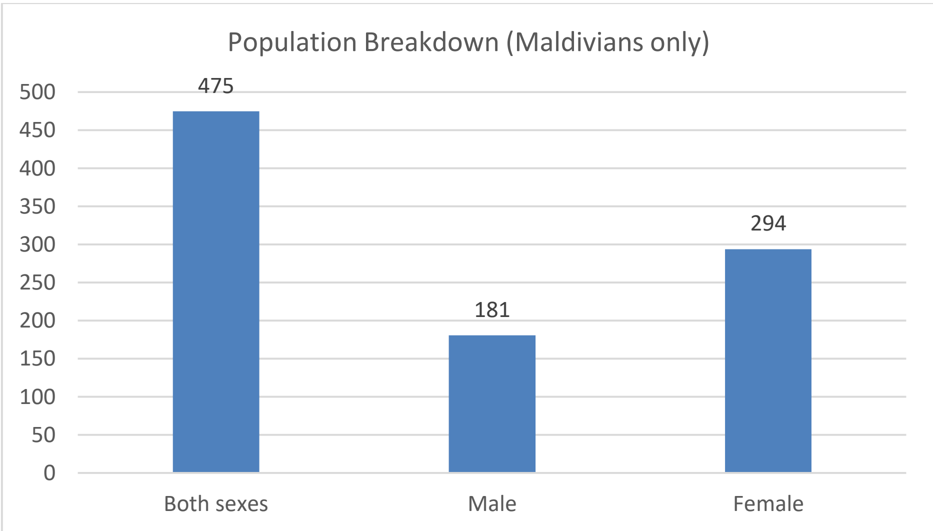


Figure 6.4: Population breakdown of Henbadhoo (Maldivians only)

6.6 Socio-economic condition

Fisheries, construction and carpentry industry are some of the industries in which residents of Henbadhoo are employed. Some residents find employment in other resorts in the atoll. There is 1 restaurant that was not operational during the time of survey.

6.7 Existing water and sanitation situation

The island does not have a water supply network or a sewerage system. Sanitation is carried out on this island by the use of septic tanks. Each household has one or two septic tanks, and the septic tanks are cleaned periodically by disposing the septic waste to sea. On average, there is an approximate distance of 7.54 meters between septic tanks and nearest well. Work is currently being carried out to install a conventional gravity sewerage system in the island with a sea outfall pipe of total length 227 meters of which 121 meters is offshore.

The primary source of both cooking and drinking water on this island is rainwater that is collected in either household or community rainwater tanks. As this runs out in many households during the dry season, many houses have to borrow rainwater from other households or community rainwater tanks. Some take water from the water plant.

6.8 Results

6.8.1 Water sources and water use

Based on domestic, commercial, institutional and industrial water usage, a total of 101,347 liters of groundwater are estimated to be used every day. Otherwise stated, 206 liters of groundwater are used per capita per day. The respective water use situations are detailed in the following sections.

6.8.1.1 Domestic water use situation

Based on the questionnaire to collect data on domestic water consumption, a summary of results is present in this section.

According to the survey, 100% of the households surveyed uses HDPE rainwater tanks as their main storage for water. A total of 100% households use rainwater for drinking and 100% use it for cooking. None of the surveyed houses use rainwater for bathing or washing.

0% of the households use groundwater as drinking. Groundwater is mainly used for non-potable use in all the households surveyed. The following table summarizes the data for Henbadhoo island.

Table 6.3: Groundwater and rainwater use data for Henbadhoo Island

Rainwater	
Households with rainwater tanks	100%
Rainwater use for drinking	100%
Rainwater use for cooking	100%
Rainwater use for bathing and washing	0%
Groundwater	
Groundwater as drinking source	0%
Groundwater for cooking	0%
Groundwater for non-potable use	100%
Total number of household wells surveyed	(10%)
Percentage of wells surveyed fitted with pumps	100%

Based on the survey questionnaire, average daily water demand per capita for domestic purposes has been estimated based on the average amount of water used per person for showering, toilet flushing, laundry and gardening, this data is shown in table 6.4. The total domestic water use is estimated to be 204 liters per capita per day.

Table 6.4: Domestic Water Usage in Henbadhoo Island

Shower/ Liters per capita per day	Toilet/ Liters per capita per day	Laundry/ Liters per capita per day	Gardening/ Liters per capita per day	**Total/ Liters per capita per day**
126	26	23	29	**204**

6.8.1.2 Commercial water use situation

There were no operational commercial institutes that used groundwater in Henbadhoo Island at the time of survey.

6.8.1.3 Institutional water use situation

Based on the questionnaire to collect data on institutional water consumption, a summary of results is present in this section. Three institutions were surveyed, namely the council office, powerhouse and school. Groundwater in the institutions in Henbadhoo Island are mainly used for flushing toilets, gardening and mopping. A total of approximately 997 liters of groundwater are estimated to be used per day by the institutions. Therefore, a total of approximately 2.03 liters of groundwater are estimated to be used per capita per day by the institutions of Henbadhoo Island.

Table 6.5: Water Usage in Institutions in Henbadhoo Island

	Water Flushed (Liters per day)	**Gardening (Liters per day)**	**Mopping (Liters per day)**	**Total Water Usage (Liters per day)**	**Total Water Usage by all institutions (Liters per day)**	**Institutional Groundwater Usage (Liters per capita per day)**
Council Office	85	-	-	85	997	2.03
Powerhouse	97	-	-	97		
School	501	270	44	815		

6.8.2 Groundwater quality

Groundwater quality measurements were made at selected wells in Henbadhoo for both physical and microbiological testing.

The following Table 6.6 summarizes the water quality results.

Table 6.6: Summary of groundwater quality tests from Henbadhoo, April 2019

Sample No	Odour	Physical Appearance
gw1	yes	Clear
gw2	yes	Clear
gw3	yes	Clear with particles
gw4	yes	Clear with particles
gw5	yes	Clear with particles
gw6	yes	Clear with particles
gw7	yes	Clear with particles
gw8	yes	Clear with particles and living organisms
gw9	yes	Clear with particles
gw10	yes	Clear with particles
gw11	yes	Pale yellow with particles
gw12	yes	Clear
gw13	yes	Pale yellow with particles
gw14	yes	Pale yellow with particles
gw15	yes	Pale yellow with particles

Sample No	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
gw1	1948.9	1134	7.07	0.18	2.03	31.1	0.87	44.6	20.89	0.19		
gw2	5298.2	3077	7.1	0.12	1.61	31.2	2.51	38.9	11.03	0.27		
gw3	3836.2	2267	7.07	0.17	1.54	30.2	1.81	38.5	15.29	0.16	>2420	261
gw4	5838	3389	7.06	0.05	-	31.3	2.78	38.0	8.96	0.47	>2420	>2420
gw5	3174.8	2127	7.28	0.15	3.42	23.4	1.71	30.1	11.37	0.29		
gw6	5284.9	3043	7.25	0.1	1.57	31.8	2.47	42.2	32.86	1.08		
gw7	3515.9	2057	7.04	0	1.6	30.8	1.64	36.9	10.43	0.27		
gw8	7491.2	4352	7.23	0.4	1.62	31.2	3.63	32.7	8.78	0.54		
gw9	3878.2	2262	7.03	0.17	2.0	31.0	1.81	36.7	25.47	0.3		
gw10	2583	1446	7.38	0.04	1.55	33.4	1.12	28.7	5.7	0.19		
gw11	5398.7	3055	7.49	0.13	1.52	32.8	2.48	56.6	9.66	0.9		
gw12	6453.9	3590	7.32	0.26	1.42	33.8	2.94	34.1	10.31	0.17	>2420	886
gw13	3698.8	2178	7.68	0.08	1.91	30.4	1.74	23.6	3.51	0.18	>2420	>2420
gw14	2441.1	1419	7.52	0.28	3.41	31.2	1.1	16.2	16.23	0.2		
gw15	2757.4	1621	8.15	1.06	5.79	30.5	1.27	16.9	3.09	0.18		

	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)
WHO Standards	Suggested maximum limit of freshwater for potable purposes = 1500 µS/cm Suggested maximum limit of freshwater for non-potable purposes = 2500 µS/cm	-	-	-	-	-

	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
WHO Values	-	Guideline Value = 50 mg/L-NO3	Natural Level of Ammonia < 0.2 mg/L Threshold odour concentration = 1.5 mg/L Taste threshold = 35 mg/L	-	-	-

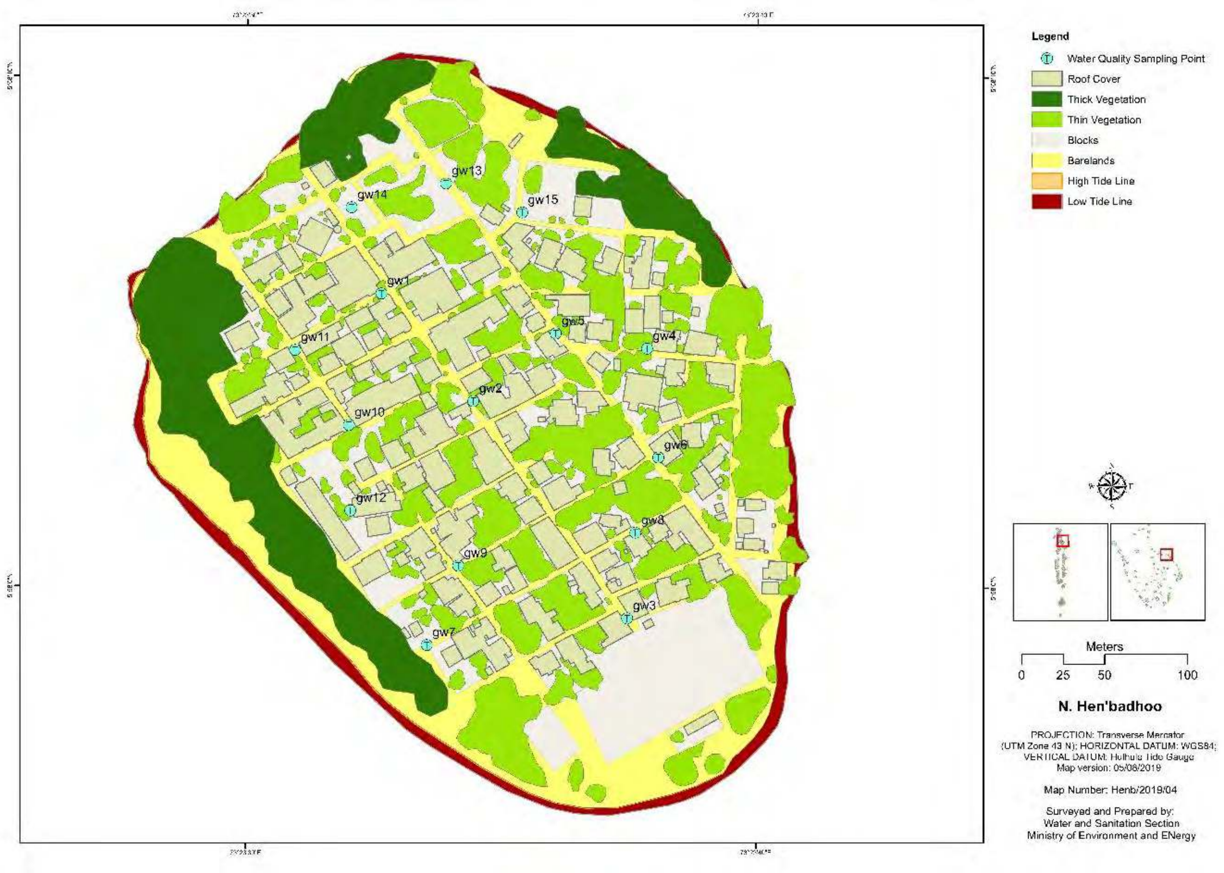


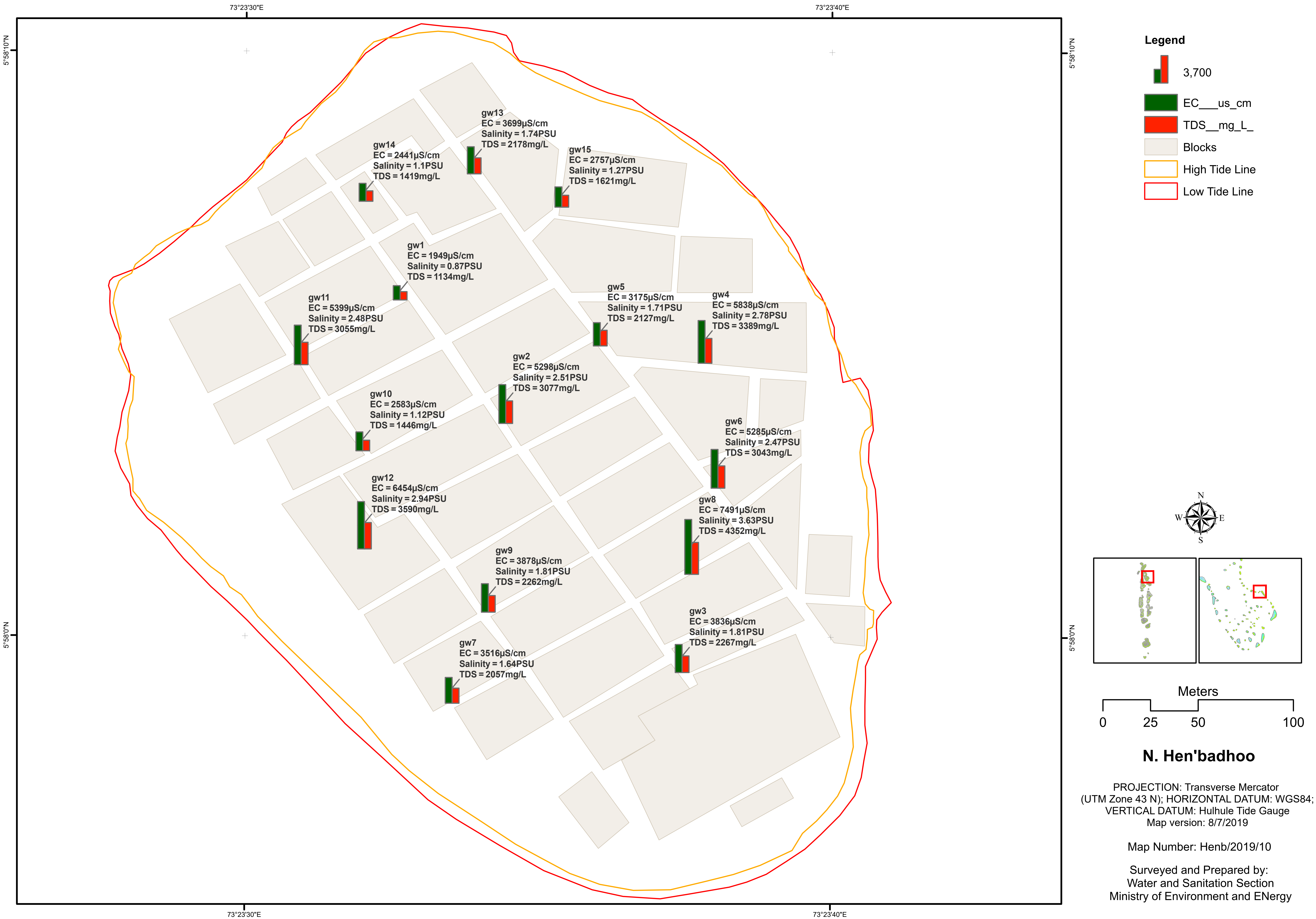
Figure 6.5: Location of groundwater sampling points in Henbadhoo Island

Based on the full results and the summary shown in Table 8.5, the following observations are made:

- The Electrical Conductivity (EC) of the groundwater is generally very high. The average EC of approximately 4240 µS/cm considerably exceeds both the acceptable limit for potable water of 1,500 µS/cm and the acceptable limit for freshwater for non-potable purposes of 2500 µS/cm (refer section 2.2). All 15 of the tested water samples exceeded the limit for potable water and 13 of the tested water samples exceed the limit for freshwater for non-potable uses. The EC of the samples throughout the island were high regardless of the location where the water was sampled.
- Total dissolved solids were generally high and ranged from 1134 mg/L to 4352 mg/L with an average of 2468 mg/L.
- The pH ranged from 7.03 to 8.15 with an average pH of 7.31.
- Turbidity ranged from 0 NTU to 1.06 NTU with an average of 0.21 NTU. As a guide, “crystal-clear” water has a turbidity below 1 NTU, and water becomes visibly cloudy at 4 NTU and above
- Dissolved oxygen levels ranged from 1.42 to 5.79 mg/L. The average was 2.21 mg/L.
- The salinity of groundwater ranged from 0.87 PSU to 3.63 PSU with an average of 1.99 PSU.
- The average Nitrate concentration was 34.3 mg/L which does not exceed the WHO guideline limit of 50 mg/L. The Nitrate concentrations ranged from lowest concentration of 16.2 mg/L to the highest concentration of 56.6 mg/L. Only 1 of the 15 tested water samples exceeded the WHO guideline limit for Nitrate concentrations.
- Ammonia concentrations were generally very high. The average ammonia concentration was 12.91 mg/L. This exceeds the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. All of the tested water samples exceeded the WHO guideline. Natural levels of ammonia are generally below 0.2 mg/L (WHO, 1993) and no tests showed concentrations below this level. Out of the 13 islands, water samples from Henbadhoo had the highest ammonia concentration, which correlates with the highest faecal and total coliform levels. As expected, the groundwater layer is contaminated with effluent from septic tanks.
- Phosphate concentrations ranged from 0.16 mg/L to 1.08 mg/L with an average concentration of 0.36 mg/L. There is no WHO drinking water guideline value for phosphate. However, it would normally be expected that phosphate concentrations in groundwater are less than 0.1 mg/L, where there are no impacts from human wastewater (e.g. effluent from septic tanks and ‘greywater’ from kitchens and bathrooms). None of the tested water samples showed concentrations below 0.1 mg/L.
- Faecal Coliform levels were found to be significantly high and ranged from lowest count of 261 MPN/100mL to the highest count of greater than 2420 MPN/100mL with an average estimated to be greater than 1496.75 MPN/100mL. Total coliform levels were found to be extremely high, and all of the water samples tested for total coliform showed concentrations greater than 2420 MPN/100mL.. Out of the 13 islands tested, Henbadhoo had the highest faecal and total coliform contamination where all the tested water samples from throughout the island was contaminated with faecal and total coliform. As expected, the groundwater layer is contaminated with effluent from septic tanks

In conclusion, Henbadhoo Island contains groundwater with generally high Electrical Conductivity with a higher average than WHO guidance value for potable and non-potable water and high TDS. Average Nitrate concentration was lower than WHO maximum guidance value but average Ammonia concentration and average Phosphate concentration higher than expected in natural, undisturbed groundwater. In terms of microbiological contamination, a severe island wide contamination is observed where all of the tested water samples had total coliform levels higher than 2420 MPN/100ml.

Additionally, the following pages contain maps which show the main physiochemical parameters displayed on map of the island.



73°23'30"E
73°23'40"E
5°58'10"N
5°58'0"N
gw13
EC = 3699µS/cm
Salinity = 1.74PSU
TDS = 2178mg/L
gw14
EC = 2441µS/cm
Salinity = 1.1PSU
TDS = 1419mg/L
gw15
EC = 2757µS/cm
Salinity = 1.27PSU
TDS = 1621mg/L
gw1
EC = 1949µS/cm
Salinity = 0.87PSU
TDS = 1134mg/L
gw5
EC = 3175µS/cm
Salinity = 1.71PSU
TDS = 2127mg/L
gw4
EC = 5838µS/cm
Salinity = 2.78PSU
TDS = 3389mg/L
gw11
EC = 5399µS/cm
Salinity = 2.48PSU
TDS = 3055mg/L
gw2
EC = 5298µS/cm
Salinity = 2.51PSU
TDS = 3077mg/L
gw10
EC = 2583µS/cm
Salinity = 1.12PSU
TDS = 1446mg/L
gw6
EC = 5285µS/cm
Salinity = 2.47PSU
TDS = 3043mg/L
gw12
EC = 6454µS/cm
Salinity = 2.94PSU
TDS = 3590mg/L
gw8
EC = 7491µS/cm
Salinity = 3.63PSU
TDS = 4352mg/L
gw9
EC = 3878µS/cm
Salinity = 1.81PSU
TDS = 2262mg/L
gw3
EC = 3836µS/cm
Salinity = 1.81PSU
TDS = 2267mg/L
gw7
EC = 3516µS/cm
Salinity = 1.64PSU
TDS = 2057mg/L
Legend
3,700
EC___us_cm
TDS__mg_L_
Blocks
High Tide Line
Low Tide Line
N
W
E
S
Meters
0 25 50 100
N. Hen'badhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/7/2019
Map Number: Henb/2019/10
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


73°23'30"E
73°23'40"E
5°58'10"N
5°58'0"N
gw14
Turbidity = 1.28NTU
DO = 3.41mg/L
Ammonia = 16.23mg/L
Nitrate = 16.23mg/L
gw13
Turbidity = 0.08NTU
DO = 1.91mg/L
Ammonia = 3.51mg/L
Nitrate = 3.51mg/L
gw15
Turbidity = 1.06NTU
DO = 5.79mg/L
Ammonia = 3.09mg/L
Nitrate = 3.09mg/L
gw1
Turbidity = 0.18NTU
DO = 2.03mg/L
Ammonia = 20.89mg/L
Nitrate = 44.6mg/L
gw11
Turbidity = 0.13NTU
DO = 1.52mg/L
Ammonia = 9.66mg/L
Nitrate = 56.6mg/L
gw5
Turbidity = 0.15NTU
DO = 3.42mg/L
Ammonia = 11.37mg/L
Nitrate = 30.1mg/L
gw4
Turbidity = 0.05NTU
DO = mg/L
Ammonia = 8.96mg/L
Nitrate = 38mg/L
gw2
Turbidity = 0.12NTU
DO = 1.61mg/L
Ammonia = 11.03mg/L
Nitrate = 38.9mg/L
gw10
Turbidity = 0.04NTU
DO = 1.55mg/L
Ammonia = 5.7mg/L
Nitrate = 28.7mg/L
gw6
Turbidity = 0.1NTU
DO = 1.57mg/L
Ammonia = 32.86mg/L
Nitrate = 42.2mg/L
gw12
Turbidity = 0.26NTU
DO = 1.42mg/L
Ammonia = 10.31mg/L
Nitrate = 10.31mg/L
gw8
Turbidity = 0.4NTU
DO = 1.62mg/L
Ammonia = 8.78mg/L
Nitrate = 32.7mg/L
gw9
Turbidity = 0.17NTU
DO = 2mg/L
Ammonia = 25.47mg/L
Nitrate = 36.7mg/L
gw3
Turbidity = 0.17NTU
DO = 1.54mg/L
Ammonia = 15.29mg/L
Nitrate = 38.5mg/L
gw7
Turbidity = 0NTU
DO = 1.6mg/L
Ammonia = 10.43mg/L
Nitrate = 36.9mg/L
Legend
16
Turbidity (NTU)
DO__mg_L_
Ammonia (mg/L)
Phosphates (mg/L)
Blocks
High Tide Line
Low Tide Line
N
W
E
S
Meters
0
20
40
80
N. Hen'badhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 23/09/2019
Map Number: Henb/2019/11
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

6.8.3 Geophysical survey

The Resistivity tests were carried out in the locations as outlined in Figure 6.6 below.

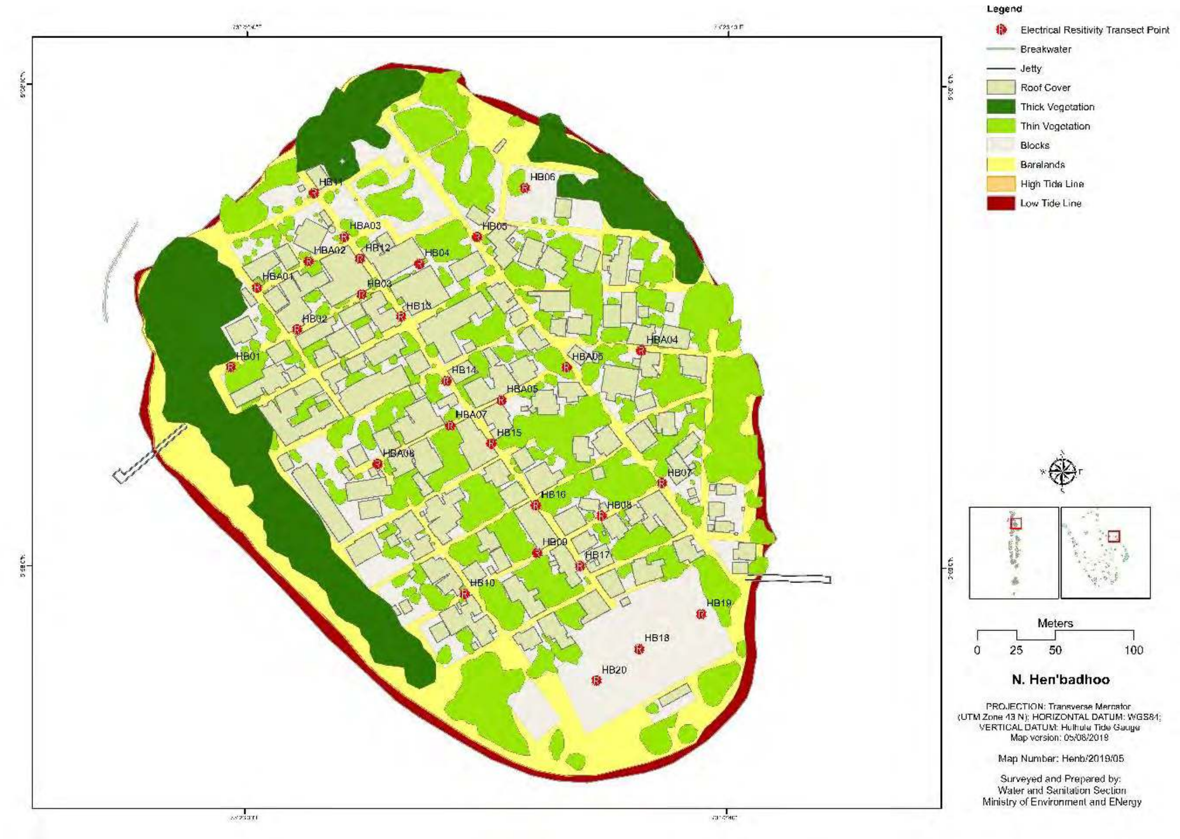


Figure 6.6: Location of ER points in Henbadhoo Island

6.8.4 Aerial surveys

Based on the aerial survey, a multiple dataset consisting of roof cover, thick vegetation area, thin vegetation area, bare lands and shorelines were extracted. This data is shown in Figure 6.7 and the table 6.7 shows the different area distribution.

Figure 6.7: Area Distribution in Henbadhoo Island

Table 6.7: Area Distribution in Henbadhoo

	Area (Square Meters)	% of total area
Roof cover	28,224	22.0%
Vegetation (Thick)	17,758	13.8%
Vegetation (Light)	34,561	26.9%
Bare lands	47,712	37.2%
Farm Lands	-	-
Wetlands (Inland)	-	-

6.8.5 Freshwater lens

Based on the ER survey the depth to groundwater level and the freshwater-saline water interface was determined for a set of transverse transects as shown in Figure 6.8. Plots in the Figure 6.9 shows the cross sections of each transect line. The dotted lines in the plots indicating a simple interpolation of levels to mean sea level in the island boundaries. These cross sections were used to identify the spatial extent and volume of the freshwater lens while they were also useful in deriving implications on the stress level of the aquifer based on the observed, localized drawdown effect in the groundwater table and up-coning in the freshwater-saline interface, defining the upper and lower boundaries of the freshwater lens in an island.

The Table 6.8 illustrates the freshwater volume calculation for the island. The area covered by freshwater for each transect line has been calculated. To estimate the total volume of available freshwater lens, the cross-section area of freshwater extent under each transect was multiplied by the distance between two transects. The sum of these lengths represents the cumulative length of the island

and thus, the above estimation could represent the total volume of the freshwater lens sandwiched between the groundwater table on top and freshwater-saline water interface in the bottom. Then the actual groundwater storage within this freshwater lens was calculated by multiplying the estimated total lens volume with the porosity of the topsoil in the island.

This estimation represents the total available freshwater volume within the freshwater lens at any given time (time of the measurement). The measurements were carried out towards the end of the dry period and the freshwater lens is presumed to be undergoing a 'stressed' condition due to continued groundwater abstractions despite reduced recharge in the dry period. Falkland (1994) method can be used to estimate the freshwater lend thickness under salient conditions using average annual rainfall, length and width of the island, and the comparison was used as a measure of stress level of the freshwater lens.

Table 6.8: Freshwater Volume Calculation for Henbadhoo Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
	Start		0		0	0			
			14		0	0			
	HBA01	GPS0001	79	1.3792	0.309	-0.451	24		
2	HBA02	GPS0002	112	1.4107	0.411	-0.229	23		
	HBA03	GPS0003	143	1.3914	0.371	-1.239	35		
			274		0	0	105		
	End		288		0	0	0		
	Total						188	62	11,675
	Start		0		0	0			
			17		0	0			
	HB01	GPS5001	66	1.0722	0.235	-1.118	33		
	HB02	GPS5002	115	1.368	0.4	-1.23	73		
	HB03	GPS5003	162	1.3996	0.22	-2.03	91		
3	HB04	GPS5004	203	1.354	0.214	-2.426	102		
	HB05	GPS5005	244	1.2099	0.273	-1.67	93		
	HB06	GPS5006	289	1.6808	0.381	-0.916	72		
			328		0	0	26		
	End		346		0	0	0		
	Total						490	63	30,632
	Start		0		0	0			
			18		0	0			
	HBA08	GPS0008	105	1.1693	0.38	-0.781	61		
	HBA07	GPS0007	157	1.1472	0.247	-1.603	79		
4	HBA06	GPS0006	194	1.3785	0.411	-1.181	63		
	HBA05	GPS0005	240	1.4532	0.273	-1.67	82		
	HBA04	GPS0004	288	1.4498	0.48	-0.916	80		
			333		0	0			
	End		351		0	0	44		0
	Total						409	93	38,108
5	Start		0		0	0			

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
			15		0	0			
	HB10	GPS5010	84	1.4878	0.58	-2.29	99		
	HB09	GPS5009	137	1.596	0.526	-1.54	131		
	HB08	GPS5008	185	1.6795	0.61	-1.05	88		
	HB07	GPS5007	223	1.5375	0.538	-0.96	60		
			286		0	0	47		
	End		301		0	0	0		
	Total						426	106	44,985
6	Start		0		0	0			
			11		0	0			
	HB20	GPS0018	88	1.4354	0.295	-1.125	55		
	HB18	GPS0015	122	1.4744	0.284	-2.056	65		
	HB19	GPS0017	167	1.3485	0.209	-0.931	77		
			207		0	0	23		
	End		218		0	0	0		
	Total						220	96	21,196
									146,595

Volume of lens = 146,595 m^3

Groundwater Storage = Porosity (15%) x Lens volume (m^3) = 21,989 m^3

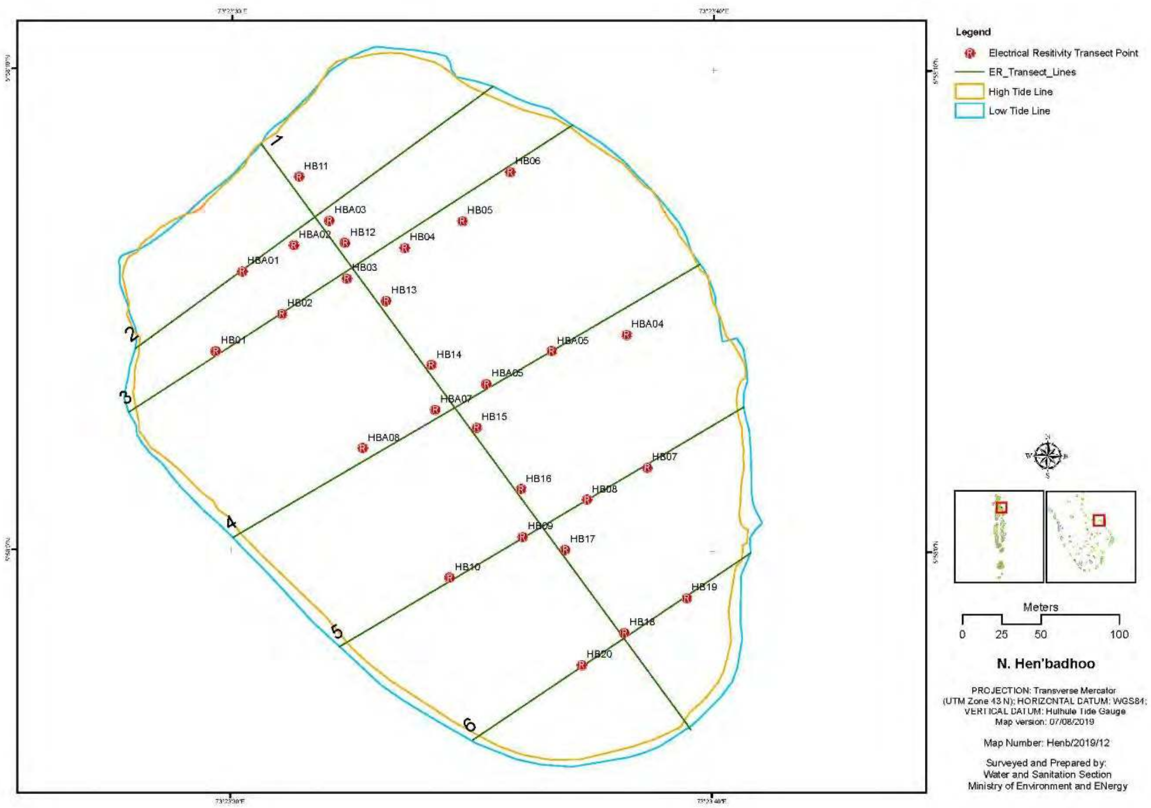
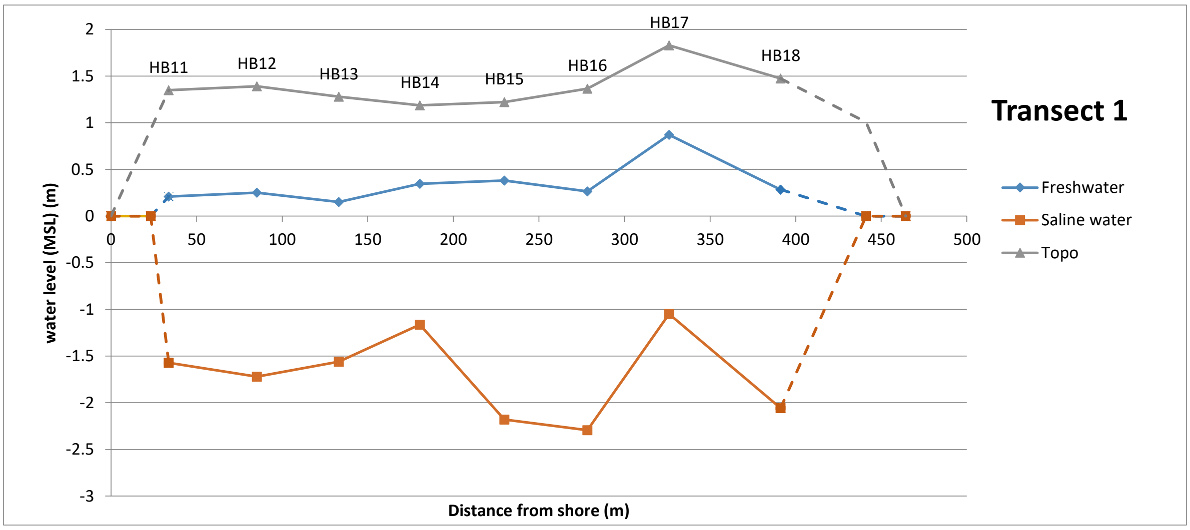
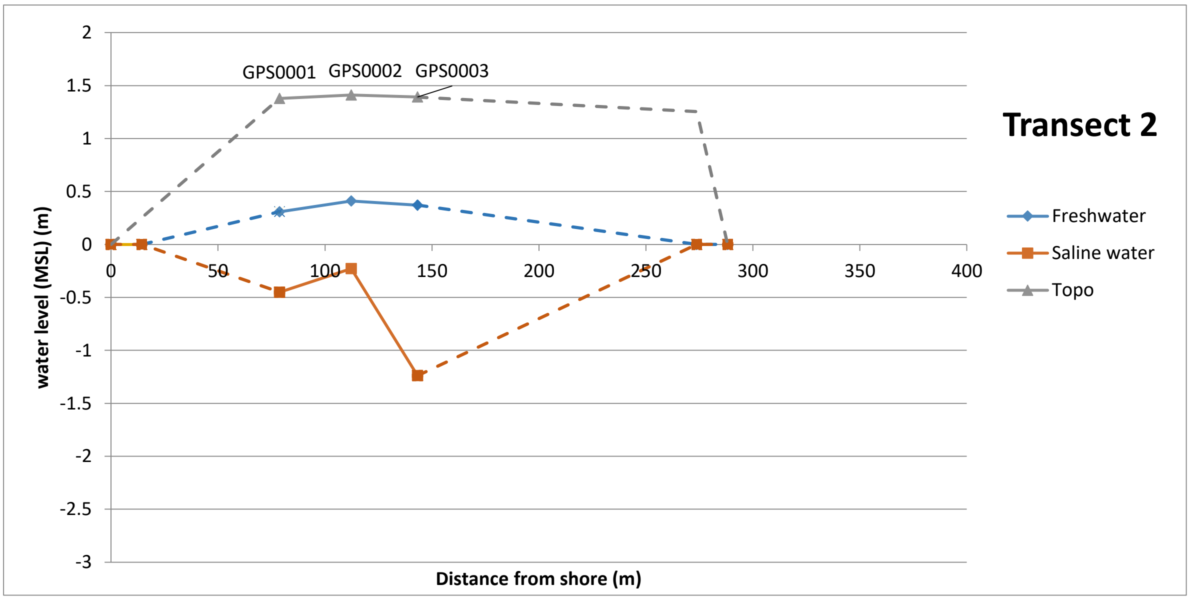


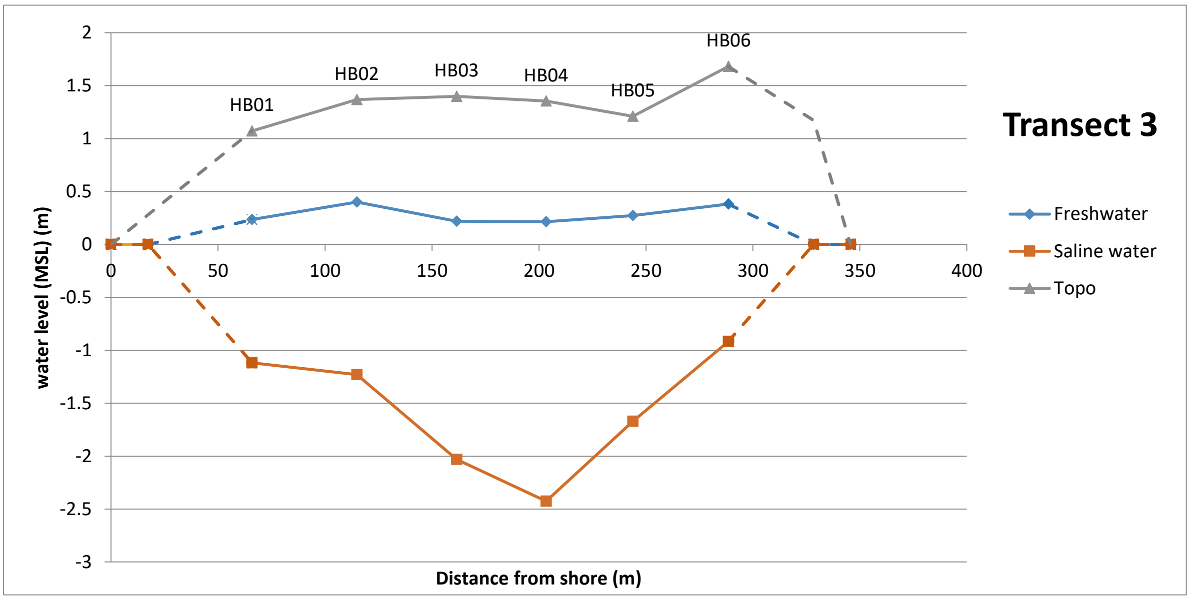
Figure 6.8: ER transect lines in Henbadhoo Island

Table 6.9: ER Survey Results of Longitudinal Sections for Henbadhoo Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)
Longitudinal section 1	Start		0	0	0	0
			23	0.930	0	0
	HB11	GPS0016	34	1.3484	0.208	-1.572
	HB12	GPS0009	85	1.3902	0.25	-1.72
	HB13	GPS0010	133	1.2791	0.15	-1.56
	HB14	GPS0011	180	1.1864	0.346	-1.164
	HB15	GPS0012	230	1.2227	0.38	-2.18
	HB16	GPS0013	278	1.3661	0.266	-2.294
	HB17	GPS0014	326	1.8294	0.872	-1.05
	HB18	GPS0015	391	1.4744	0.284	-2.056
			441	1.006	0	0
	End		464	0	0	0


Transcect 1
HB11
HB12
HB13
HB14
HB15
HB16
HB17
HB18
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo


Transcect 2
GPS0001
GPS0002
GPS0003
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo


Transcect 3
HB01
HB02
HB03
HB04
HB05
HB06
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo

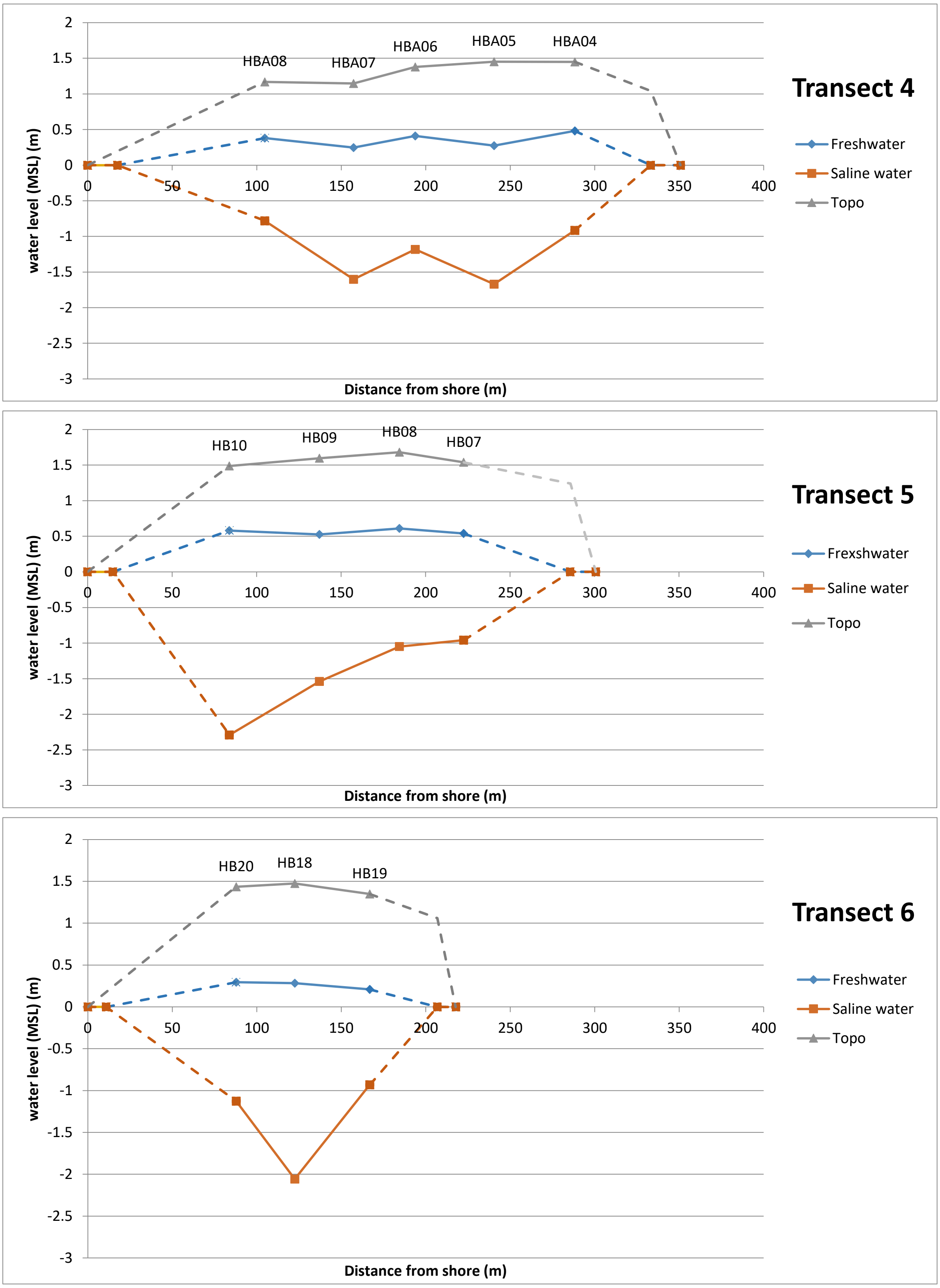


Figure 6.9: Cross-sections of transect lines in Henbadhoo Island

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented below.

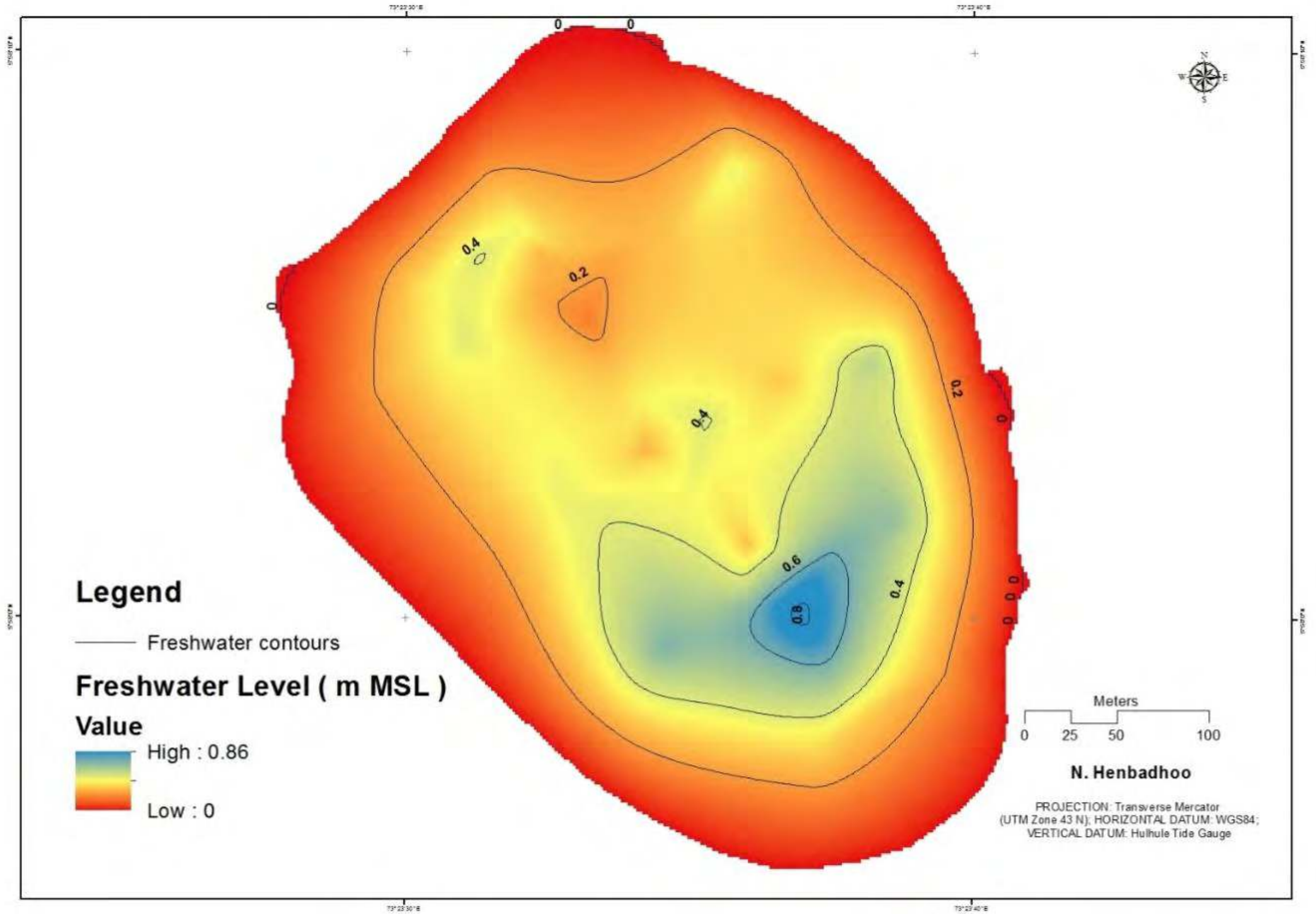


Figure 6.10: Freshwater Level in Henbadhoo Island

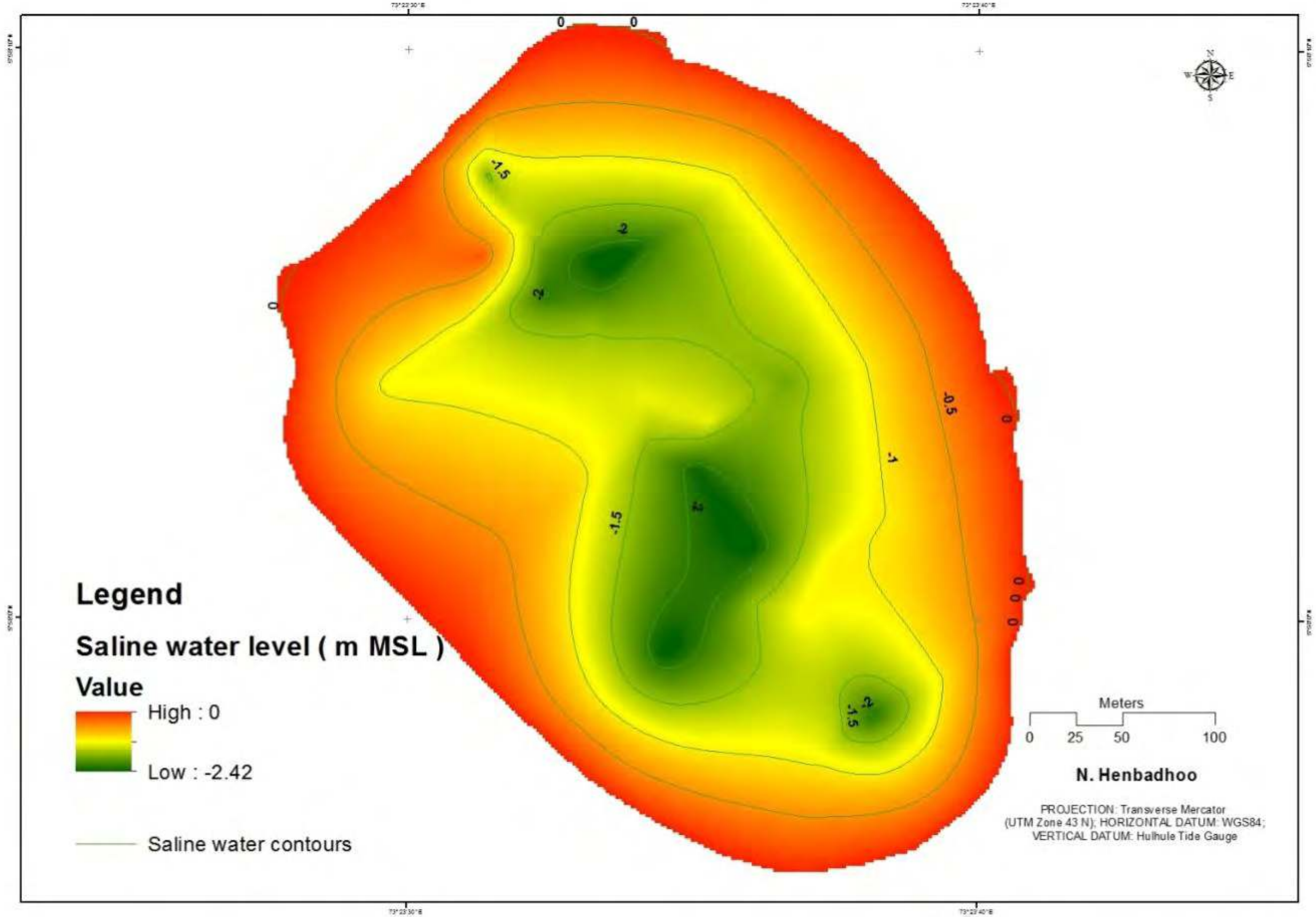


Figure 6.11: Saline water Level in Henbadhoo Island

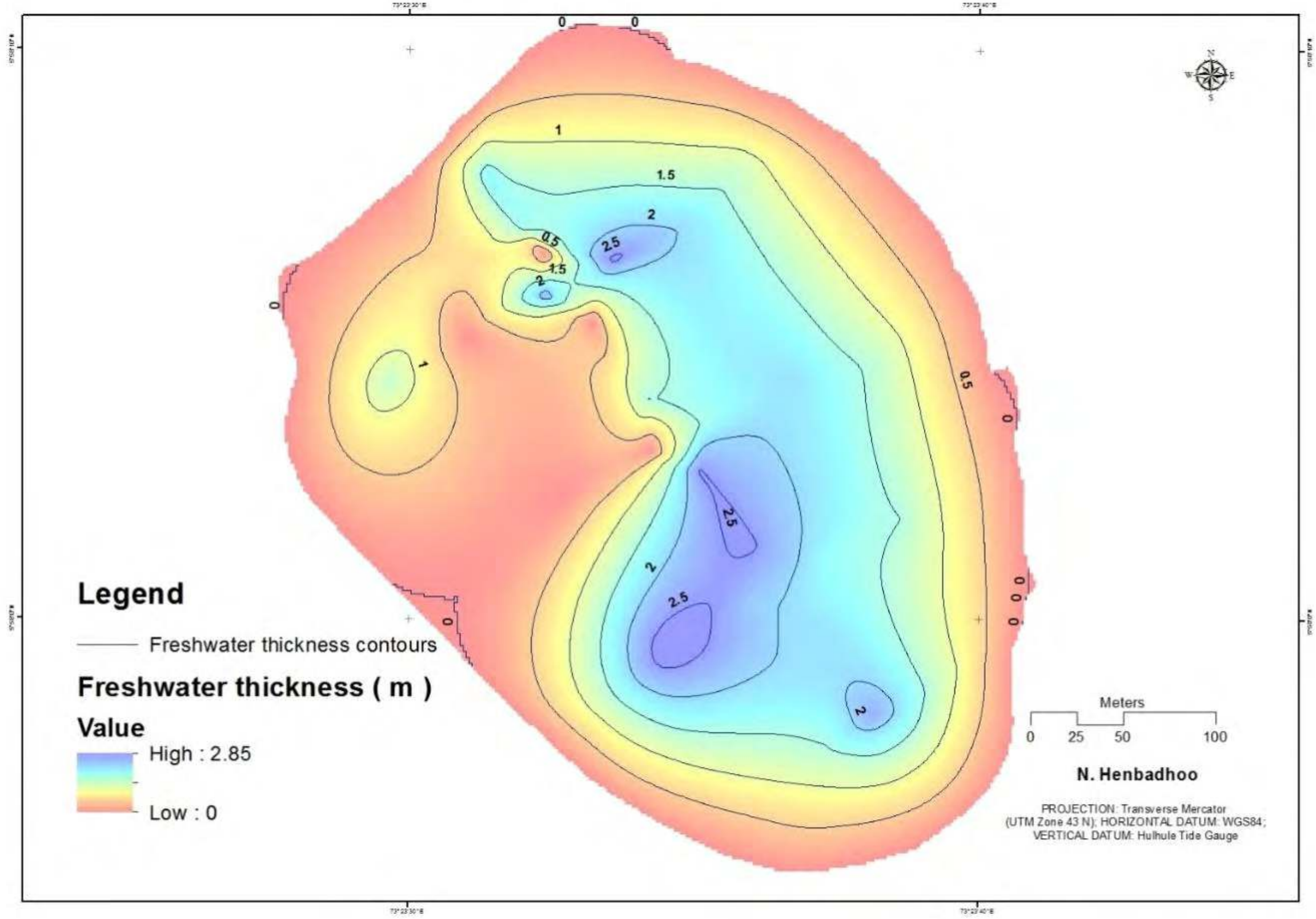


Figure 6.12: Freshwater thickness in Henbadhoo Island

The maximum freshwater thickness of the island is 2.85 m. According to Falkland, 1994, the freshwater level thickness of the island is 6 m. The relevant calculations are as follows;

Average Annual Rainfall = 1850 mm/yr

Width of the island = 351 m

Length of the island = 467 m

Freshwater lens Thickness (m)

= (6.94*log(width of the island)-14.38)*Average Annual Rainfall = 6 m

6.8.6 Water balance and recharge

An annual estimation is carried out based on water balance method. Rainwater harvesting is calculated using number of rainwater harvesting units in the island. According to the spatial mean annual rainfall of Maldives, the island is reported as 1850 mm/year. Evapotranspiration was estimated using crop water requirement for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. The groundwater extractions were estimated from amount of water usage in different sectors (residential, resorts, restaurants, agriculture and farming).The difference between recharge and groundwater extraction is taken to estimate different in storage.

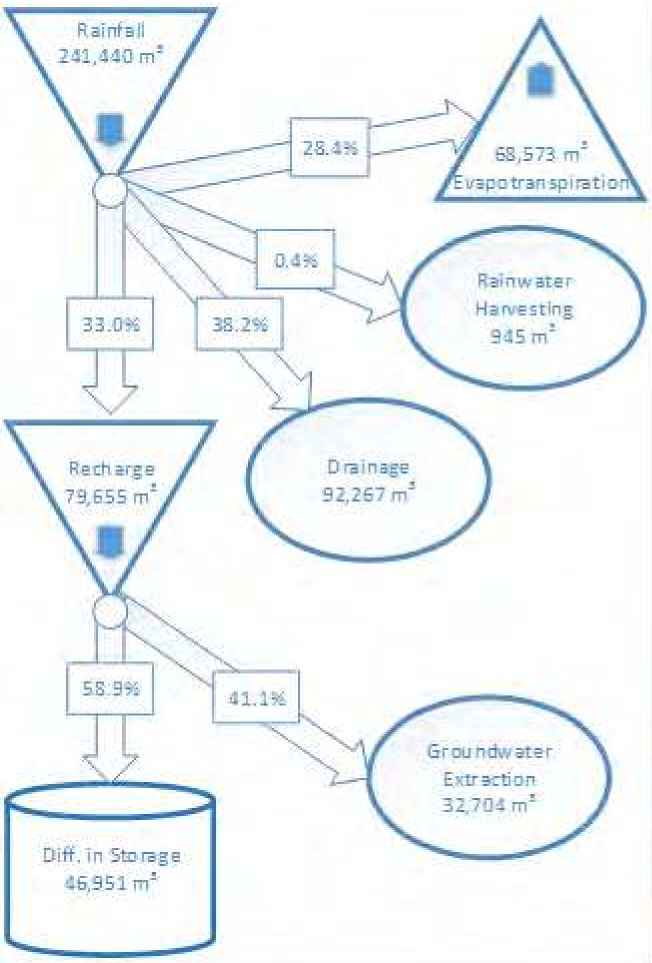


Figure 6.13: Schematic of water balance in Henbadhoo Island

6.8.7 Sustainable yield of the lens

Sustainable yield of the water lens refers to the safe extraction potential of a given groundwater aquifer without significantly affecting its quality or quantity. This parameter is an important factor in the sustainable development of islands as it allows planning and design of water and sanitation intervention in islands.

The island has a sustainable yield of 129 m^3 per day which was calculated subtracting groundwater extraction from recharge volume derived from water balance (Figure 6.13). According to Metai & Unit, n.d., based on geophysical investigations and drilling programme concluded that the safe sustainable yield was about 10% of mean annual rainfall. Such that the expected sustainable yield for the island should be 66 m^3 per day.

6.8.8 Permeability test

Permeability tests were carried out in the locations as outlined in Figure 6.14.

Figure 6.14: Locations of permeability tests in Henbadhoo Island

The estimated permeability values for the above test locations are presented below.

Table 6.10: The estimated permeability Values

r_e		0.0260
r_l		0.0285

Point	H	Tu	Cs	H/r_e	Q	K (m/s)	K (m/day)	Q (l/min)	Q (m^3/s)
HBPT1	0.6	1.0	43	23.1	1.2E-04	1.89E-04	16.36	7.0	0.00012
HBPT2	0.7	1.1	50	26.9	5.0E-05	6.43E-05	5.55	3.0	0.00005
HBPT3	0.5	0.8	40	19.2	5.0E-06	1.08E-05	0.94	0.3	0.00001

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m^3/s), H = Height of water in well (m), l = length of perforated section (m), r_l = outside radius of casing (radius of hole in consolidated material) (m), r_e = effective radius of well = r_l (area of perforations) / (outside area of perforated section of casing) : $r_l = r_e$ in consolidated material that will stand open and is not cast, C_u and C_s =Conductivity Coefficients, and T_u = distance from water level in casing to water table (m).

6.8.9 Groundwater availability

1) The selected Henbadhoo island has dimensions of width = 351 m and length = 467 m, with a total land area of 13.60 ha, a population of 491 persons, and a land use of built-up area 2.82 ha (22.0%), thick vegetation 1.78 ha (13.8%), light vegetation 3.45 ha (26.9%), and bare lands 4.77 ha (37.2%).

2) In order to recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of freshwater lens (FWL) and its associated recharge-discharge characteristics, 28 number of Electrical Resistivity (ER) location readings along 06 representatively selected transects were collected.

3) Soil overburden permeability tests (constant head) were carried out at 03 locations. In addition, groundwater level was also recorded at 05 locations where groundwater water quality samples were tested.

4) Permeability tests were carried out at representatively selected 03 number of locations. The measured permeability (K m/day) values ranged from a minimum of 0.94 m/day to a maximum of 16.36 m/day, with an average of 7.62 ± 7.92 m/day (Mean ± 1 Standard Deviation).

5) The ground elevation values ranged from a minimum of 0.92 m MSL to a maximum of 1.84 m MSL, with an average of 1.38 ± 0.20 m MSL (Mean ± 1 Standard Deviation).

6) The upper boundary of the freshwater lens (FWL) varied from a minimum of 0.15 m MSL to a maximum of 0.87 m MSL, with an average of 0.36 ± 0.16 m MSL (Mean ± 1 Standard Deviation).

7) The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -2.43 m MSL to a maximum of -0.23 m MSL, with an average of -1.39 ± 0.56 m MSL (Mean ± 1 Standard Deviation).

8) Accordingly, the freshwater lens (FWL) thickness values ranged from a minimum of 0.00 m to a maximum of 2.87 m, with an average of 1.31 ± 0.93 m (Mean ± 1 Standard Deviation).

9) The groundwater profile in the island is characterised by a relatively Low (0.39%) Rainwater Harvesting, relatively Very High (38.22%) Drainage, relatively Low (32.99%) Recharge, while the water use shows relatively Very High (41.06%) Groundwater extraction, leading to relatively Very Low (58.94%) Difference in Balance Storage.

10) The freshwater lens (FWL) volume calculated based on ER transect test data is 21,989 m^3 with a maximum FWL thickness of 2.87 m. The potential maximum FWL volume and thickness estimated based on Falkland (1994) method are 10,869 m^3 and 6.07 m.

6.8.10 Conclusive Comments and Recommendations

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 129 m^3 per day, while it is 66 m^3 per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 101 m^3 per day and this exceeds the allowable Safe Yield in the island by 153% (stressed) with moderate up-coning and moderate drawdown in freshwater lens cross-sections. At present, there exists no island-wide sewerage network or water supply network. The water samples tested were found to be Highly Odorous with 100.0% or 15/15 samples tested producing odour. The Hydrological condition of the freshwater lens aquifer can be categorised as Moderate based on above measurements and findings while Water quality aspects can be regarded as Contaminated with an Average Electrical Conductivity (EC) of 4,239.95 ± 1,631.26 µS/cm with measured values ranging from a minimum of 1,948.90 µS/cm to a maximum of 7,491.20 µS/cm, and an Average Ammonia Concentration of 12.91 ± 8.17 mg/L with measured values ranging from a minimum of 3.09 mg/L to a maximum of 32.86 mg/L. The Availability of space for incorporating recharge measures and related infrastructure is Low while therefore the Potential for Recharging is considered to be Moderate to Low.

The ER test results indicate up-coning at several cross sections, indicating that the freshwater lens is stressed. The readings were taken towards the end of the dry period and the freshwater lens can be assumed to be depleted at the time of measurement. Overall recommendation for groundwater recharging would be to use trenches along the roads and recharging pits within individual land blocks.

7 R. MADUVVARI ISLAND

7.1 General overview of the island

The island of Maduvvari is located at 05°29’05”N and 72°53’56”E in the Raa Administrative Atoll. The island is 671 m long and 342 m wide and has an area of 22.0 Hectares. The population of the island is 1449, via the 2014 Census. The island does not have an existing water network. The island has a sewerage system to which most houses are connected to. The island has a harbor built on its northern side.

Table 7.1: Basic statistical information on Maduvvari island in Raa Atoll.

Name of the island	R.Maduvvari
Longitude and Latitude	05°29’05”N, 72°53’56”E
Area	21.6 ha
Population (Census, 2014)	1449
Distance from Atoll Capital (R. Ungoofaaru)	25.03km
Distance from Male’	160.27km
Harbour	Present
Island sewerage network	Yes
Water supply network	No
Other infrastructure	

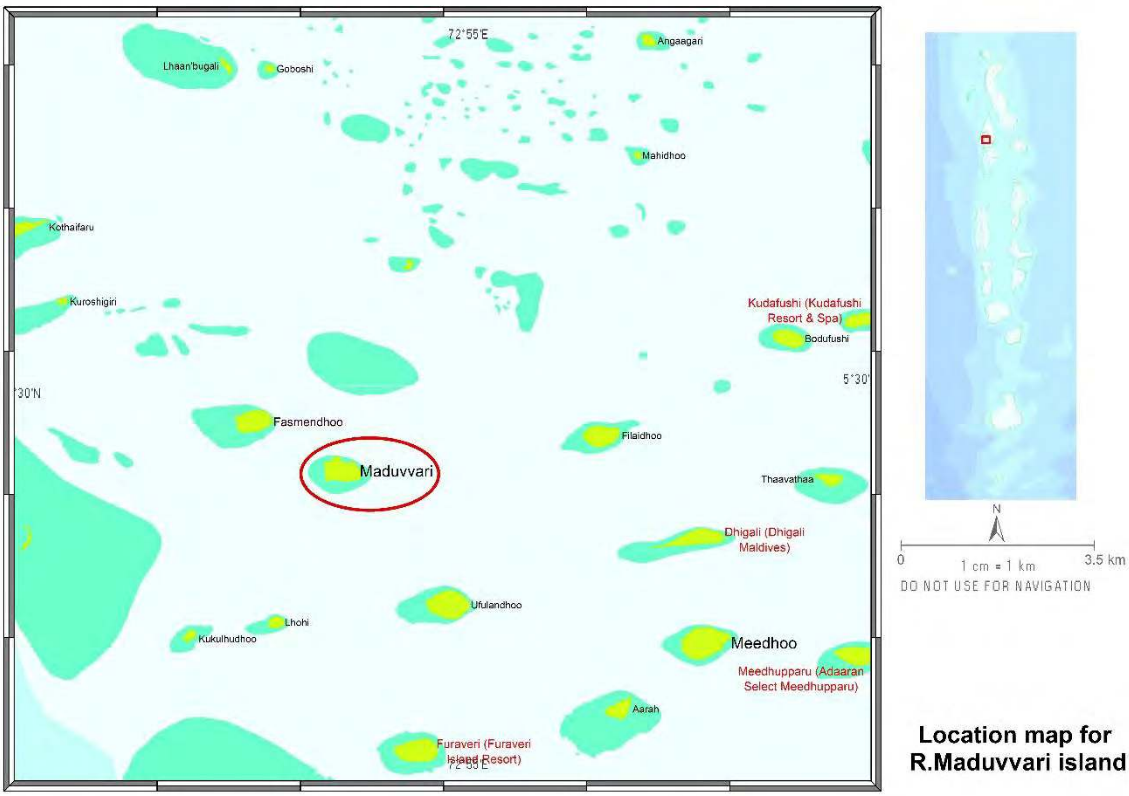


Figure 7.1: Location map for Maduvvari Island, Raa Atoll.

7.2 Geology and vegetation

The island is approximately is 671 m long and 342 m wide and has an area of 22.0 Hectares. The island has relatively little vegetation with about a tenth of the islands surface covered by it. The vegetation isn't grouped in one place and spread around the island. There is a harbour on the northern side of the island built on top of reclaimed land. No farming takes place on the island with the exception of home gardens.

7.3 Topography

The island has a topography that ranges from an elevation of 0.92 meters to 2.72 meters above Mean Sea Level, with an average elevation of 1.70 meters above MSL. Figure 3.2 shows map of Maduvvari Island showing spot heights and digital surface model (DSM).

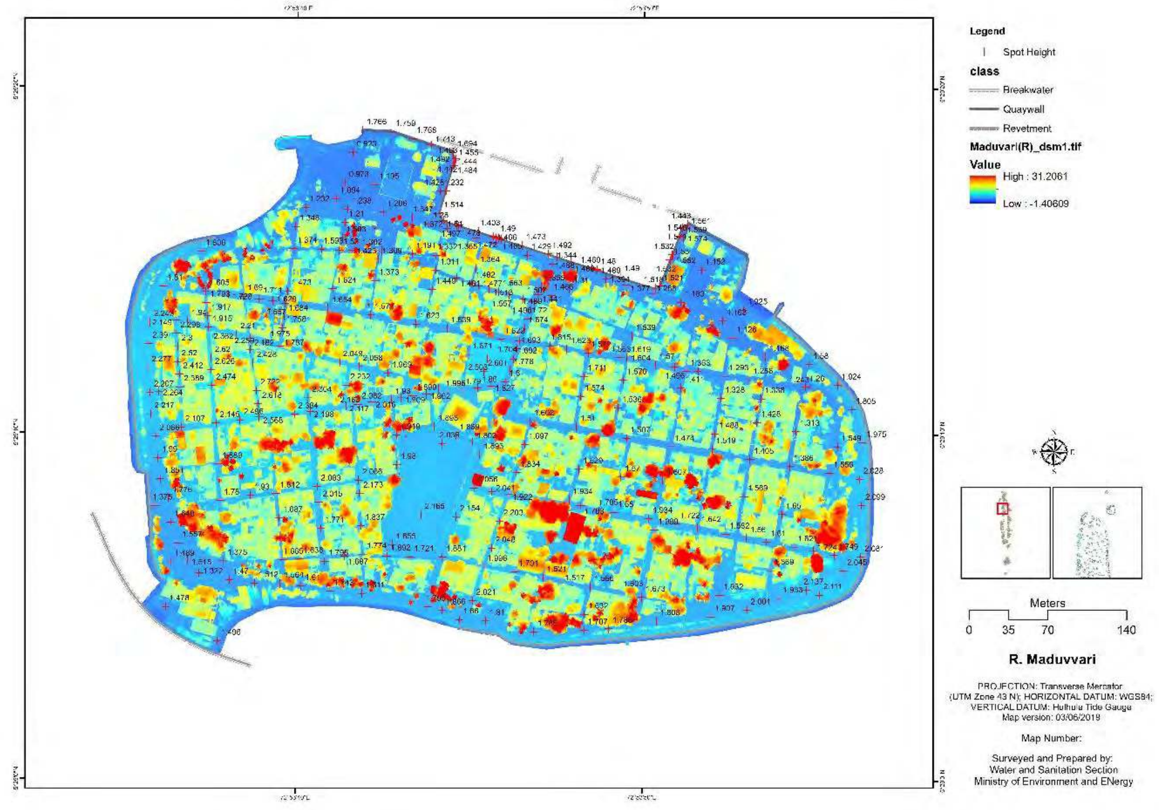


Figure 7.2: Map of Maduvvari Island showing spot heights and digital surface model (DSM)

7.4 Climate

Maduvvari experiences the typical two monsoons namely, north east monsoon from November to April and South-west monsoons from April to November. There are no specific wind and rainfall data available for Maduvvari as there are no weather monitoring stations on the island.

7.5 Demography

The island has a registered population of 1449 people via the 2014 Census. This data may be inaccurate now as the island council reports a larger population of 2. For the total population there are 39 more males than females (51:49 percent). However, when considering only populations are almost equal with only 2 more males than females. This is due to the foreign population having mostly men (48 men as opposed to 11 women). The following graphs and table illustrate the demographic breakdown.

Table 7.2: Demographic Breakdown of Maduvvari Island

Atoll	locality	Resident population (Census, 2014)								
		Total			Maldivians			Foreigners		
		Both sexes	Male	Female	Both sexes	Male	Female	Both sexes	Male	Female
R	Maduvvari	1,449	744	705	1,390	696	694	59	48	11

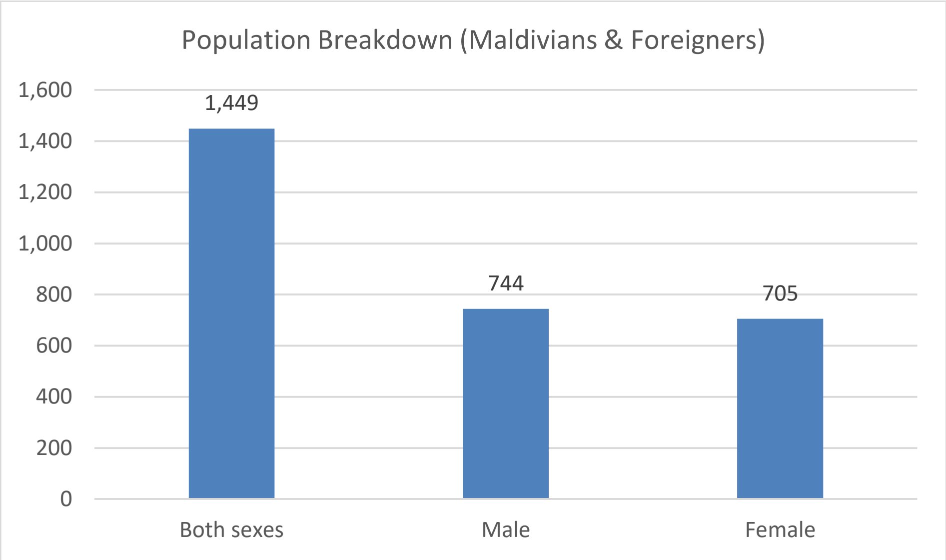


Figure 7.3: Population breakdown of Maduvvari (Maldivians & Foreigners)

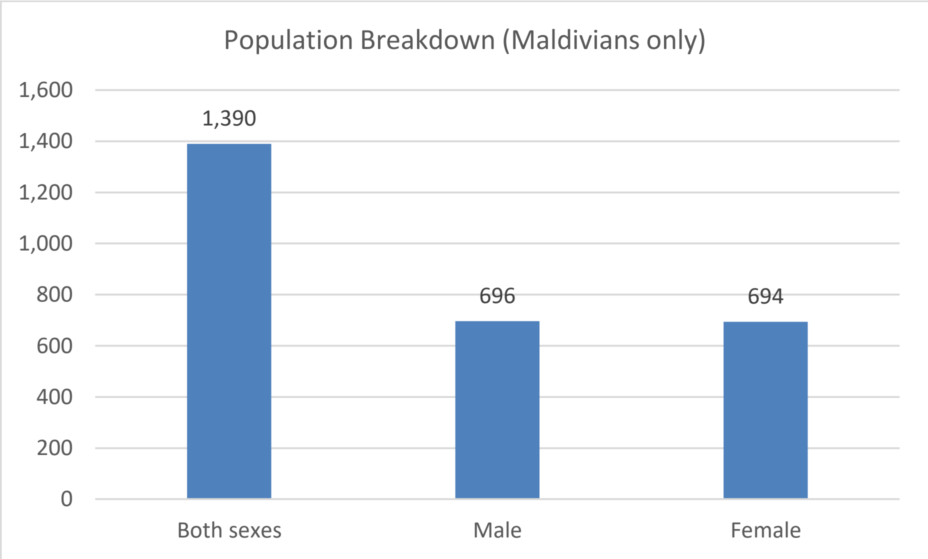


Figure 7.4: Population breakdown of Maduvvari (Maldivians)

7.6 Socio-economic condition

R. Maduvvari has a high population in comparison to its area. It is a very densely populated island.

7.7 Existing water and sanitation situation

The Island does not have an existing water supply network but does have a sewerage network to which almost all the households are connected to. Out of the 23 houses surveyed, only one house was not connected to the island sewerage network and still used septic tanks for sanitation purposes. This house claims a distance of 15.25 meters between their septic tank and nearest well.

The main source of drinking water on the island is rainwater that's collected in either household or community tanks, or bottled water. Rainwater is the primary source of water for cooking. The rainwater tends to run out during the dry season in most houses. Because of this many houses take water from community tanks, or from other households. Some even resort to using bottled water.

7.8 Results

7.8.1 Water sources and water use

Based on domestic, commercial and institutional water usage, a total of 288,755 liters of groundwater are estimated to be used every day. Otherwise stated 199 liters of groundwater are used per capita per day. The respective water use situations are detailed in the following sections. There is no industrial water usage on this island.

7.8.1.1 Domestic water use situation

Based on the questionnaire to collect data on domestic water consumption, a summary of results are present in this section.

According to the survey, 100% of the households surveyed uses HDPE rainwater tanks as their main storage for water. A total of 70% households use rainwater for drinking and 100% use it for cooking. None of the surveyed houses use rainwater for bathing or washing.

0% of the households use groundwater for drinking or cooking. Groundwater is mainly used for non-potable use in all the households surveyed.

The following table 7.3 summarizes the data for Maduvvari island.

Table 7.3: Groundwater and rainwater use data for Maduvvari Island

Rainwater	
Households with rainwater tanks	100%
Rainwater use for drinking	70%
Rainwater use for cooking	100%
Rainwater use for bathing and washing	0%
Groundwater	
Groundwater as drinking source	0%
Groundwater for cooking	5%
Groundwater for non-potable use	100%
Total number of household wells surveyed	(10%)
Percentage of wells surveyed fitted with pumps	70%

Based on the survey questionnaire, average daily water demand per capita for domestic purposes has been estimated based on the average amount of water used per person for showering, toilet flushing, laundry and gardening, this data is shown in table 7.4. The total domestic water use is estimated to be 195 liters per capita per day.

Table 7.4: Domestic Water Usage in Maduvvari Island

Shower/ Liters per capita per day	Toilet/ Liters per capita per day	Laundry/ Liters per capita per day	Gardening/ Liters per capita per day	**Total/ Liters per capita per day**
102	30	21	42	**195**

7.8.1.2 Commercial water use situation

Based on the questionnaire to collect data on commercial water consumption, a summary of results is present in this section. A total of 1 restaurant was surveyed. Maduvvari Island does not have any guesthouses.

For the restaurants, the main use of groundwater was for dishwashing and toilet use. A total of 1 restaurant was surveyed and from this data, the water consumption for the total 3 restaurants on Maduvvari Island was estimated to be 4565 liters per day. Otherwise stated, the commercial water usage in Maduvvari is a total of 3.15 liters per capita per day.

7.8.1.3 Institutional water use situation

Based on the questionnaire to collect data on institutional water consumption, a summary of results is present in this section. The institutions surveyed for this study was the council office and the school. Groundwater in the institutions in Maduvvari Island are mainly used for gardening, mopping floors and flushing toilets. A total of approximately 1,823 liters of groundwater are estimated to be used per day by the institutions. Therefore, a total of approximately 1.23 liters of groundwater are estimated to be used per capita per day by the institutions of Maduvvari Island.

	Water Flushed (Liters per day)	Gardening (Liters per day)	Mopping (Liters per day)	Total Water Usage (Liters per day)	Total Water Usage by all institutions (Liters per day)	Institutional Groundwater Usage (Liters per capita per day)
Council Office	218	-	40	258	1,823	1.23
School	1,159	300	106	1565		

7.8.2 Groundwater quality

Groundwater quality measurements were made at selected wells in Maduvvari for both physical and microbiological testing.

The following table summarizes the water quality results.

Table 7.5: Summary of groundwater quality tests from Maduvvari, April 2019

Sample No	Odour	Physical Appearance
gw1	yes	Clear with particles
gw2	yes	Clear with particles
gw3	yes	Clear with particles
gw4	yes	Clear with particles
gw5	yes	Clear with particles
gw6	yes	Clear with particles
gw7	yes	Clear with particles
gw8	yes	Clear with particles
gw9	yes	Clear with particles
gw10	yes	Clear with particles
gw11	yes	Clear with particles
gw12	yes	Clear with particles
gw13	yes	Clear with particles
gw14	yes	Clear with particles
gw15	yes	Clear with particles
gw16	yes	Clear
gw17	yes	Clear with particles
gw18	yes	Clear with particles
gw19	yes	Clear with particles
gw20	yes	Clear with particles
gw21	yes	Clear with particles
gw22	yes	Clear with particles

Sample No	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
gw1	1767	1031	7.25	0.42	2.48	31.0	0.79	16.7	1.72	0.22		
gw2	2645.2	1527	7.49	0.28	4.01	31.6	1.19	35.4	2.77	0.69		
gw3	1044.2	614	7.93	1.02	5.1	30.6	0.46	12.0	1.11	0.28		
gw4	6085	3499	7.39	0.17	2.21	31.8	2.87	56.9	6.09	0.37		
gw5	4858.3	2791	7.28	0.03	1.62	31.9	2.26	96.3	5	0.66	225	225
gw6	2210.5	1303	7.42	0.47	2.23	30.4	1.01	103.5	2.6	0.12		
gw7	2073.7	1216	7.43	0	4.64	30.7	0.94	58.6	2.18	0.4		
gw8	2072.8	1231	7.61	0.12	2.73	29.9	0.95	47.5	2.51	0.15		
gw9	9043.1	5446	7.17	0.39	2.6	29.2	4.63	47.5	9.1	0.65		
gw10	1148.3	667	7.4	0.38	3.59	31.2	0.5	40.1	1.02	0.59		
gw11	1597.1	942	7.85	0.94	5.04	30.3	0.72	17.2	1.35	0.08		
gw12	1700.3	1006	7.29	0.2	1.82	30.2	0.77	24.9	1.53	0.26		
gw13	1626.1	931	7.41	0.31	2.43	32.1	0.71	24.3	1.41	0.29		
gw14	4019.5	2361	7.24	0.52	2.16	30.6	1.89	27.7	4.15	0.33		
gw15	2124	1258	7.2	0.1	2.36	30.1	0.97	121.3	2.26	0.28		
gw16	868.6	498	8.16	0.15	4.47	32.1	0.37	24.8	0.72	0.06	>2420	238
gw17	6275.4	3661	7.3	0.09	1.58	31.0	3.02	26.9	60.4	0.18	>2420	571
gw18	3097.9	1760	7.46	0.14	3.85	32.6	1.38	28.9	2.65	0.25	>2420	594
gw19	19,924	11433	7.28	0.06	1.22	31.9	10.27	73.4	20.53	0.86		
gw20	1185.8	720	8.13	0.77	4.48	28.7	0.54	12.8	1.18	0.08		
gw21	2783.7	1659	7.37	1.3	3.63	29.7	1.31	115.8	2.45	0.18		
gw22	3020.3	1796	7.31	0.19	3.25	29.9	1.42	66.6	2.71	0.46		

	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)
WHO Standards	Suggested maximum limit of freshwater for potable purposes = 1500 µS/cm Suggested maximum limit of freshwater for non-potable purposes = 2500 µS/cm	-	-	-	-	-

	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
WHO Values	-	Guideline Value = 50 mg/L-NO3	Natural Level of Ammonia < 0.2 mg/L Threshold odour concentration = 1.5 mg/L Taste threshold = 35 mg/L	-	-	-

Figure 7.5: Location of groundwater sampling points in Maduvvari Island

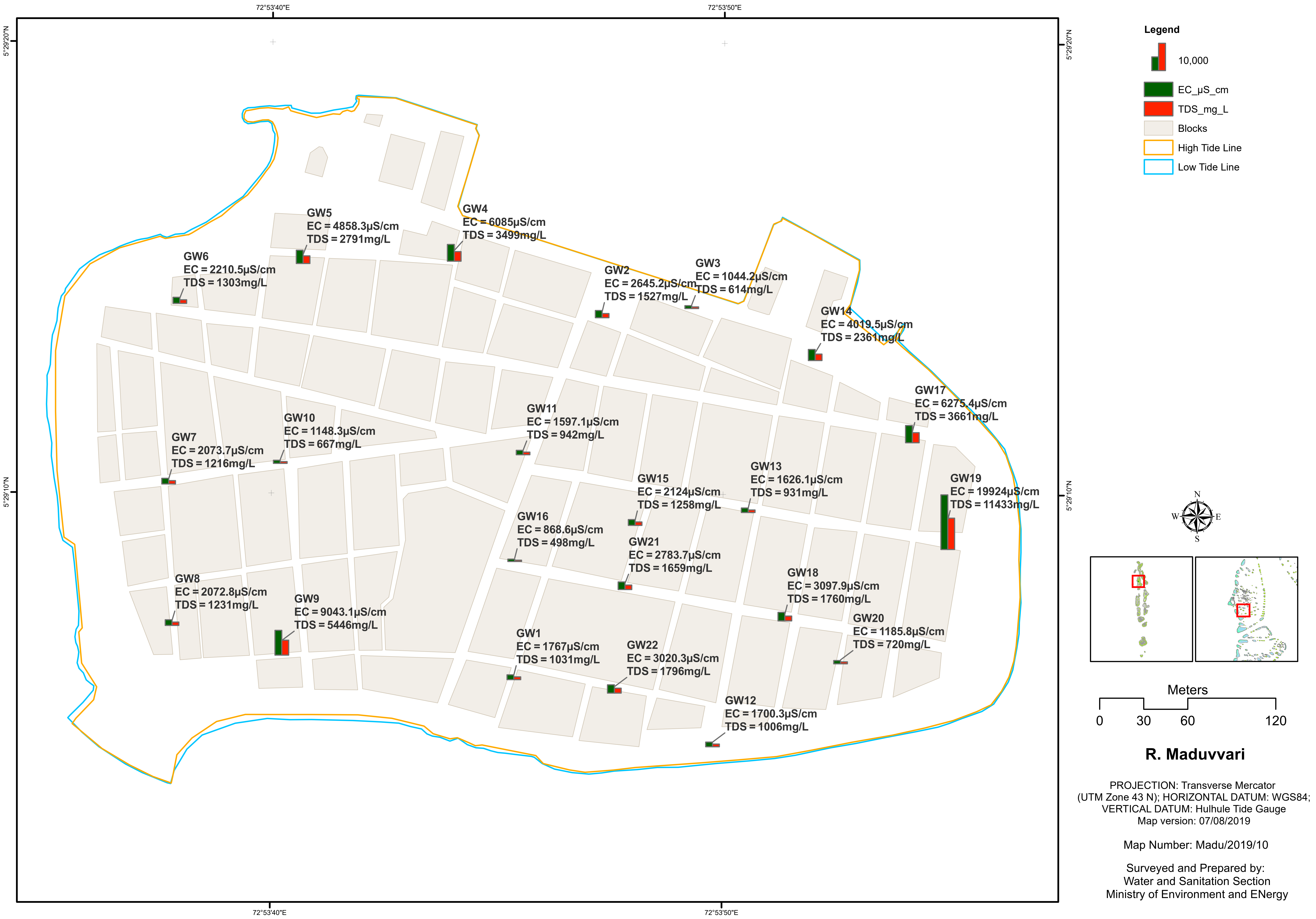
Based on the full results and the summary shown in Table 10.5, the following observations are made:

- The Electrical Conductivity (EC) of the groundwater is generally high. The average EC of 3690 µS/ exceeds the acceptable limit for potable water of 1,500 µS/cm and the acceptable limit for freshwater for non-potable purposes of 2500 µS/cm (refer section 2.2). 21 of the 22 tested water samples exceeded the limit for potable water of 1,500 µS/cm and 10 of the 22 tested water samples exceeded the limit for freshwater for non-potable uses. Water samples tested from the buffer zone of 50m from the shoreline had higher EC compared to water samples tested from the center of the island.

- Total dissolved solids were generally high and ranged from 498 mg/L to 11,433 mg/L with an average reading of 2152 mg/L. As TDS readings are calculated from Specific Conductance and Conductivity, the trends shown in TDS of samples are similar to EC trends.
- The pH ranged from 7.17 to 8.16 with an average reading of 7.47.
- Turbidity ranged from 0 NTU to 1.3 NTU with an average of 0.37 NTU. As a guide, “crystal-clear” water has a turbidity below 1 NTU, and water becomes visibly cloudy at 4 NTU and above.
- The salinity of groundwater ranged from 0.37 to 10.27 with an average reading of 1.77. It should be noted that 10.27 is the only reading with a higher value than 5.
- The average Nitrate concentration was 49.1 mg/L which does not exceed the WHO guideline limit of 50 mg/L. The Nitrate concentrations ranged from lowest concentration of 12 mg/L to the highest concentration of 121.3 mg/L. It should be noted that 8 of 22 (36.4%) tested water samples exceeded the WHO guideline limit for Nitrate concentrations.
- Ammonia concentrations were generally high. The average ammonia concentration was 6.16 mg/L. This exceeds the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. It was found that 16 of the 22 (72.7%) tested water samples exceeded this WHO guideline. Natural levels of ammonia are generally below 0.2 mg/L (WHO, 1993) and no tests showed concentrations below this level. There is no apparent correlation between increasing levels of ammonia and other nutrients.
- Phosphate concentrations ranged from 0.06 mg/L to 0.86 mg/L with an average concentration of 0.34 mg/L. There is no WHO drinking water guideline value for phosphate. However, it would normally be expected that phosphate concentrations in groundwater are less than 0.1 mg/L, where there are no impacts from human wastewater (e.g. effluent from septic tanks and ‘greywater’ from kitchens and bathrooms). None of the tested water samples showed concentrations below 0.1 mg/L.
- Total coliform levels were found to be very high, and showed concentrations ranging from 225 MPN/100mL to concentrations greater than 2420 MPN/100mL with an average concentration estimated to be greater than 1871.25 MPN/100mL. Faecal Coliform levels were found to be high and ranged from lowest count of 225 MPN/100mL to the highest count of 594 MPN/100mL with an average of 407 MPN/100mL. As expected, the groundwater layer is contaminated with effluent from septic tank

In conclusion, Maduvvari Island contains groundwater with generally high Electrical Conductivity with a higher average than WHO guidance value for potable and non-potable water and high TDS. Nitrate concentration was higher than WHO maximum guidance value and average Ammonia concentration and average Phosphate concentration was higher than expected in natural, undisturbed groundwater. In terms of microbiological contamination, an island wide contamination is observed.

Additionally, the following pages contain maps which show the main physiochemical parameters displayed on map of the island.


72°53'40"E
72°53'50"E
5°29'20"N
5°29'10"N
Legend
10,000
EC_µS_cm
TDS_mg_L
Blocks
High Tide Line
Low Tide Line
GW1 EC = 1767µS/cm TDS = 1031mg/L
GW2 EC = 2645.2µS/cm TDS = 1527mg/L
GW3 EC = 1044.2µS/cm TDS = 614mg/L
GW4 EC = 6085µS/cm TDS = 3499mg/L
GW5 EC = 4858.3µS/cm TDS = 2791mg/L
GW6 EC = 2210.5µS/cm TDS = 1303mg/L
GW7 EC = 2073.7µS/cm TDS = 1216mg/L
GW8 EC = 2072.8µS/cm TDS = 1231mg/L
GW9 EC = 9043.1µS/cm TDS = 5446mg/L
GW10 EC = 1148.3µS/cm TDS = 667mg/L
GW11 EC = 1597.1µS/cm TDS = 942mg/L
GW12 EC = 1700.3µS/cm TDS = 1006mg/L
GW13 EC = 1626.1µS/cm TDS = 931mg/L
GW14 EC = 4019.5µS/cm TDS = 2361mg/L
GW15 EC = 2124µS/cm TDS = 1258mg/L
GW16 EC = 868.6µS/cm TDS = 498mg/L
GW17 EC = 6275.4µS/cm TDS = 3661mg/L
GW18 EC = 3097.9µS/cm TDS = 1760mg/L
GW19 EC = 19924µS/cm TDS = 11433mg/L
GW20 EC = 1185.8µS/cm TDS = 720mg/L
GW21 EC = 2783.7µS/cm TDS = 1659mg/L
GW22 EC = 3020.3µS/cm TDS = 1796mg/L
N
S
E
W
Meters
0 30 60 120
R. Maduvvari
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 07/08/2019
Map Number: Madu/2019/10
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


72°53'40"E
72°53'50"E
5°29'20"N
5°29'10"N
Legend
30
Turbidity_NTU_
DO_mg_L
Ammonia_mg_L
Phosphates_mg_L
Blocks
High Tide Line
Low Tide Line
GW6 Turbidity = 0.47NTU DO = 2.23mg/L Nitrate = 103.5mg/L Ammonia = 2.6mg/L Phosphate = 0.12mg/L Nitrate = 103.5mg/L
GW5 Turbidity = 0.03NTU DO = 1.62mg/L Nitrate = 96.3mg/L Ammonia = 5mg/L Phosphate = 0.66mg/L Nitrate = 96.3mg/L
GW4 Turbidity = 0.17NTU DO = 2.21mg/L Nitrate = 56.9mg/L Ammonia = 6.09mg/L Phosphate = 0.37mg/L Nitrate = 56.9mg/L
GW2 Turbidity = 0.28NTU DO = 4.01mg/L Nitrate = 35.4mg/L Ammonia = 2.77mg/L Phosphate = 0.69mg/L Nitrate = 35.4mg/L
GW3 Turbidity = 1.02NTU DO = 5.1mg/L Nitrate = 12mg/L Ammonia = 1.11mg/L Phosphate = 0.28mg/L Nitrate = 12mg/L
GW14 Turbidity = 0.52NTU DO = 2.16mg/L Nitrate = 27.7mg/L Ammonia = 4.15mg/L Phosphate = 0.33mg/L Nitrate = 27.7mg/L
GW17 Turbidity = 0.09NTU DO = 1.58mg/L Nitrate = 26.9mg/L Ammonia = 60.4mg/L Phosphate = 0.18mg/L Nitrate = 26.9mg/L
GW7 Turbidity = 0NTU DO = 4.64mg/L Nitrate = 58.6mg/L Ammonia = 2.18mg/L Phosphate = 0.4mg/L Nitrate = 58.6mg/L
GW10 Turbidity = 0.38NTU DO = 3.59mg/L Nitrate = 40.1mg/L Ammonia = 1.02mg/L Phosphate = 0.59mg/L Nitrate = 40.1mg/L
GW11 Turbidity = 0.94NTU DO = 5.04mg/L Nitrate = 17.2mg/L Ammonia = 1.35mg/L Phosphate = 0.08mg/L Nitrate = 17.2mg/L
GW13 Turbidity = 0.31NTU DO = 2.43mg/L Nitrate = 24.3mg/L Ammonia = 1.41mg/L Phosphate = 0.29mg/L Nitrate = 24.3mg/L
GW19 Turbidity = 0.06NTU DO = 1.22mg/L Nitrate = 73.4mg/L Ammonia = 20.53mg/L Phosphate = 0.86mg/L Nitrate = 73.4mg/L
GW16 Turbidity = 0.15NTU DO = 4.47mg/L Nitrate = 24.8mg/L Ammonia = 0.72mg/L Phosphate = 0.06mg/L Nitrate = 24.8mg/L
GW21 Turbidity = 1.3NTU DO = 3.63mg/L Nitrate = 115.8mg/L Ammonia = 2.45mg/L Phosphate = 0.18mg/L Nitrate = 115.8mg/L
GW18 Turbidity = 0.14NTU DO = 3.85mg/L Nitrate = 28.9mg/L Ammonia = 2.65mg/L Phosphate = 0.25mg/L Nitrate = 28.9mg/L
GW8 Turbidity = 0.12NTU DO = 2.73mg/L Nitrate = 47.5mg/L Ammonia = 2.51mg/L Phosphate = 0.15mg/L Nitrate = 47.5mg/L
GW9 Turbidity = 0.39NTU DO = 2.6mg/L Nitrate = 47.5mg/L Ammonia = 9.1mg/L Phosphate = 0.65mg/L Nitrate = 47.5mg/L
GW1 Turbidity = 0.42NTU DO = 2.48mg/L Nitrate = 16.7mg/L Ammonia = 1.72mg/L Phosphate = 0.22mg/L Nitrate = 16.7mg/L
GW22 Turbidity = 0.19NTU DO = 3.25mg/L Nitrate = 66.6mg/L Ammonia = 2.71mg/L Phosphate = 0.46mg/L Nitrate = 66.6mg/L
GW20 Turbidity = 0.77NTU DO = 4.48mg/L Nitrate = 12.8mg/L Ammonia = 1.18mg/L Phosphate = 0.08mg/L Nitrate = 12.8mg/L
GW12 Turbidity = 0.2NTU DO = 1.82mg/L Nitrate = 24.9mg/L Ammonia = 1.53mg/L Phosphate = 0.26mg/L Nitrate = 24.9mg/L
N
W
E
S
Meters
0 30 60 120
R. Maduvvari
PROJECTION: Transverse Mercator (UTM Zone 43 N); HORIZONTAL DATUM: WGS84; VERTICAL DATUM: Hulhule Tide Gauge
Map version: 23/09/2019
Map Number: Madu/2019/11
Surveyed and Prepared by: Water and Sanitation Section Ministry of Environment and ENergy

7.8.3 Geophysical survey

The Resistivity tests were carried out in the locations as outlined in Figure 7.6 below.

Figure 7.6: Location of ER points in Maduvvari Island

7.8.4 Aerial surveys

Based on the aerial survey, a multiple dataset consisting of roof cover, thick vegetation area, thin vegetation area, bare lands and shorelines were extracted. This data is shown in Figure 7.7 and the table 7.6 shows the different area distribution.

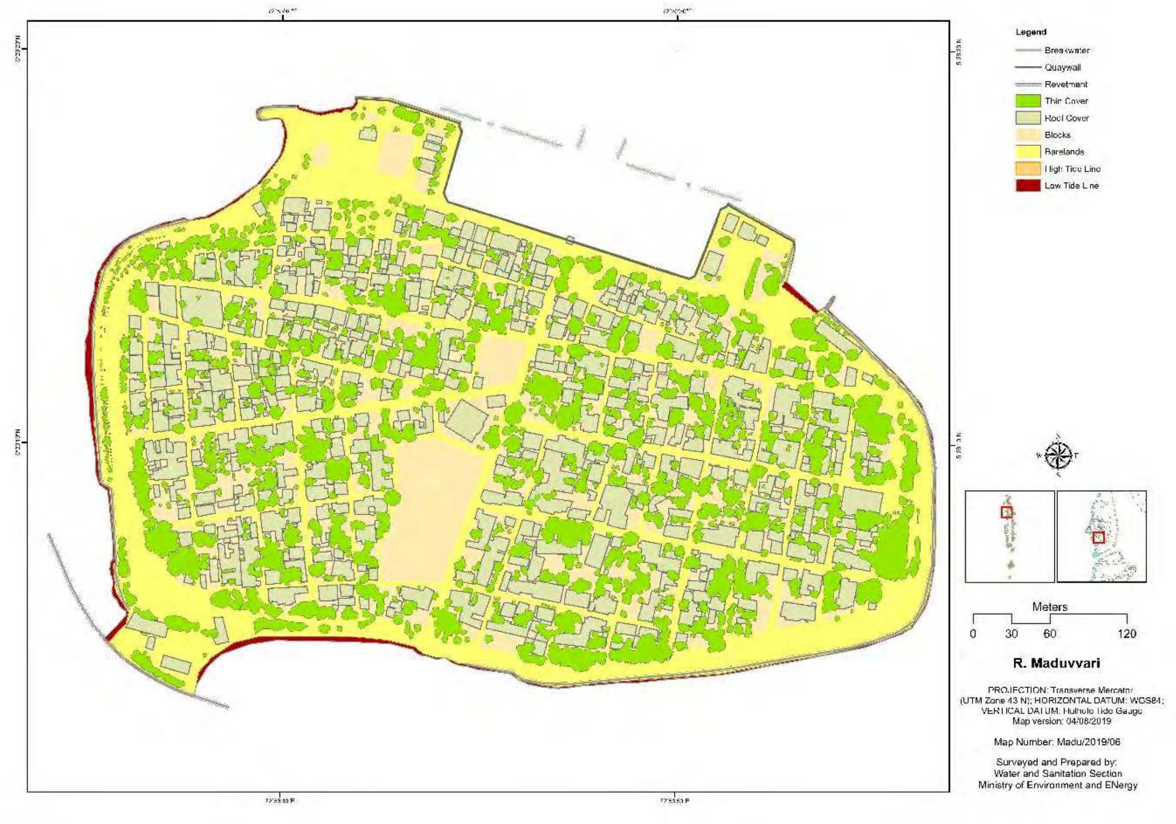


Figure 7.7: Area Distribution in Maduvvari Island

Table 7.6: Area Distribution in Maduvvari

	Area (Square Meters)	% of total area
Roof cover	61,072.64	27.2%
Vegetation (Thick)	0	0%
Vegetation (Light)	51,510.92	23.0%
Bare lands	111,647	49.8%
Farm Lands	-	-
Wetlands (Inland)	-	-

7.8.5 Freshwater lens

Based on the ER survey the depth to groundwater level and the freshwater-saline water interface was determined for a set of transverse transects as shown in Figure 7.8. Plots in the Figure 7.9 shows the cross sections of each transect line. The dotted lines in the plots indicating a simple interpolation of levels to mean sea level in the island boundaries. These cross sections were used to identify the spatial extent and volume of the freshwater lens while they were also useful in deriving implications on the stress level of the aquifer based on the observed, localized drawdown effect in the groundwater table and up-coning in the freshwater-saline interface, defining the upper and lower boundaries of the freshwater lens in an island.

The Table 7.7 illustrate the freshwater volume calculation for the island. The area covered by freshwater for each transect line has been calculated. To estimate the total volume of available freshwater lens, the cross-section area of freshwater extent under each transect was multiplied by the distance between two transects. The sum of these lengths represents the cumulative length of the island and thus, the above estimation could represent the total volume of the freshwater lens sandwiched between the groundwater table on top and freshwater-saline water interface in the bottom. Then the actual groundwater storage within this freshwater lens was calculated by multiplying the estimated total lens volume with the porosity of the topsoil in the island.

This estimation represents the total available freshwater volume within the freshwater lens at any given time (time of the measurement). The measurements were carried out towards the end of the dry period and the freshwater lens is presumed to be undergoing a ‘stressed’ condition due to continued groundwater abstractions despite reduced recharge in the dry period. Falkland (1994) method can be used to estimate the freshwater lend thickness under salient conditions using average annual rainfall, length and width of the island, and the comparison was used as a measure of stress level of the freshwater lens.

Table 7.7: Freshwater Volume Calculation for Maduvvari Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
3	Start		0	0	0	0			
			18	0.260	0	0			
	MV12	GPS5012	118	1.727	0.187	-0.873	62		
	MV11	GPS5011	177	2.011	0.71	-1.89	108		
	MV10	GPS5010	222	2.504	0.664	-2.071	120		
	MV9	GPS5009	272	1.952	0.53	-1.58	122		
	MV8	GPS5008	321	1.476	0.436	0.056	61		
			337	0.698	0	0	3		
	End		355	0	0	0	0		
	Total						476	144.2	68643.5
4	Start		0	0	0	0			
			17	1.019	0	0			
	MV7	GPS5007	30	1.775	0.255	-0.265	8		
	MV6	GPS5006	70	1.947	0.46	-0.533	30		
	MV5	GPS5005	119	2.053	0.573	-2.68	103		
	MV4	GPS5004	167	1.810	0.33	-3.69	176		
	MV3	GPS5003	216	1.815	0.395	-2.37	166		
	MV2	GPS5002	269	1.721	0.201	-1.19	110		
	MV1	GPS5001	317	1.441	0.15	0.15	34		
			327	0.513	0	0	0		
	End		344	0	0	0	0		
	Total						627	251	157333
5	Start		0	0	0	0			
	MVA1	GPS0007	18	1.773	0.393	0.143	2		
	MVA2	GPS0006	69	1.756	0.456	-0.084	20		
	MVA3	GPS0005	117	1.806	0.566	-0.554	39		
	MVA4	GPS0004	164	1.493	0.493	-1.017	63		
	MVA5	GPS0001	209	1.496	0.356	-1.344	72		
	MVA6	GPS0002	270	1.409	0.299	-0.121	64		
	MVA7	GPS0008	305	1.208	0.158	0.158	7		
			350	0.855	0	0	0		
	End		368	0	0	0	0		

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
	Total						268	130	34827
6	Start		0	0	0	0			
			13	1.106	0	0	0		
	MVA8	GPS0009	16	1.388	0.198	0.198	0		
	MVA10	GPS0012	30	1.220	0.252	0.252	0		
	MVA9	GPS0010	58	1.216	0.299	0.299	0		
	MVA15	GS10135	105	1.391	0.43	-0.61	24		
			242	1.273	0	0	71		
	End		255	0	0	0	0		
	Total						96	83.2	7971
									268774

Volume of lens = 268774 m^3

Groundwater Storage = Porosity (15%) x Lens volume (m^3) =40316 m^3

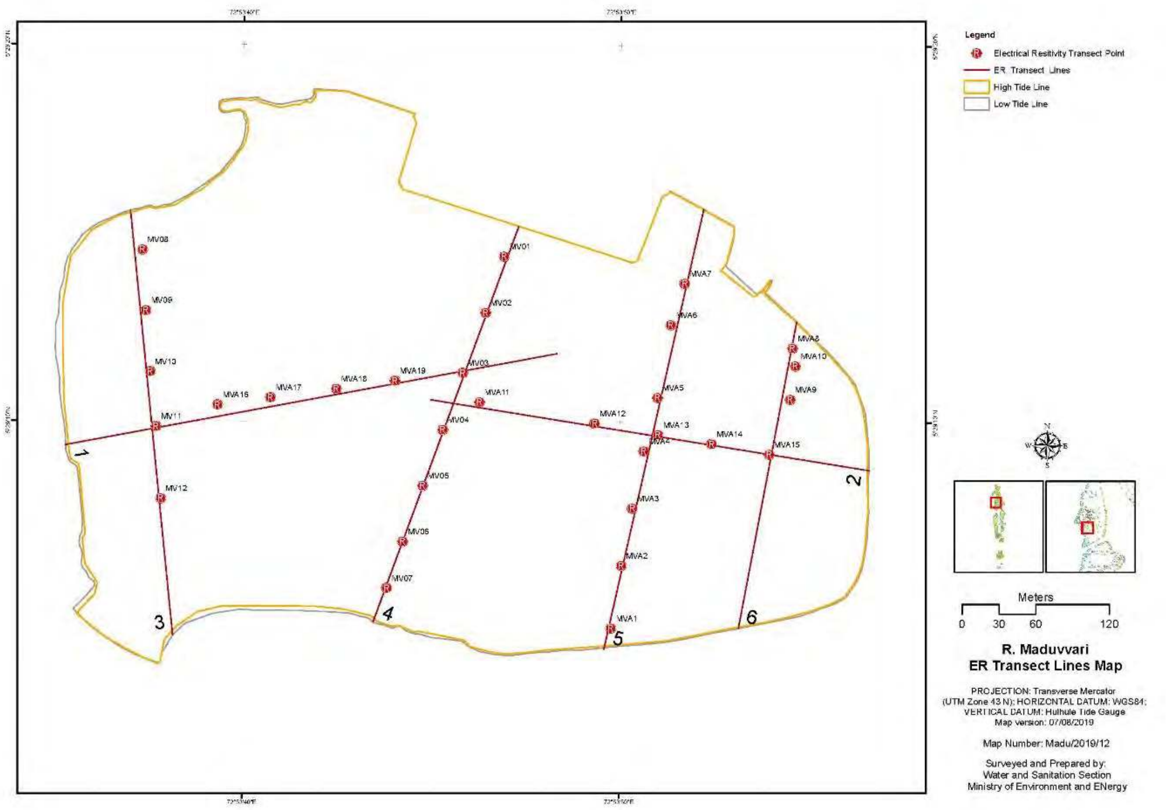
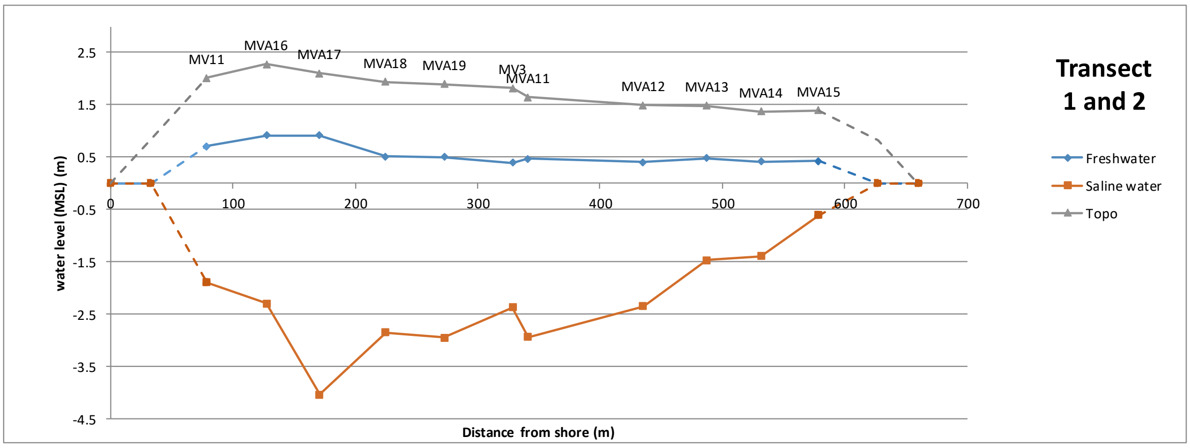
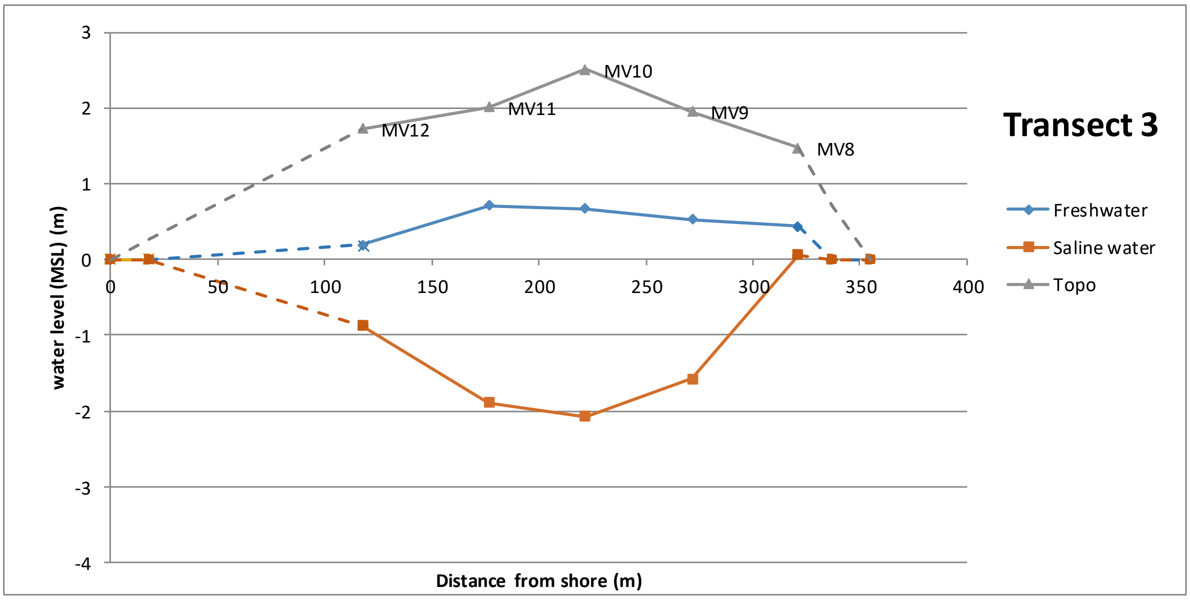
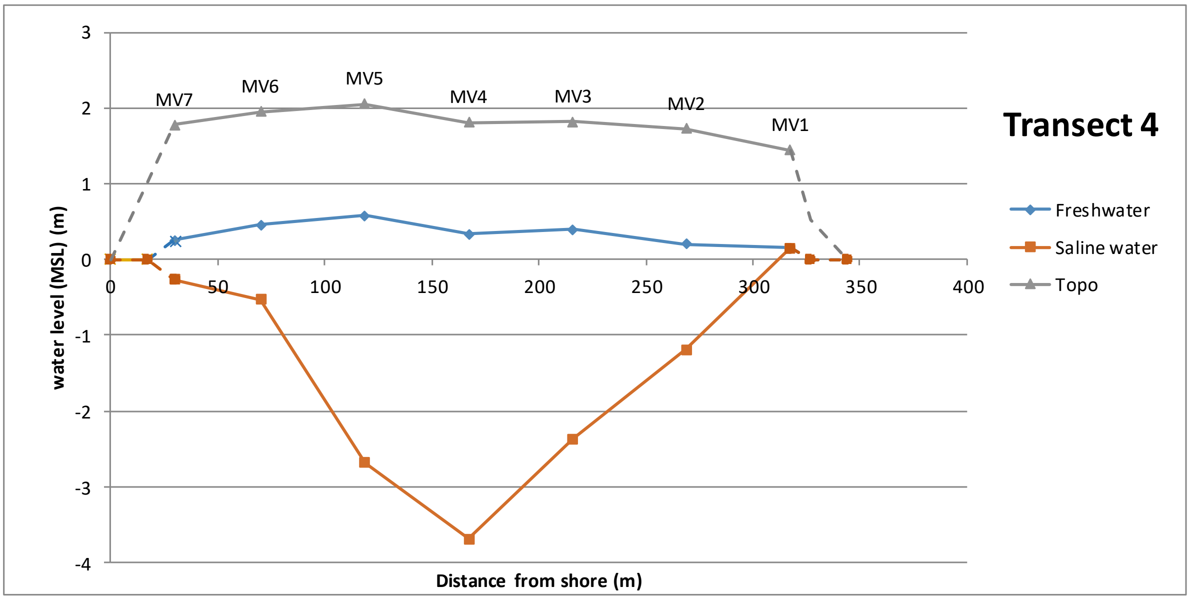


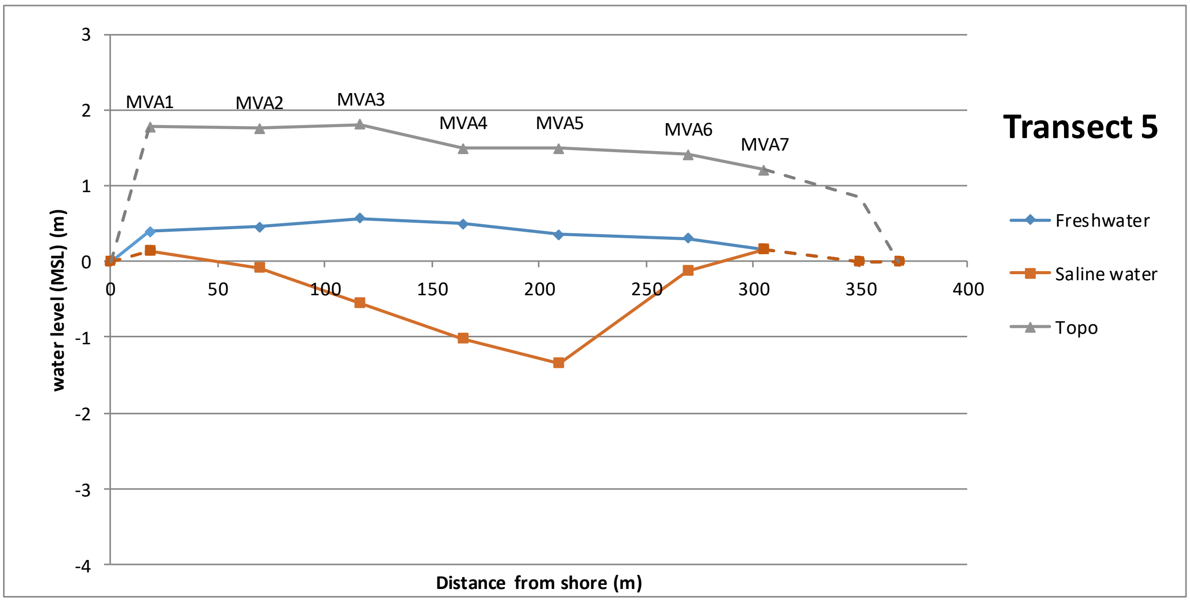
Figure 7.8: ER transect lines in Maduvvari Island

Table 7.8: ER Survey Results of Longitudinal Sections for Maduvvari Island









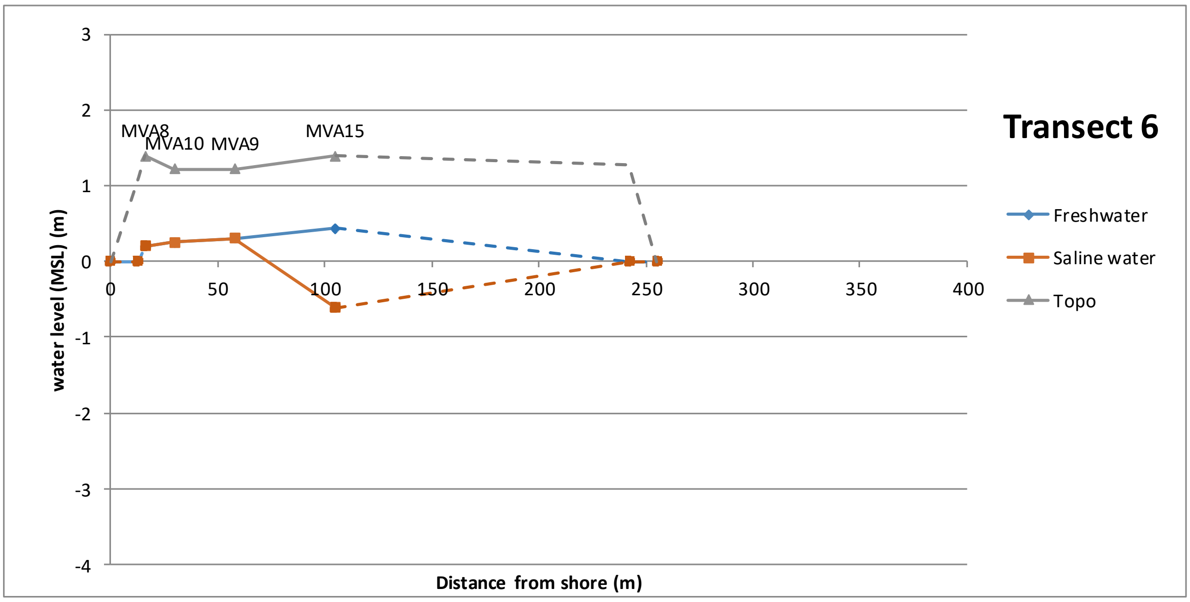


Figure 7.9: Cross-sections of transect lines in Maduvvari Island

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented below.

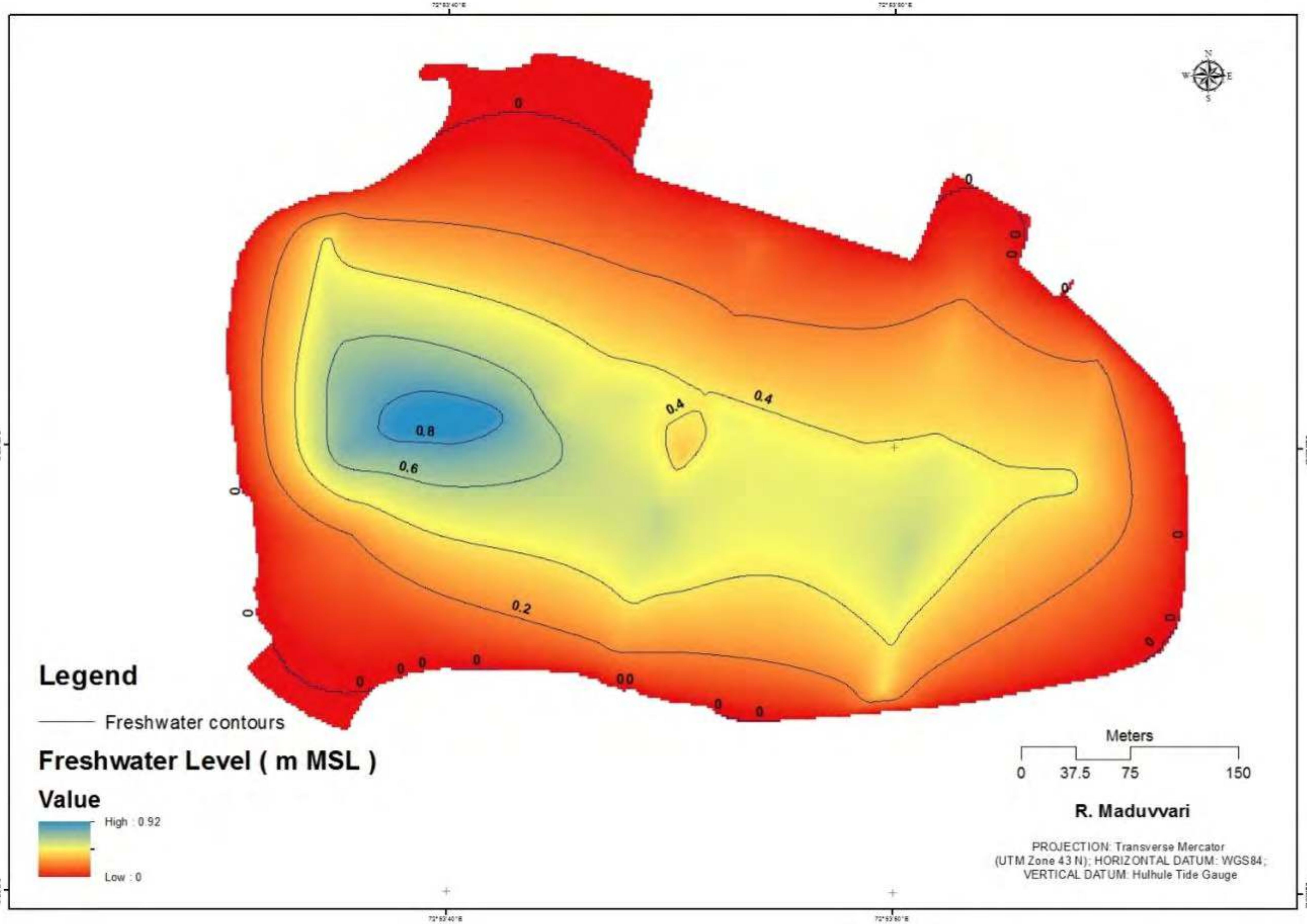


Figure 7.10: Freshwater Level in Maduvvari Islan

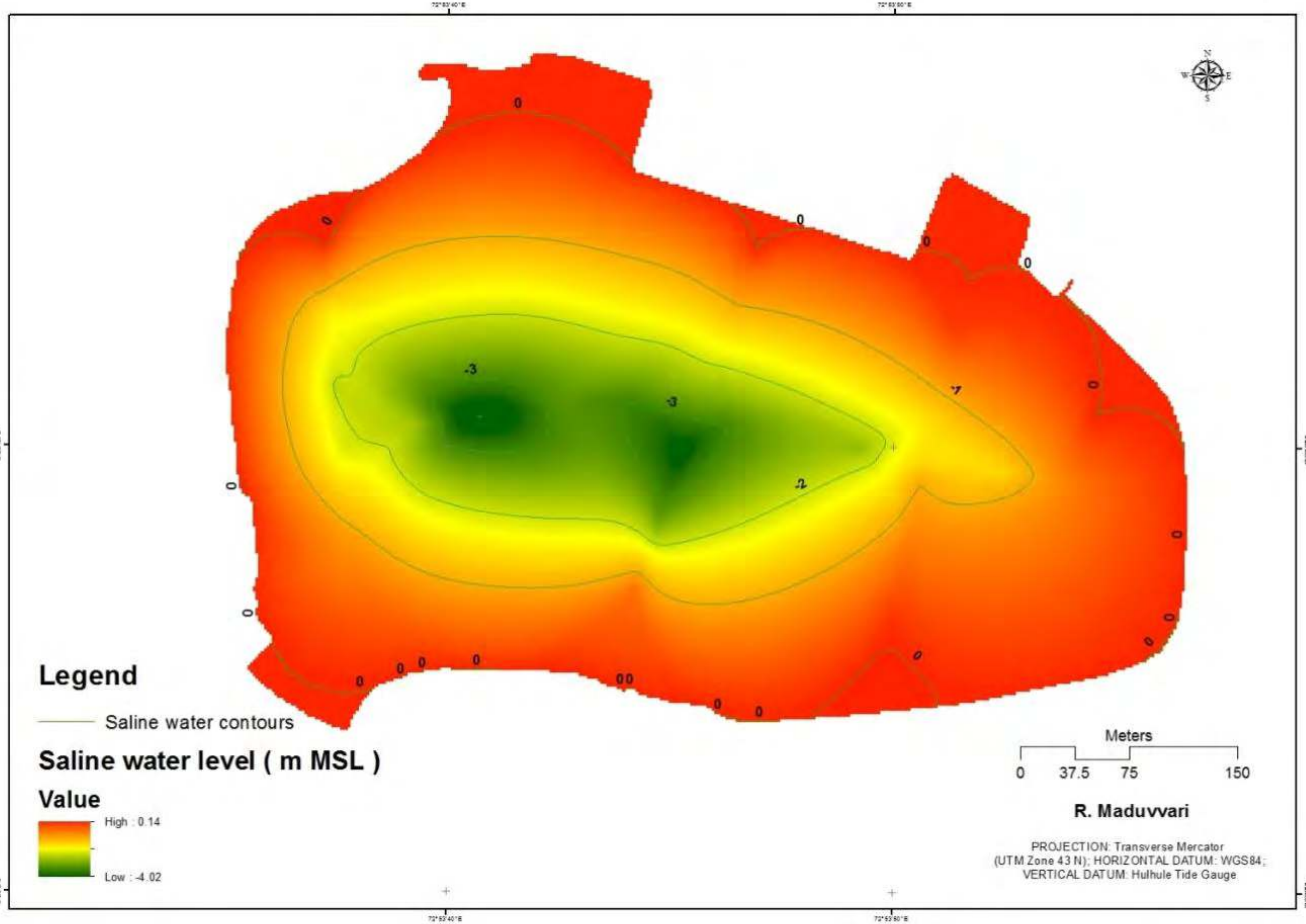


Figure 7.11: Saline water Level in Maduvvari Islan

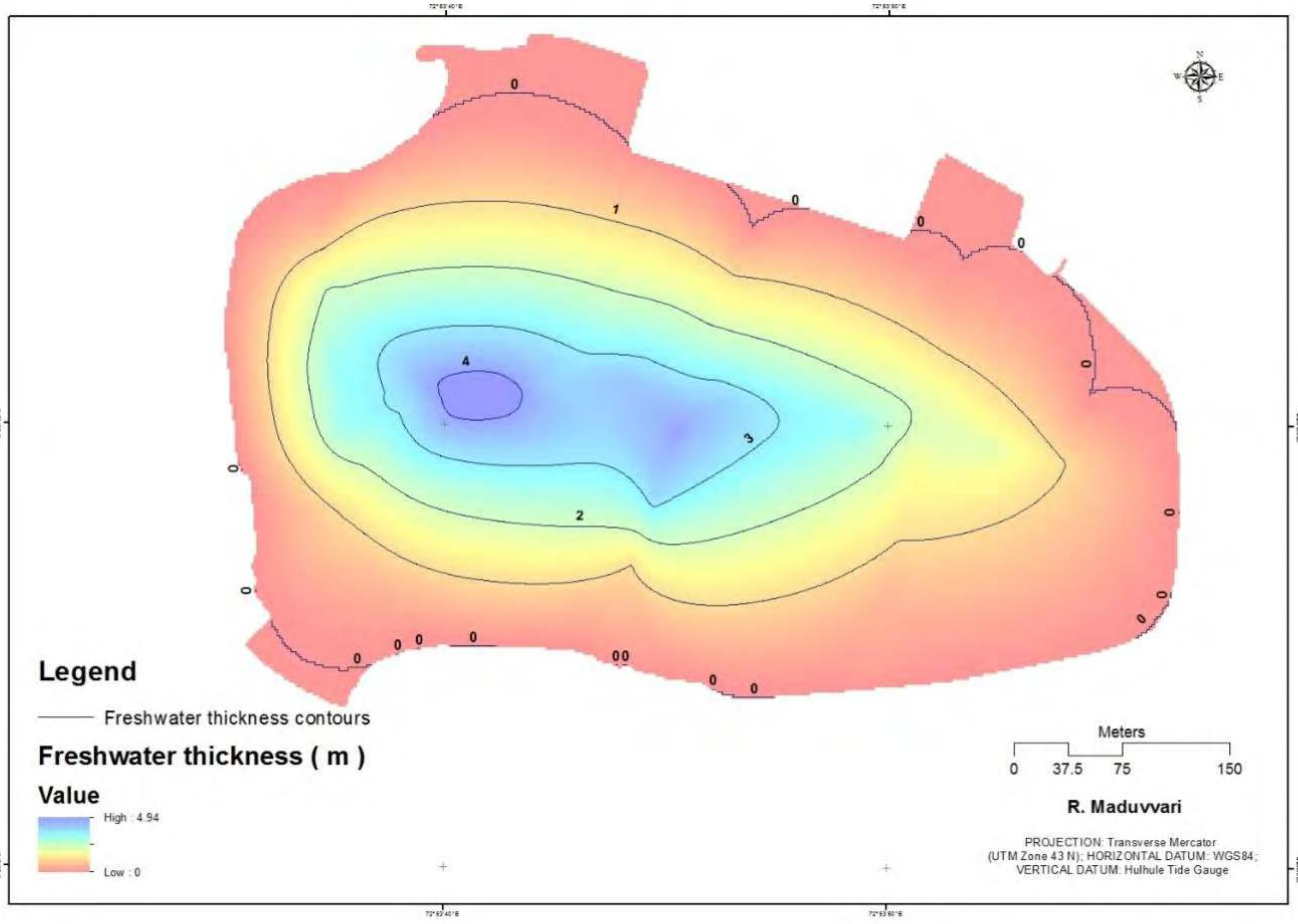


Figure 7.12: Freshwater thickness in Maduvvari Island

The maximum freshwater thickness of the island is 4.94 m. According to Falkland, 1994, the freshwater level thickness of the island is 6 m. The relevant calculations are as follows;

Average Annual Rainfall = 1875 mm/yr

Width of the island = 344 m

Length of the island = 676 m

Freshwater lens Thickness (m)

= (6.94*log(width of the island)-14.38)*Average Annual Rainfall = 6 m

7.8.6 Water balance and recharge

An annual estimation is carried out based on water balance method. Rainwater harvesting is calculated using number of rainwater harvesting units in the island. According to the spatial mean annual rainfall of Maldives, the island is reported as 1875 mm/year. Evapotranspiration was estimated using crop water requirement for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. The groundwater extractions were estimated from amount of water usage in different sectors (residential, resorts, restaurants, agriculture and farming).The difference between recharge and groundwater extraction is taken to estimate different in storage.

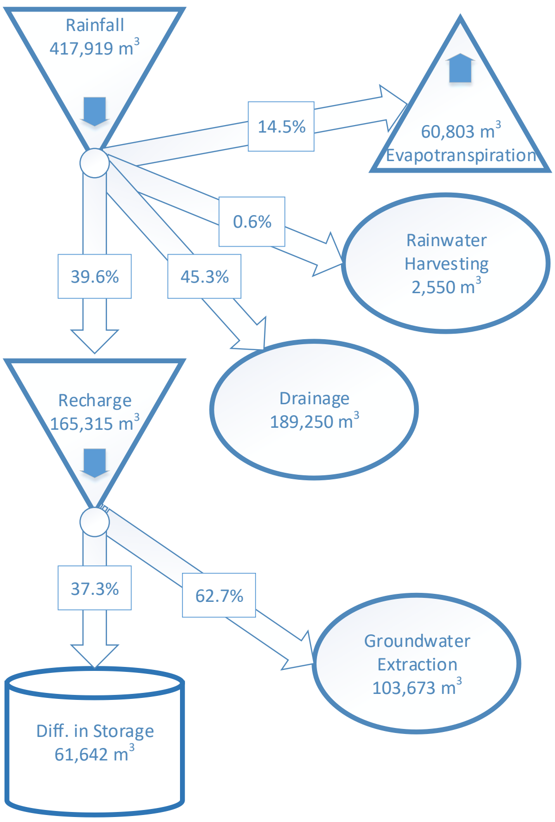


Figure 7.13: Schematic of water balance in Maduvvari Island

7.8.7 Sustainable yield of the lens

Sustainable yield of the water lens refers to the safe extraction potential of a given groundwater aquifer without significantly affecting its quality or quantity. This parameter is an important factor in the sustainable development of islands as it allows planning and design of water and sanitation intervention in islands.

The island has a sustainable yield of 169 m^3 per day which was calculated subtracting groundwater extraction from recharge volume derived from water balance (

Figure 8.13). According to Metai & Unit, n.d., based on geophysical investigations and drilling programme concluded that the safe sustainable yield was about 10% of mean annual rainfall. Such that the expected sustainable yield for the island should be 114 m^3 per day.

7.8.8 Permeability test

Permeability tests were carried out in the locations as outlined in Figure 7.14.

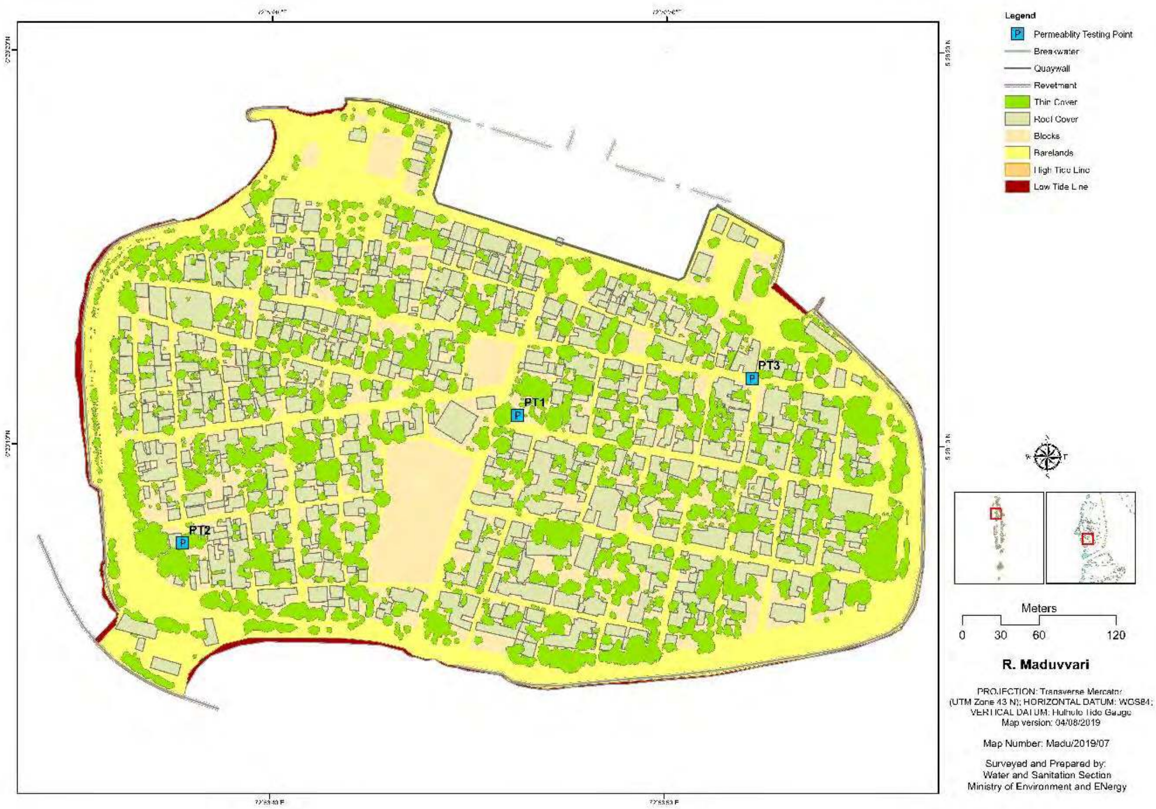


Figure 7.14: Permeability Testing Locations

The estimated permeability values for the above test locations are presented below.

Table 7.9: The estimated permeability Values

r_e		0.0260
r_l		0.0285

Point	H	Tu	Cs	H/r_e	Q	K (m/s)	K (m/day)	Q (l/min)	Q (m^3/s)
MVPT1	0.8	1.4	50	30.8	6.7E-05	6.74E-05	5.82	4.0	0.00007
MVPT2	0.8	0.9	50	30.8	8.3E-05	1.31E-04	11.32	5.0	0.00008
MVPT3	0.7	1.4	50	26.9	1.7E-04	1.68E-04	14.55	10.0	0.00017

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m^3/s), H = Height of water in well (m), l = length of perforated section (m), r_l = outside radius of casing (radius of hole in consolidated material) (m), r_e = effective radius of well = r_l (area of perforations) / (outside area of perforated section of casing) : $r_l = r_e$ in consolidated material that will stand open and is not cast, C_u and C_s =Conductivity Coefficients, and T_u = distance from water level in casing to water table (m).

7.8.9 Groundwater availability

1) The selected Maduvvari island has dimensions of width = 344 m and length = 676 m, with a total land area of 22.0 ha, a population of 1449 persons, and a land use of built-up area 6.10 ha (27.2%), thick vegetation 0.00 ha (0.0%), light vegetation 5.15 ha (23.0%), and barelands 11.16 ha (49.8%).

2) In order to recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of freshwater lens (FWL) and its associated recharge-discharge characteristics, 31 number of Electrical Resistivity (ER) location readings along 06 representatively selected transects were collected.

3) Soil overburden permeability tests (constant head) were carried out at 03 locations. In addition, groundwater level was also recorded at 06 locations where groundwater water quality samples were tested.

4) Permeability tests were carried out at representatively selected 03 number of locations. The measured permeability (K m/day) values ranged from a minimum of 5.82 m/day to a maximum of 14.55 m/day, with an average of 10.56 ± 4.41 m/day (Mean ± 1 Standard Deviation).

5) The ground elevation values ranged from a minimum of 0.92 m MSL to a maximum of 2.70 m MSL, with an average of 1.70 ± 0.32 m MSL (Mean ± 1 Standard Deviation).

6) The upper boundary of the freshwater lens (FWL) varied from a minimum of 0.15 m MSL to a maximum of 0.92 m MSL, with an average of 0.43 ± 0.19 m MSL (Mean ± 1 Standard Deviation).

7) The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -4.04 m MSL to a maximum of 0.14 m MSL, with an average of -1.58 ± 1.18 m MSL (Mean ± 1 Standard Deviation).

8) Accordingly, the freshwater lens (FWL) thickness values ranged from a minimum of 0.00 m to a maximum of 4.96 m, with an average of 1.72 ± 1.39 m (Mean ± 1 Standard Deviation).

9) The groundwater profile in the island is characterised by a relatively Very High (0.61%) Rainwater Harvesting, relatively Very High (45.28%) Drainage, relatively High (39.56%) Recharge, while the water use shows relatively Very High (62.71%) Groundwater extraction, leading to relatively Very Low (37.29%) Difference in Balance Storage.

10) The freshwater lens (FWL) volume calculated based on ER transect test data is 40,316 m^3 with a maximum FWL thickness of 4.96 m. The potential maximum FWL volume and thickness estimated based on Falkland (1994) method are 15,372 m^3 and 6.04 m.

7.8.10 Conclusive Comments and Recommendations

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 169 m^3 per day, while it is 114 m^3 per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 284 m^3 per day and this exceeds the allowable Safe Yield in the island by 254% (Moderately stressed) with moderate up-coning and moderate drawdown in freshwater lens cross-sections. At present, there exists an island-wide sewerage network but no water supply network. The water samples tested were found to be Highly Odorous with 100.0% or 22/22 samples tested producing odour. The Hydrological condition of the freshwater lens aquifer can be categorised as Good based on above measurements and findings while Water quality aspects can be regarded as Contaminated with an Average Electrical Conductivity (EC) of 3,689.58 ± 4,155.67 µS/cm with measured values ranging from a minimum of 868.60 µS/cm to a maximum of 19,924.00 µS/cm, and an Average Ammonia Concentration of 6.16 ± 12.84 mg/L with measured values ranging from a minimum of 0.72 mg/L to a maximum of 60.40 mg/L.

The ER test results indicate up-coning at several cross sections, indicating that the freshwater lens is stressed. The readings were taken towards the end of the dry period and the freshwater lens can be assumed to be depleted at the time of measurement. The Availability of space for incorporating recharge measures and related infrastructure is Low while therefore the Potential for Recharging is considered to be Moderate to Low. Overall recommendation for groundwater recharging would be to use recharging trenches in roads and recharging pits in individual households and land blocks.

8 B. DHARAVANDHOO ISLAND

8.1 General overview of the island

The island of Dharavandhoo is located on the south eastern periphery of Baa Atoll at coordinates 73°08'E, 05°09'N. The island has an area of about 65 ha measure to about 525 m in width and 1497 m in length. The census 2014 shows the population of the island to be about 839 residents. The island has a harbour on the northern side of the island build in 1997. Additionally breakwaters were constructed on the north eastern lagoon as coastal protection measures. Dharavandhoo Island also has domestic airport built on the southern half of the island. The following table outlines some basic information about the island and the following map outlines the location of Dharavandhoo.

Table 8.1: Basic statistical information on Dharavandhoo island in Baa Atoll.

Name of the island	B.Dharavandhoo
Longitude and Latitude	73° 7'56.05"E, 5° 9'26.83"N
Area	0.65km^2
Population (Census, 2014)	839
Distance from Atoll Capital (B.Eydhafushi)	9km
Distance from Male'	122km
Harbour	Present
Island sewerage network	No
Water supply network	No
Other infrastructure	Airport

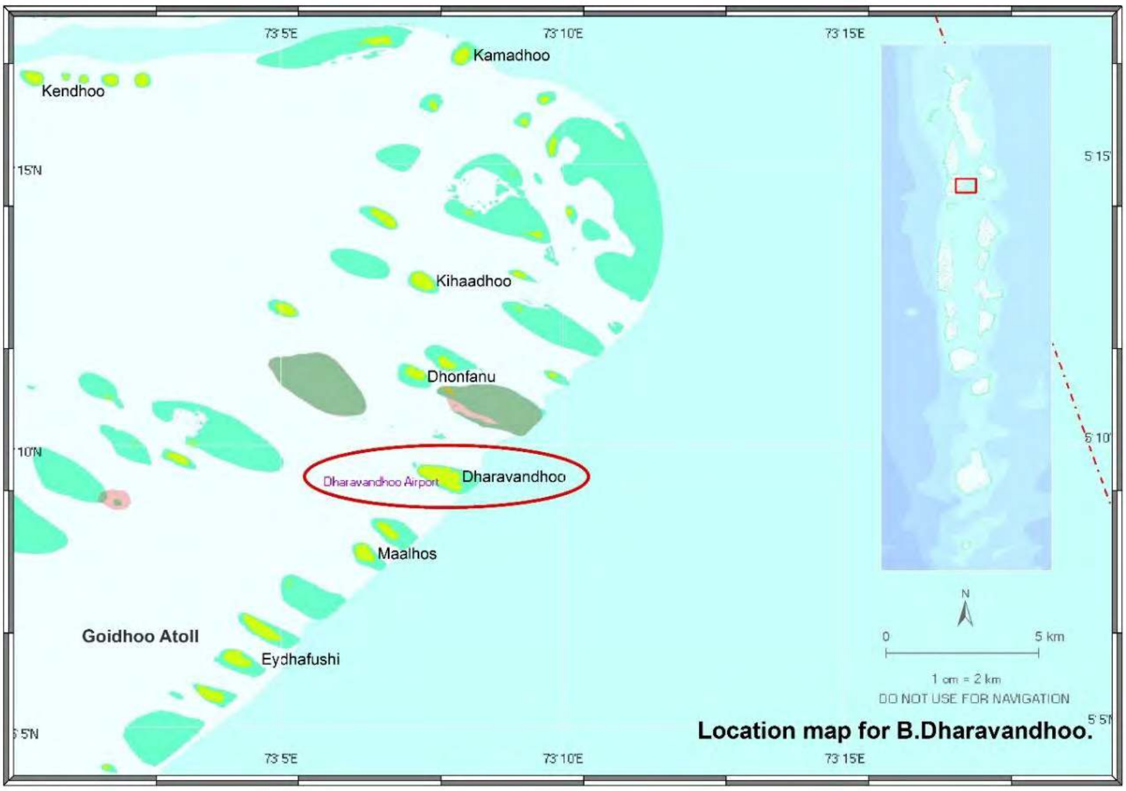


Figure 8.1: Location map for Dharavandhoo Island, Baa Atoll.

8.2 Geology and vegetation

Dharavandhoo has general characteristics similar to other islands of Maldives with an average elevation of 1.3 metres from mean sea level. Approximately one third of the southern half of the island is utilized for a domestic airport. Within the balance land, about 40% is forest which is located on the western side. The length of the island is approximately 1500 metres and width at the widest point is about 600 metres. The majority of vegetation in the forested area comprise of coconut trees. There are a number of other tropical native vegetation in this area, all of which are potential sources of organic matter input to the groundwater lens. There are no farms or farming activities undertaken anywhere in the island other than home gardens.

Based on the surveys undertaken, the groundwater table lies approximately 1.2 metres below the ground surface. The average water table is uniform throughout the island and no significant differences have been recorded from the surveying data. The freshwater lens is influenced by the tidal variation twice in 24 hours. These tidal variations are considered to be influenced by the change in in permeability levels of the soil in different parts of the island. The soil in the top layer of most roads are compacted due to vehicle movement whereas soil compaction is significantly less elsewhere.

8.3 Topography

Dharavandhoo has a topography that ranges from 0.48 meters to 1.74 meters above MSL with an average of 1.28 meters above MSL. Figure 8.2 shows the spot heights taken on Dharavandhoo Island.

Figure 8.2: Dharavandhoo Map with spot heights

8.4 Climate

Dharavandhoo experiences the typical two monsoons namely, north east monsoon from November to April and South-west monsoons from April to November. There are no specific wind and rainfall data available for Dharvandhoo as there are no weather monitoring stations on the island.

8.5 Demography

Dharavandhoo island has a registered population of 857 as per the latest census (2014) with a total of 739 locals and 118 foreigners. However, this figure is not accurate as the resident population has a total of 1156 people according to Island Council. Within the total population, there are slightly more males than females when the population as a whole is considered. However, when only the Maldivian population is considered, there is approximately equal number of males and females. The following table and graphs illustrate the various demographic breakdown of Dharavandhoo.

Table 8.2: Demographic Breakdown of Dharavandhoo Island

Atoll	locality	Resident population (Census, 2014)								
		Total			Maldivians			Foreigners		
		Both sexes	Male	Female	Both sexes	Male	Female	Both sexes	Male	Female
B	Dharavandhoo	857	489	368	739	380	359	118	109	9

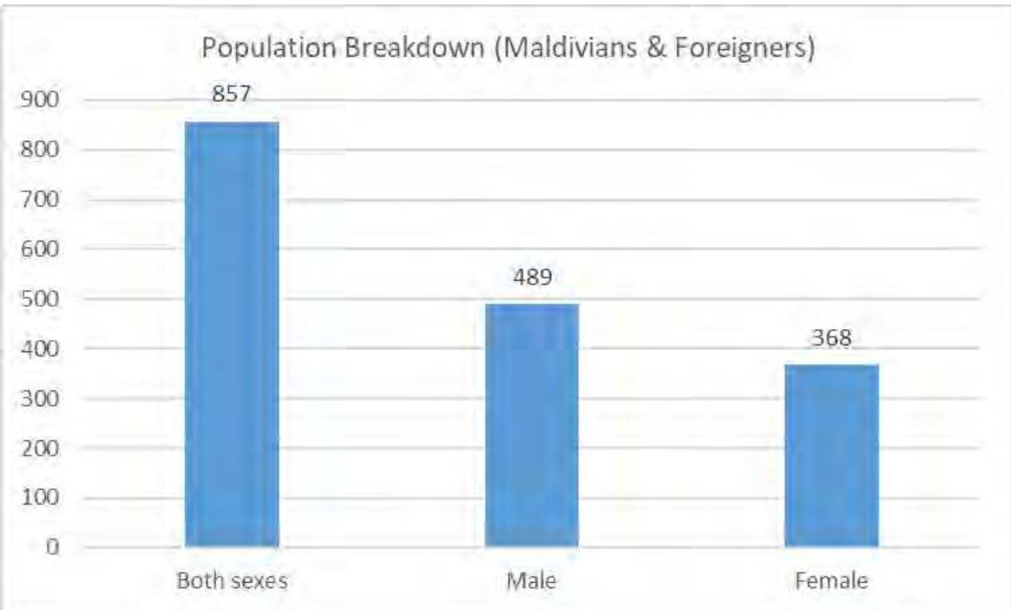


Figure 8.3: Population breakdown of Dharavandhoo (Maldivians & Foreigners)

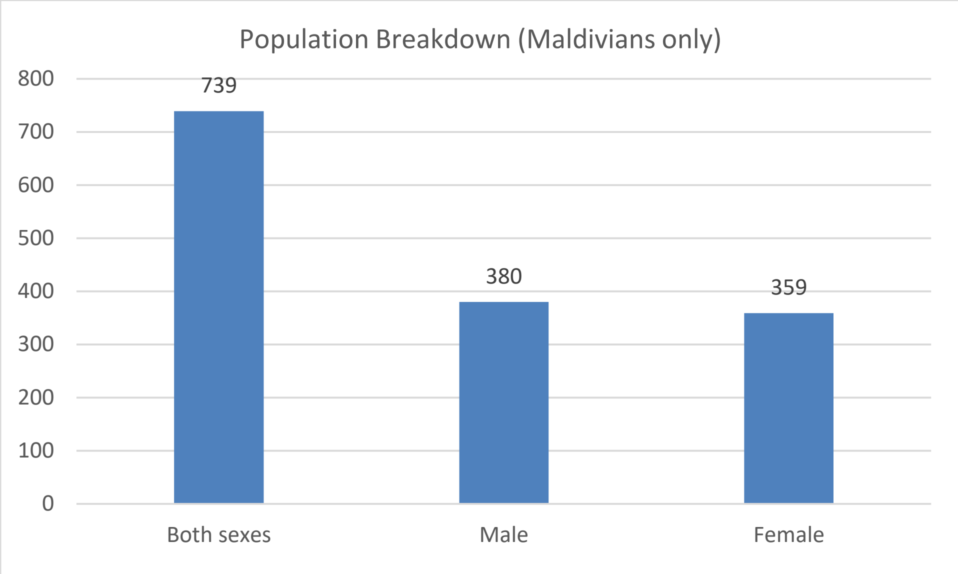


Figure 8.4: Population breakdown of Dharavandhoo (Maldivians)

8.6 Socio-economic condition

Dharavandhoo is one of the fastest growing islands in the atoll. With the opening of the domestic airport, the average income of the households have significantly been increased. The land prices in Dharavandhoo has been the most significantly impacted due to the close proximity to Hanifaru Bay, a world famous Manta and Whale shark aggregating site. The people of Dharavandhoo are engaged in a number of economic activities including tourism, trade and fishing. The island also has the highest concentration of guest houses in Baa Atoll, which brings a number of additional economic potential to the island such as establishment of diving and water sports, food outlets, shops and the development of transport network.

8.7 Existing water and sanitation situation

The island currently does not have an island wide sewerage system nor a piped drinking water system. Onsite sanitation is provided through the use of septic tanks. Each household has one or two septic tanks. 83% of households clean their septic tank by disposing septic waste to sea while the remaining 17% have not cleaned their septic tanks yet. On average, there is an approximate distance of 8.82 meters between septic tanks and nearest well.

According to the islanders, this is one of the biggest challenges faced by them and groundwater contamination is an island wide issue. The large airport runoff water from the runway is not collected nor utilized for any purpose. There is a large gutter system to collect the airport runoff with perforations to allow water infiltration. However, during heavy rain, this gets flooded and excess water is diverted to the sea. There are currently plans to setup a sewerage system and a piped drinking water network in the island.

The primary source of water for drinking and cooking is rainwater harvested from roofs.

8.8 Results

8.8.1 Water sources and water use

Based on domestic, commercial, institutional and industrial water usage, a total of 264,010 liters of groundwater are estimated to be used every day. Otherwise stated, 308 liters of groundwater are used per capita per day. The respective water use situations are detailed in the following sections.

8.8.1.1 Domestic water use situation

Based on the questionnaire to collect data on domestic water consumption, a summary of results are present in this section.

According to the survey, 95% of the households surveyed uses HDPE rainwater tanks as their main storage for water. A total of 70% households use rainwater for drinking and 95% use it for cooking. None of the surveyed houses use rainwater for bathing or washing.

None (0%) of the households use groundwater as drinking. Groundwater is mainly used for non-potable use in all the households surveyed.

The following table summarizes the groundwater and rainwater use data for Dharavandhoo Island.

Table 8.3: Groundwater and rainwater use data for Dharavandhoo

Rainwater	
Households with rainwater tanks	95%
Rainwater use for drinking	70%
Rainwater use for cooking	95%
Rainwater use for bathing and washing	0%
Groundwater	
Groundwater as drinking source	0%
Groundwater for cooking	5%
Groundwater for non-potable use	100%
Total number of household wells surveyed	20 (10%)
Percentage of wells surveyed fitted with pumps	100%

Based on the survey questionnaire, average daily water demand per capita for domestic purposes has been estimated based on the average amount of water used per person for showering, toilet flushing, laundry and gardening. This data is shown in table 8.4. The total domestic water use is estimated to be 252 liters per capita per day.

Table 8.4: Domestic Water Usage in Dharavandhoo

Shower/ Liters per capita per day	Toilet/ Liters per capita per day	Laundry/ Liters per capita per day	Gardening/ Liters per capita per day	**Total/ Liters per capita per day**
94	34	46	78	**252**

8.8.1.2 Commercial water use situation

Based on the questionnaire to collect data on commercial water consumption, a summary of results are present in this section. A total of 2 restaurants and 11 guesthouses were surveyed.

For the guesthouses, the main use of groundwater was for showers, toilet flushing, gardening and dish washing for those guesthouses which contained restaurants. The following table presents a summary. A total of 38,889 liters of groundwater are used daily by 11 guesthouses in Dharavandhoo.

Table 8.5: Water Usage in Guesthouses in Dharavandhoo Island

Name of Guesthouse	Number of rooms	Average occupancy throughout the year	Total Volume of water per day (Liters)	Total Volume of water per guest per day (Liters)
Kihaa Beach	20	>50%	6961	249
Dharavandhoo Stay	5	>50%	3481	249
Hiyaa Ilaa	4	Fully occupied for the majority of the year	2766	229
Aveyla Manta Village	16	>80%	6689	249
LVIS Blancura Hotel	7	>80%	2828	249
Biosphere Inn	3	>80%	1660	304
Reposo Maldives	6	>80%	2919	269
Star Tree	12	>80%	4848	249
Blue World Dharavandhoo	4	>80%	2216	249
Manta Retreat	6	>80%	2724	249
Hanifaru Transit Inn	4	>50%	1797	249
Total:			**38,889**	

For the restaurants, the main use of groundwater was for dishwashing and toilet use. A total of 2 restaurants were surveyed and from this data, the total groundwater consumption for the 5 restaurants on this island was estimated to be 2802 liters per day.

8.8.1.3 Institutional water use situation

Based on the questionnaire to collect data on institutional water consumption, a summary of results are present in this section. Four institutions were surveyed for this study namely the island powerhouse, council office, school and health center. Groundwater in the institutions in Dharavandhoo Island are mainly used for gardening, mopping floors and flushing toilets. A total of approximately 5957 liters of groundwater are estimated to be used per day by the institutions. Therefore, a total of approximately 6.95 liters of groundwater are estimated to be used per capita per day by the institutions of Dharavandhoo Island.

Table 8.6: Water Usage in Institutions in Dharavandhoo

	Water Flushed (Liters per day)	Gardening (Liters per day)	Mopping (Liters per day)	Total Water Usage (Liters per day)	Total Water Usage (Liters per day)	Institutional Groundwater Usage (Liters per capita per day)
Powerhouse	79	231	0	310	5957	6.95
Council Office	47	540	0	587		
School	1662	3240	40	4942		
Health Center	117	0	0	117		

8.8.2 Groundwater quality

Groundwater quality measurements were made at selected wells in Dharavandhoo for both physical and microbiological testing.

The following table Table 8.7: Summary of groundwater quality tests from Dharavandhoo, April 2019 summarizes the water quality results.

Table 8.7: Summary of groundwater quality tests from Dharavandhoo, April 2019

Sample No	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
gw1	1034.5	609	7.18	0.35	2.12	30.5	0.46	78.5	1.22	0.15		
gw2	2094.2	1226	7.47	4.37	2.11	30.8	0.95	19.6	2.15	0.13		
gw3	1300.3	756	7.56	0.52	1.27	31.2	0.57	10.5	3.48	0.52	2420	211
gw4	1288.7	739	7.09	2.55	1.3	32.0	0.56	11.1	4.46	0.09	356	75
gw5	772.9	458	7.22	0.75	1.29	30.2	0.34	10.2	0.71	0.11		
gw6	1026.1	612	7.19	0.49	2.04	29.7	0.46	46.0	1.22	0.13		
gw7	1170.6	697	7.24	0.76	1.67	29.8	0.53	41.0	1.4	1.29		
gw8	712.6	425	8.05	0.35	5.04	29.7	0.31	12.6	0.74	0.07		
gw9	770.1	458	7.47	0.00	2.48	29.9	0.34	21.9	0.86	0.05	687	344
gw10	621.3	362	7.63	0.56	3.6	31.1	0.27	3.8	0.36	0.15		
gw11	902.6	500	7.29	0.51	1.22	34.1	0.37	39.0	0.68	0.42		
gw12	678.1	391	7.78	0.96	5.91	31.7	0.29	22.2	0.41	<0.05		
gw13	739.4	428	7.69	0.96	4.69	31.4	0.29	9.8	0.9	0.05	>2420	166

Sample No	Odour	Physical Appearance
gw1	Yes	Clear
gw2	Yes	Clear with particles
gw3	Yes	Clear with particles
gw4	Yes	Clear with particles
gw5	No	Clear with particles
gw6	Yes	Clear with particles
gw7	Yes	Clear with particles
gw8	No	Clear with particles
gw9	Yes	Clear
gw10	No	Clear with particles
gw11	Yes	Clear
gw12	Yes	Clear with particles
gw13	No	Cloudy

	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)
WHO Standards	Suggested maximum limit of freshwater for potable purposes = 1500 µS/cm Suggested maximum limit of freshwater for non-potable purposes = 2500 µS/cm	-	-	-	-	-

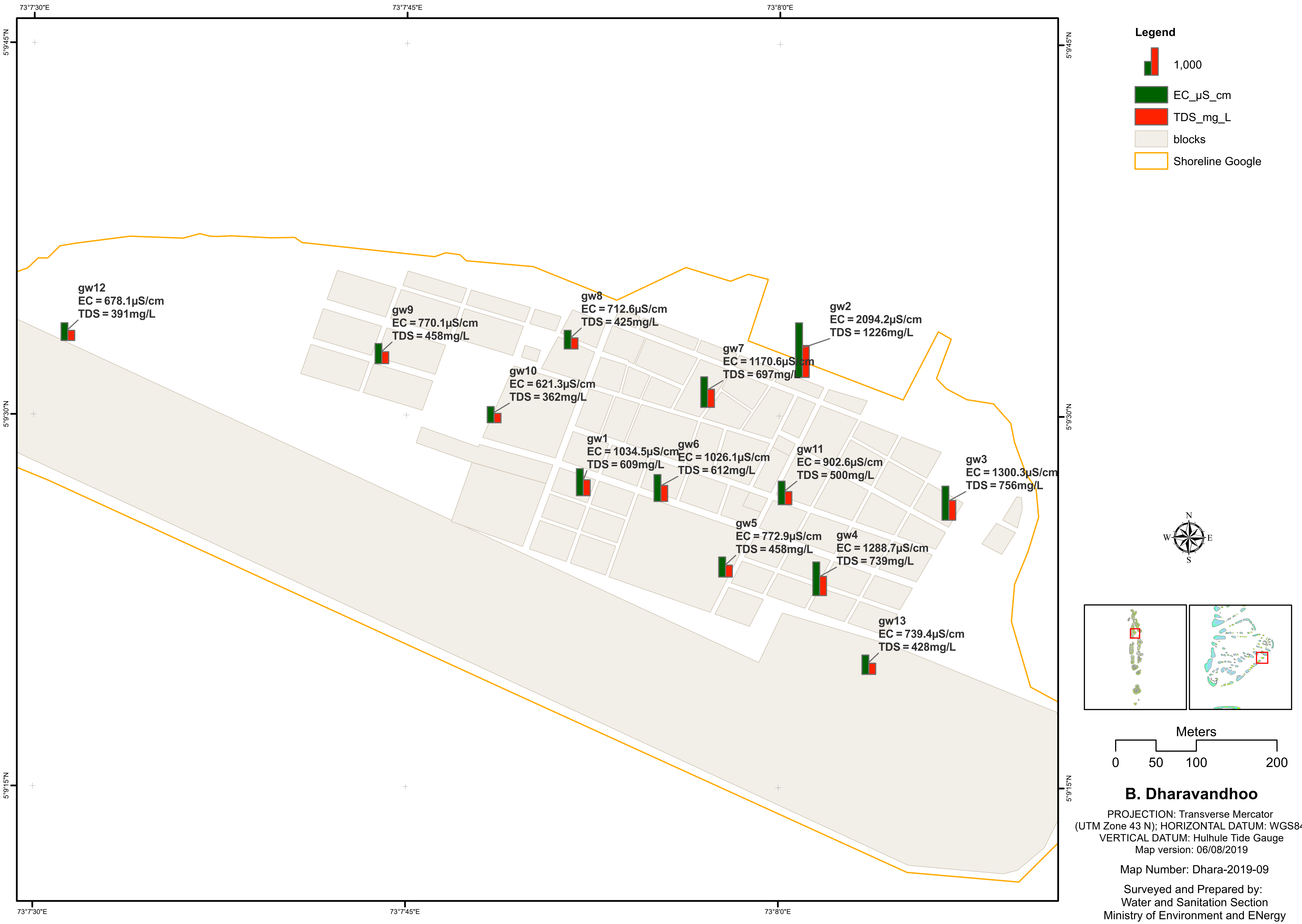
	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
WHO Standards	-	Guideline Value = 50 mg/L-NO3	Natural Level of Ammonia < 0.2 mg/L Threshold odour concentration = 1.5 mg/L Taste threshold = 35 mg/L	-	-	-

Figure 8.5: Location of groundwater sampling points in Dharavandhoo Island

Based on the full results and the summary shown in Table 3.7, the following can be summarized for Dharavandhoo:

- In terms of electrical conductivity (EC) readings of groundwater, Dharavandhoo island's groundwater is very fresh (It is noted here that these readings were taken in April, which is the dry season and the hottest month of the year). Hence, the EC values in the wet season is expected to be much less.
- The EC of the groundwater is generally low, with an average of 1008.57 μS/cm which is below an acceptable limit for potable water of 1,500 μS/cm (refer section 2.2). The electrical conductivity readings range from 621.3 to 2094.2 μS/cm. Only one sample (gw2) from 13 samples (7.69%) with an EC of 2094.2 μS/cm fall within the acceptable limit for potable water. Sample gw2 has a comparatively high EC due to its close proximity to the shoreline. All the samples are below the acceptable limit for freshwater for non-potable uses (refer section 2.2).
- Total Dissolved Solids recorded ranged from 362 mg/L to 1226 mg/L with an average of 589.31 mg/L.
- The pH of groundwater ranged from 7.09 to 8.05 with an average of 7.45.
- Turbidity ranged from the lowest of 0 NTU to 4.37 NTU with an average of 1.01 NTU. As a guide, "crystal-clear" water has a turbidity below 1 NTU, and water becomes visibly cloudy at 4 NTU and above.
- Dissolved oxygen levels ranged from 1.22 to 5.91 mg/L. The average value was 2.67 mg/L.
- The salinity of groundwater ranged from 0.27 PSU to 0.95 PSU with an average of 0.44 PSU. Salinity is expressed in Practical Salinity Units, PSU which is equivalent to PPT.
- The average Nitrate concentration was 25.1 mg/L and therefore does not exceed the WHO guideline limit of 50 mg/L. 1 of the 13 tested water samples (7.7%) exceeded this limit of 50 mg/L. The Nitrate concentrations ranged from 8.5 mg/L to 78.5 mg/L.
- Ammonia concentrations were generally low. The average ammonia concentration was 1.43 mg/L. This is within the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. Only two (2) tested water samples exceeded this limit (3.48 and 4.46 mg/L.) Natural concentration levels of ammonia are generally below 0.2 mg/L (WHO, 1993) and no tests showed concentrations below this level. There is no apparent correlation between increasing levels of ammonia and other nutrients.
- Phosphate concentrations were moderate. All values except one were within the range 0.05-1.29 mg/L with an average of 0.26 mg/L. One phosphate value (gw12) was below 0.05 mg/L. There is no WHO drinking water guideline value for phosphate. However, it would normally be expected that phosphate concentrations in groundwater are less than 0.1 mg/L, where there are no impacts from human wastewater (e.g. effluent from septic tanks and 'greywater' from kitchens and bathrooms). Only 3 of 13 samples tested were below 0.1 mg/L.
- Total coliform levels were also found to be significant and ranged from lowest count of 356 MPN/100 mL to the highest count of more than 2420 MPN/100 mL, with an average count of 1470.75 MPN/100 mL. Faecal Coliform levels were found to be less significant and ranged from lowest count of 75 MPN/100mL to the highest count of 344 MPN/100mL. From all the islands surveyed, groundwater from Dharavandhoo showed the lowest average faecal coliform levels. However, the groundwater layer is contaminated with effluent from septic tanks.

In conclusion, Dharavandhoo Island contains groundwater with generally low Electrical Conductivity with a lower average than WHO guidance value for potable and non-potable water and low TDS. Nitrate concentration was lower than WHO maximum guidance value, average Ammonia concentration lower than expected in natural, undisturbed groundwater but average Phosphate concentration higher than expected in natural, undisturbed groundwater. In terms of microbiological contamination, an island wide contamination is observed. Additionally, the following pages contain maps which show the main physiochemical parameters displayed on map of the island.

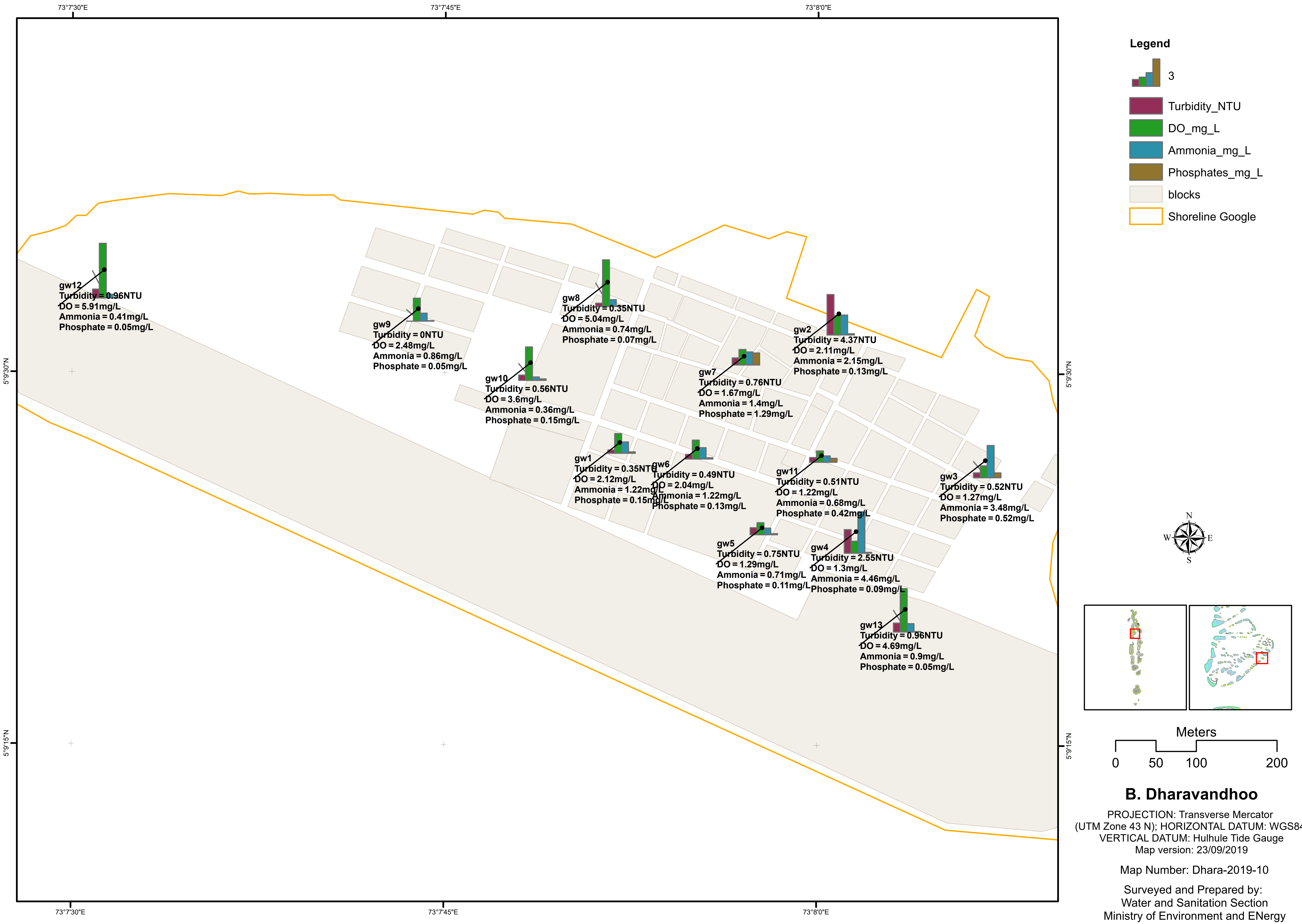


B. Dharavandhoo

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 06/08/2019

Map Number: Dhara-2019-09

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy



B. Dharavandhoo

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 23/09/2019

Map Number: Dhara-2019-10

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

8.8.3 Geophysical survey

The Resistivity tests were carried out in the locations as outlined in Figure 8.6 below.

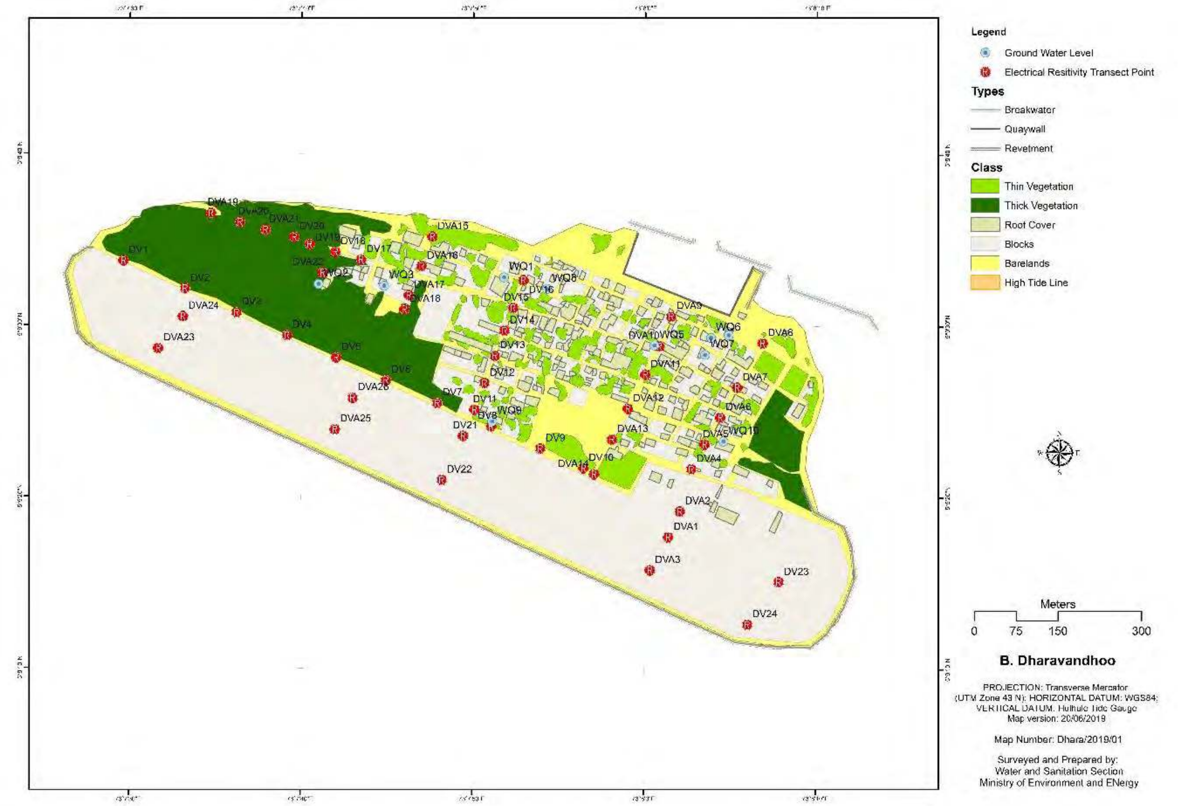


Figure 8.6: Location of ER points in Dharavandhoo Island

8.8.4 Aerial surveys

Due to the airport in Dharavandhoo island, aerial survey could not be carried out. However recent terrestrial photograph was used to extract a multiple dataset consisting of roof cover, thick vegetation area, thin vegetation area, bare lands and shorelines. This data is shown in Figure 3.6 and the Table 3.8 shows the different area distribution.

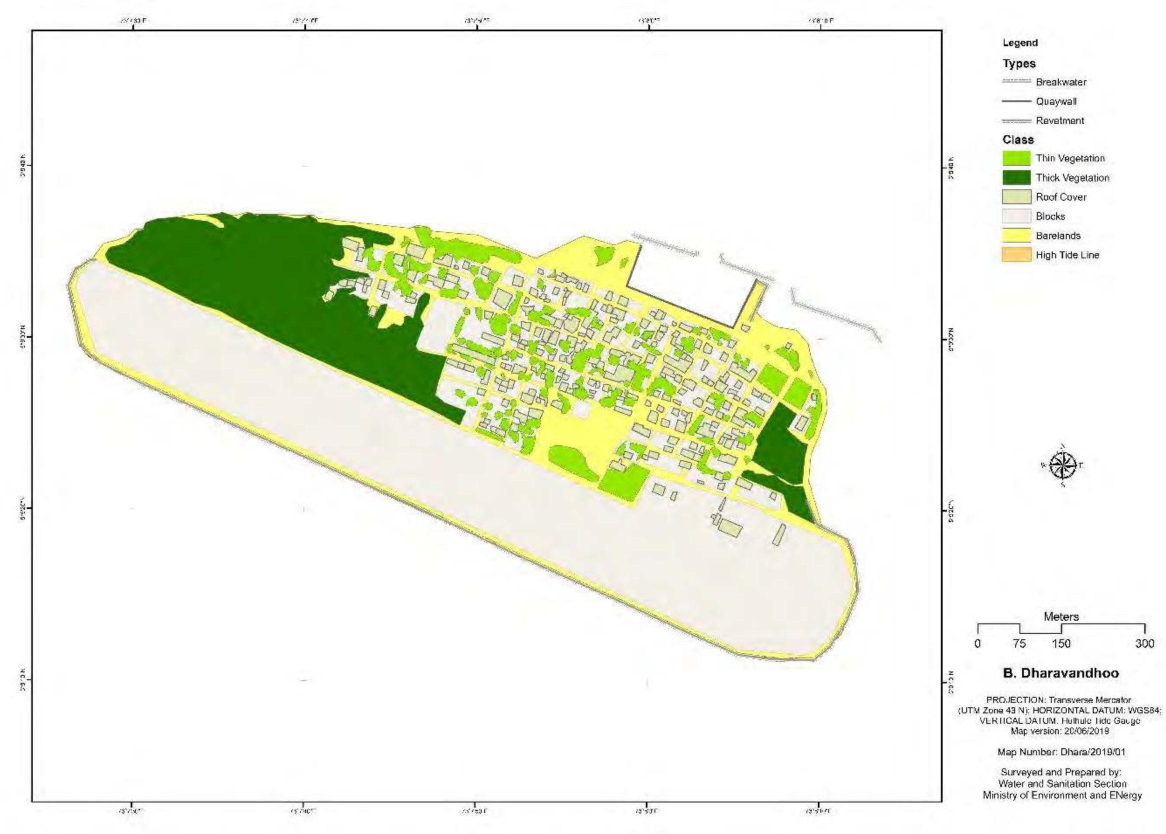


Figure 8.7: Area Distribution in Dharavandhoo Island

Table 8.8: Area Distribution in Dharavandhoo

	Area (Square Meters)	% of total area
Roof cover	43,594	6.77%
Vegetation (Thick)	109,896	16.8%
Vegetation (Light)	49,151	7.5%
Bare lands	451,954	69.0%
Farm Lands	-	-
Wetlands (Inland)	-	-

8.8.5 Water Demand

The only source of natural water is rainwater collected from the rooftops of households and institutions and groundwater extracted from shallow wells. The runoff water from the domestic airport runway is not usable as there is no mechanism for its collection and treatment.

8.8.6 Freshwater lens

Based on the ER survey the depth to groundwater level and the freshwater-saline water interface was determined for a set of transverse transects as shown in Figure 8.8. Plots in the Figure 8.9 shows the cross sections of each transect line. The dotted lines in the plots indicating a simple interpolation of levels to mean sea level in the island boundaries. These cross sections were used to identify the spatial extent and volume of the freshwater lens while they were also useful in deriving implications on the stress level of the aquifer based on the observed, localized drawdown effect in the groundwater table and up-coning in the freshwater-saline interface, defining the upper and lower boundaries of the freshwater lens in an island.

The Table 8.9 illustrate the freshwater volume calculation for the island. The area covered by freshwater for each transect line has been calculated. To estimate the total volume of available freshwater lens, the cross-section area of freshwater extent under each transect was multiplied by the distance between two transects. The sum of these lengths represents the cumulative length of the island and thus, the above estimation could represent the total volume of the freshwater lens sandwiched between the groundwater table on top and freshwater-saline water interface in the bottom. Then the actual groundwater storage within this freshwater lens was calculated by multiplying the estimated total lens volume with the porosity of the topsoil in the island.

This estimation represents the total available freshwater volume within the freshwater lens at any given time (time of the measurement). The measurements were carried out towards the end of the dry period and the freshwater lens is presumed to be undergoing a 'stressed' condition due to continued groundwater abstractions despite reduced recharge in the dry period. Falkland (1994) method can be used to estimate the freshwater lend thickness under salient conditions using average annual rainfall, length and width of the island, and the comparison was used as a measure of stress level of the freshwater lens.

Table 8.9: Freshwater Volume Calculation for Dharavandhoo Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
1	Start		0		0	0			
			14		0	0			
	DV24	ER	33	0.999	0.1799	-2.6601	27		
	DV23	ER	126	1.112	0.18	-2.46	255		
			264		0	0	183		
	End		278		0	0	0		
	Total						464	117	54,521
2	Start		0		0	0			
			28		0	0			
	DVA3	ER	55	1.181	0.0703	-2.3197	32		
	DVA1	ER	123	1.096	0.0496	-3.6504	207		
	DVA2	ER	174	1.18	0.19	-3.48	188		
	DVA4	ER	250	0.683	-0.2195	-3.1095	249		
	DVA5	ER	300	0.632	-0.3396	-2.4696	126		
	DVA6	ER	357	0.586	-0.44	-3.28	142		
	DVA7	ER	418	0.479	-0.4204	-3.3904	176		
	DVA8	ER	509	1.052	0.1201	-2.0999	237		

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
			536		0	0	30		
	End		564		0	0	0		
	Total						1387	223	308,963
	Start		0		0	0			
			26		0	0			
	DVA14	ER	168	1.321	0.2296	-4.2804	319		
	DVA13	ER	239	1.617	0.3804	-3.8496	313		
	DVA12	ER	302	1.372	0.3196	-4.8604	295		
3	DVA11	ER	370	1.442	0.2299	-3.1001	290		
	DVA10	ER	427	1.238	0.19	-1.58	146		
	DVA9	ER	484	1.211	0.1002	-1.6398	100		
			499		0	0	13		
	End		525		0	0	0		
	Total						1476	196	288,739
	Start		0		0	0			
			25		0	0			
	DV22	ER	47	0.986	0.2202	-2.4398	29		
	DV21	ER	135	1.219	0.2204	-3.1096	263		
	DV11	ER	186	1.197	0.1297	-4.7503	209		
	DV12	ER	237	1.2	0.3003	-3.6397	225		
4	DV13	ER	290	1.344	0.2396	-4.0504	216		
	DV14	ER	338	1.377	0.3099	-3.6901	199		
	DV15	ER	381	1.415	0.3801	-3.5999	173		
	DV16	ER	434	1.507	0.4097	-3.0403	197		
			484		0	0	86		
	End		510		0	0	0		
	Total						1598	206	329,331
	Start		0		0	0			
			24		0	0			
	DVA25	ER	50	1.085	0.1698	-1.4902	22		
	DVA26	ER	116	0.943	0.0804	-1.9496	121		
	DVA18	ER	296	1.74	0.4401	-2.5599	454		
5	DVA17	ER	325	1.367	0.3896	-3.3704	96		
	DVA16	ER	381	1.461	0.3703	-3.2297	206		
	DVA15	ER	436	1.6	0.4553	-0.7847	135		
			448		0	0	7		
	End		472		0	0	0		
	Total						1042	281	293,207
6	Start		0		0	0			
			17		0	0			

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
	DVA23	ER	49	1.144	0.1405	-1.9195	32		
	DVA24	ER	122	1.045	0.1601	-2.1399	160		
	DV2	ER	166	1.213	0.1799	-2.1021	100		
	DVA19	ER	313	1.337	0.2898	-0.8502	252		
			326		0	0	7		
	End		343		0	0	0		
	Total						552	281	154,866
									1,429,627

Table 8.10: ER Survey Results of Longitudinal Sections for Dharavandhoo Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)
7	Start		0		0	0
			75		0	0
	DV1	ER	64	1.002	0.1197	0.1197
	DV2	ER	186	1.213	0.1799	-2.1021
	DV3	ER	289	1.154	0.2202	-2.6298
	DV4	ER	387	1.135	0.1902	-2.8898
	DV5	ER	483	1.327	0.2901	-3.1199
	DV6	ER	583	1.121	0.1003	-3.4897
	DV7	ER	682	1.293	0.2198	-4.2802
	DV8	ER	790	1.102	0.2602	-4.4798
	DV9	ER	887	1.017	0.1404	-3.9996
	DV10	ER	969	1.241	0.1996	-4.1204
	DVA14	ER	991	1.321	0.2296	-4.2804
	DVA2	ER	1162	1.18	0.19	-3.48
	DVA23	ER	1370	1.144	0.1405	-1.9195
			1422		0	0
	End		1497		0	0
8	Start		0		0	0
			60		0	0
	DVA19	ER	49	1.337	0.2898	-0.8502
	DVA20	ER	103	1.34	0.4222	-2.0378
	DVA21	ER	151	1.311	0.3235	-2.1265
	DV20	ER	205	1.312	0.3066	-2.7134

	DV19	ER	234	1.6	0.5262	-2.5738
	DV18	ER	282	1.306	0.3103	-3.1697
	DV17	ER	331	1.317	0.2503	-3.2697
	DVA17	ER	428	1.367	0.3896	-3.3704
	DV14	ER	616	1.377	0.3099	-3.6901
	DVA11	ER	881	1.442	0.2299	-3.1001
	DVA7	ER	1043	0.479	-0.4204	-3.3904
			1137		0	0
	End		1196		0	0

Volume of lens = 1,429,627m^3

Groundwater Storage = Porosity (20%) x Lens volume (m^3) = 285,925m^3

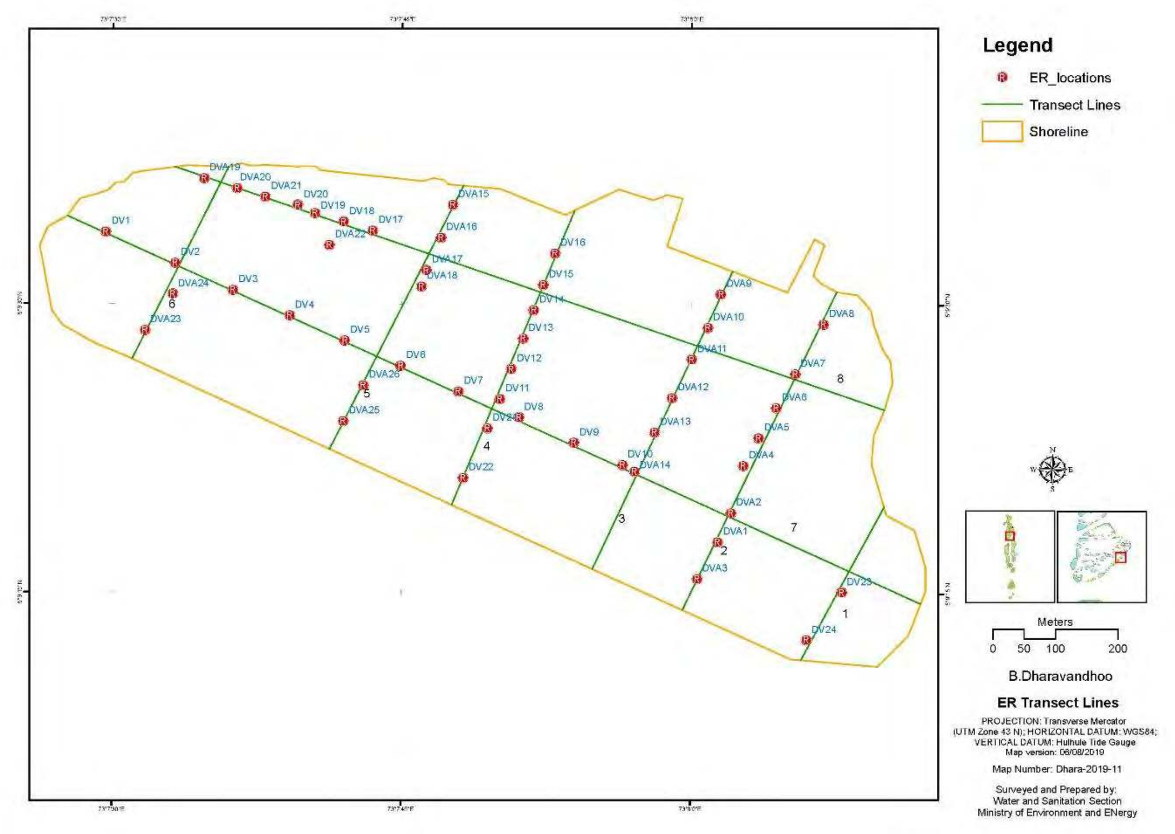
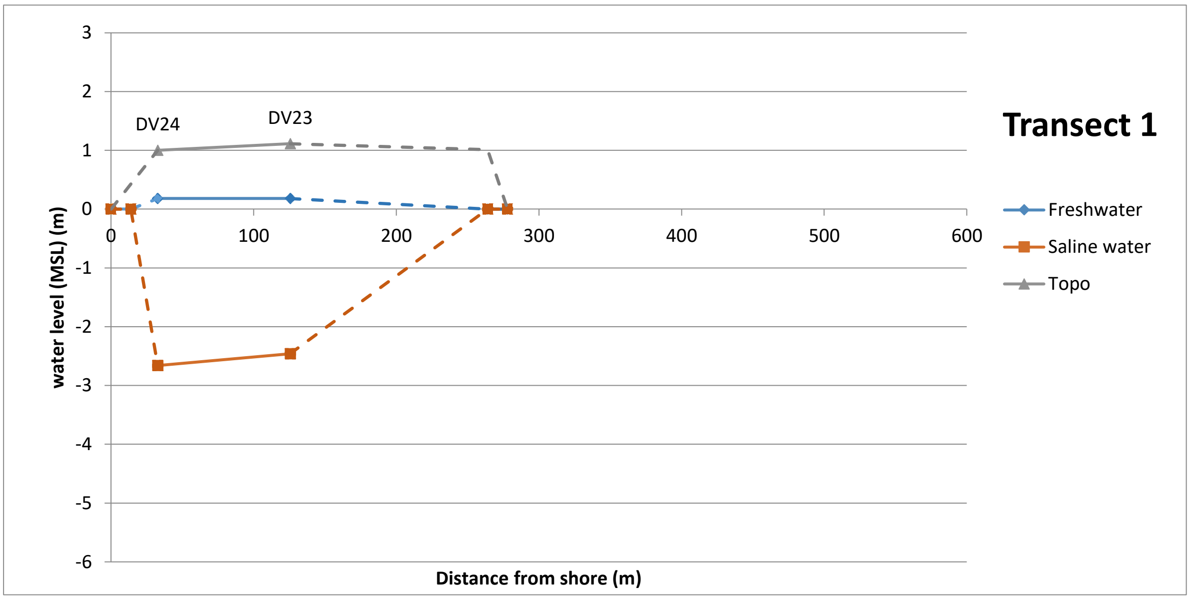
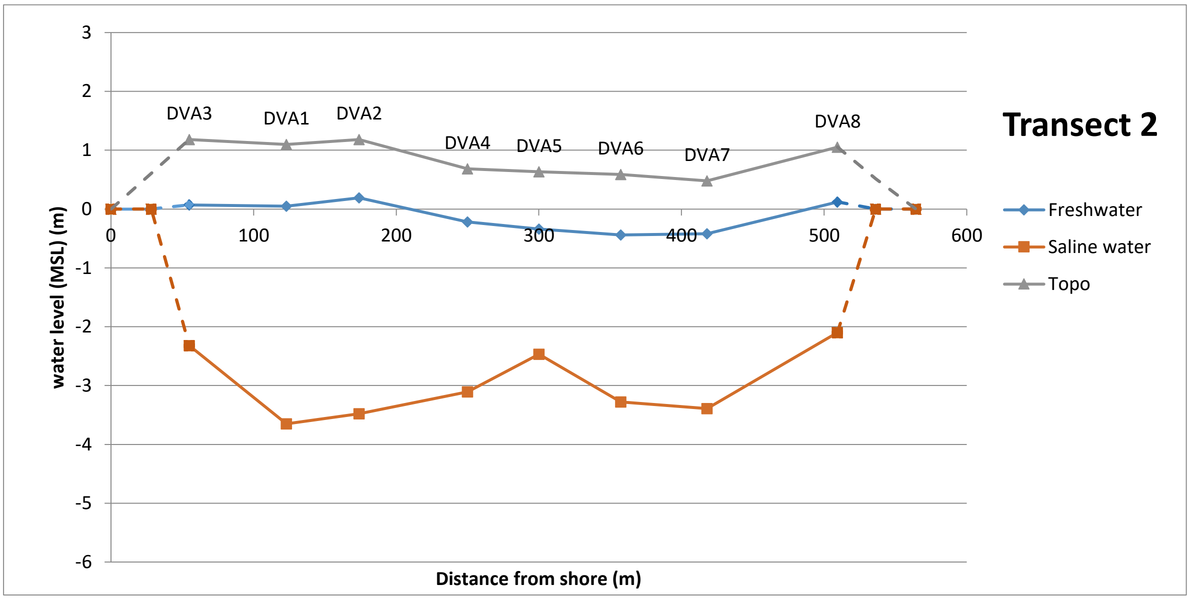
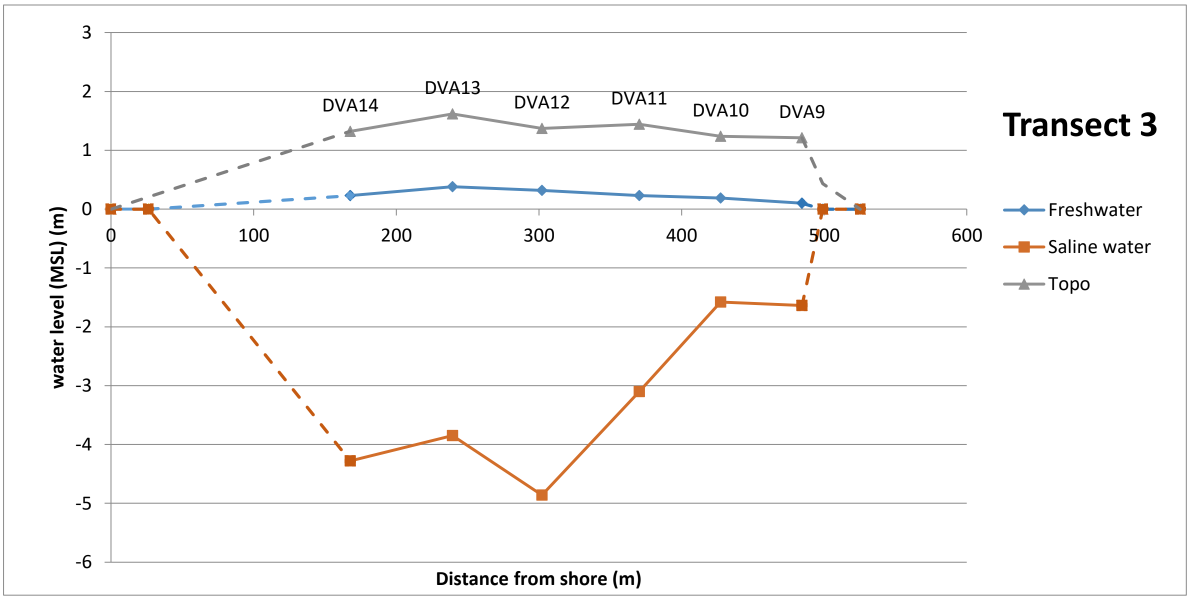
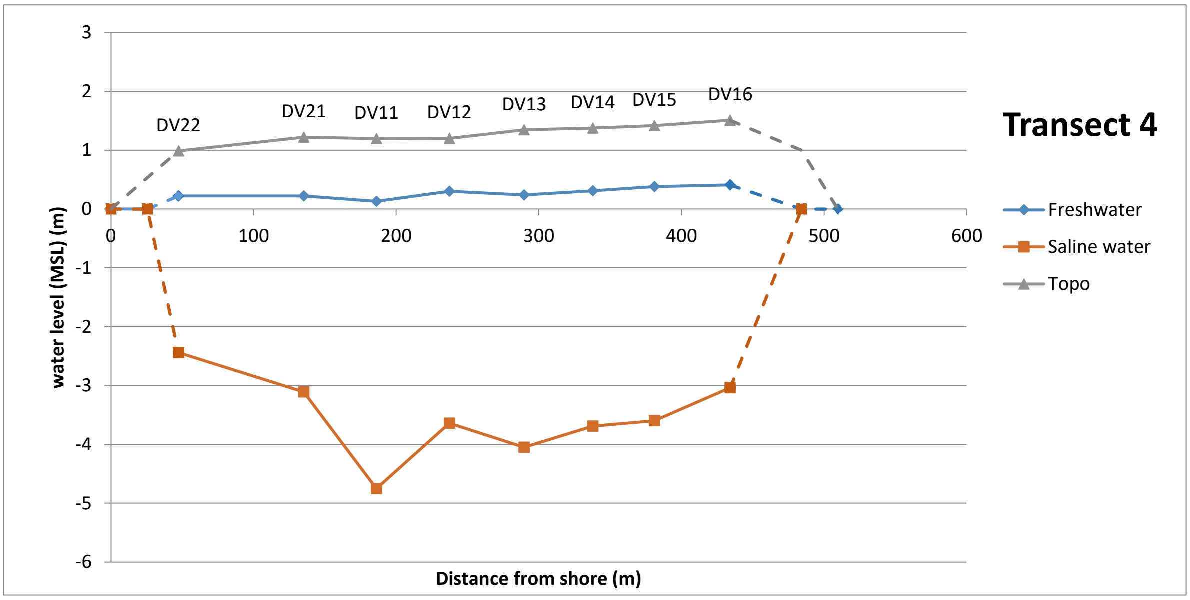


Figure 8.8: ER transect lines in Dharavandhoo Island

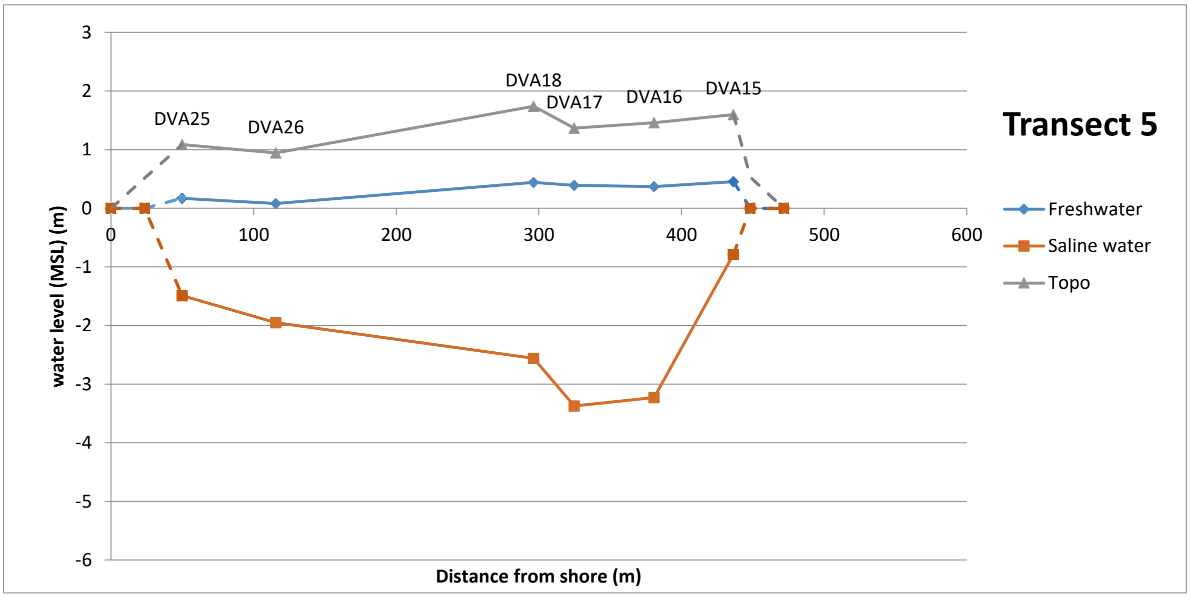

Transect 1
water level (MSL) (m)
Distance from shore (m)
DV24
DV23
Freshwater
Saline water
Topo


Transect 2
water level (MSL) (m)
Distance from shore (m)
DVA3
DVA1
DVA2
DVA4
DVA5
DVA6
DVA7
DVA8
Freshwater
Saline water
Topo

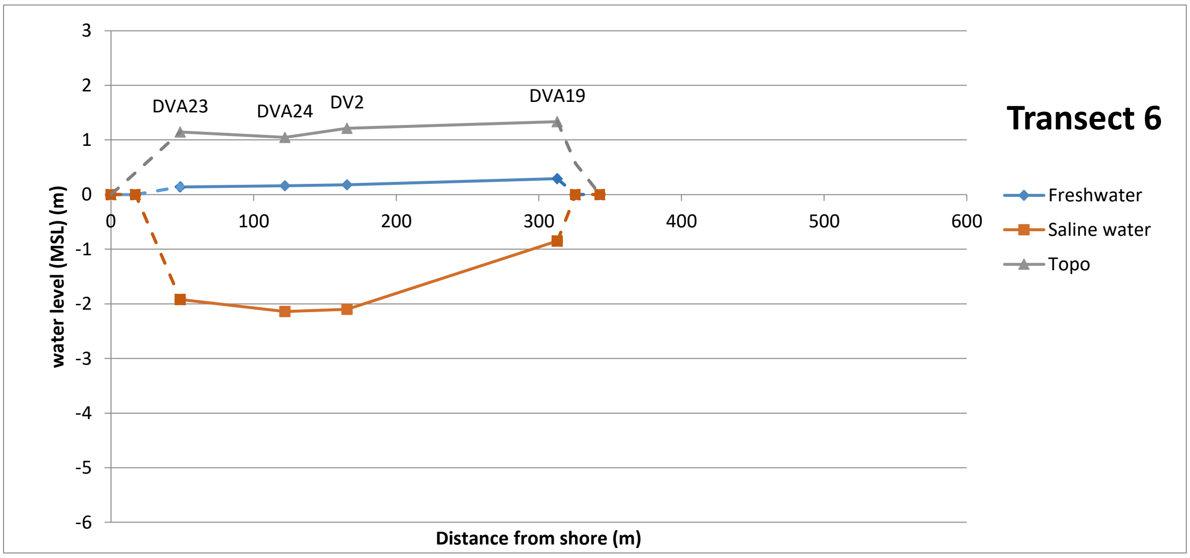

Transect 3
water level (MSL) (m)
Distance from shore (m)
DVA14
DVA13
DVA12
DVA11
DVA10
DVA9
Freshwater
Saline water
Topo



Transcect 4
DV22
DV21
DV11
DV12
DV13
DV14
DV15
DV16
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600



Transect 5
DVA25
DVA26
DVA18
DVA17
DVA16
DVA15
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600



Transect 6
DVA23
DVA24
DV2
DVA19
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600

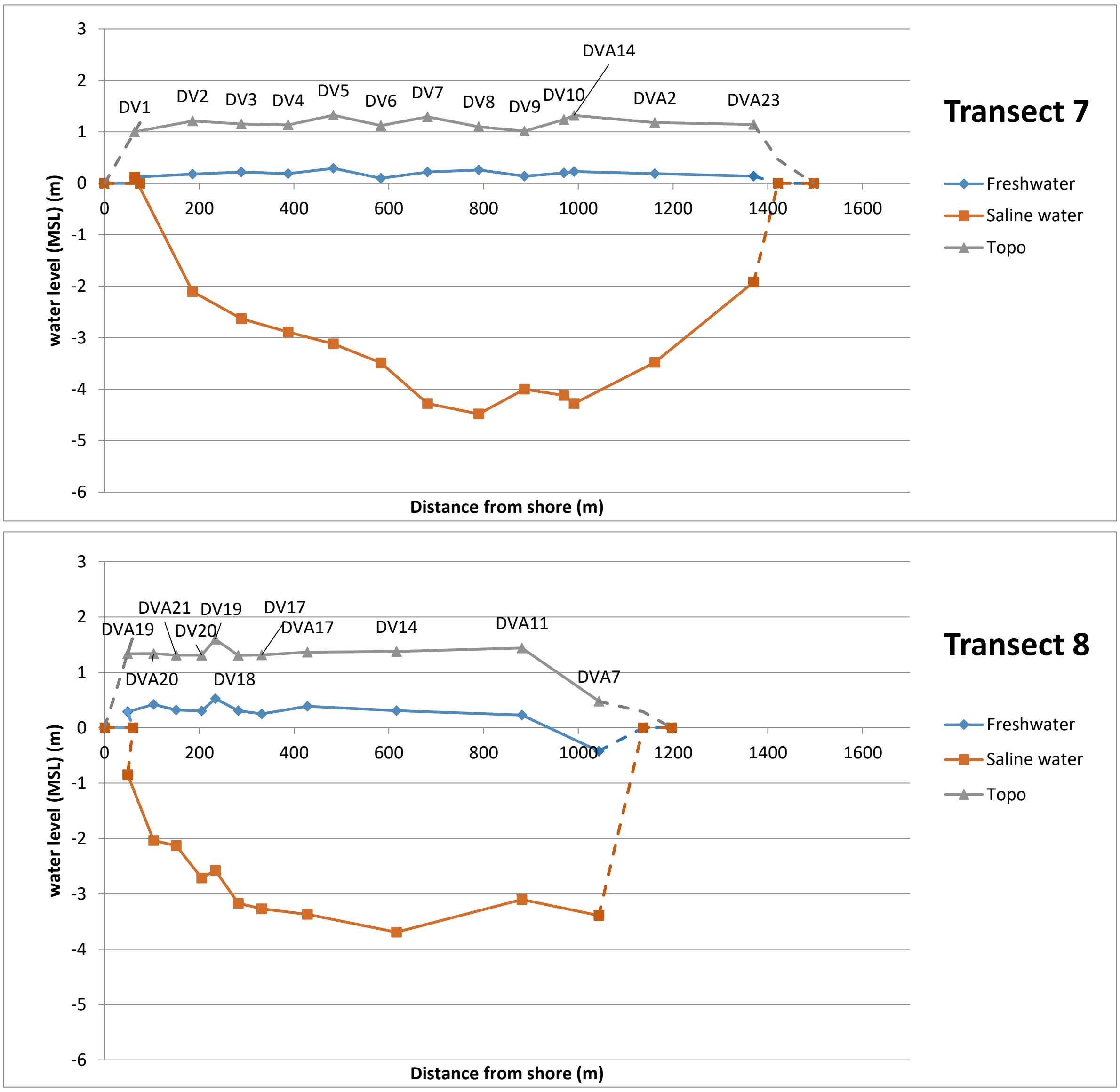


Figure 8.9: Cross sections of transect lines in Dharavandhoo Island

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented in the following pages.

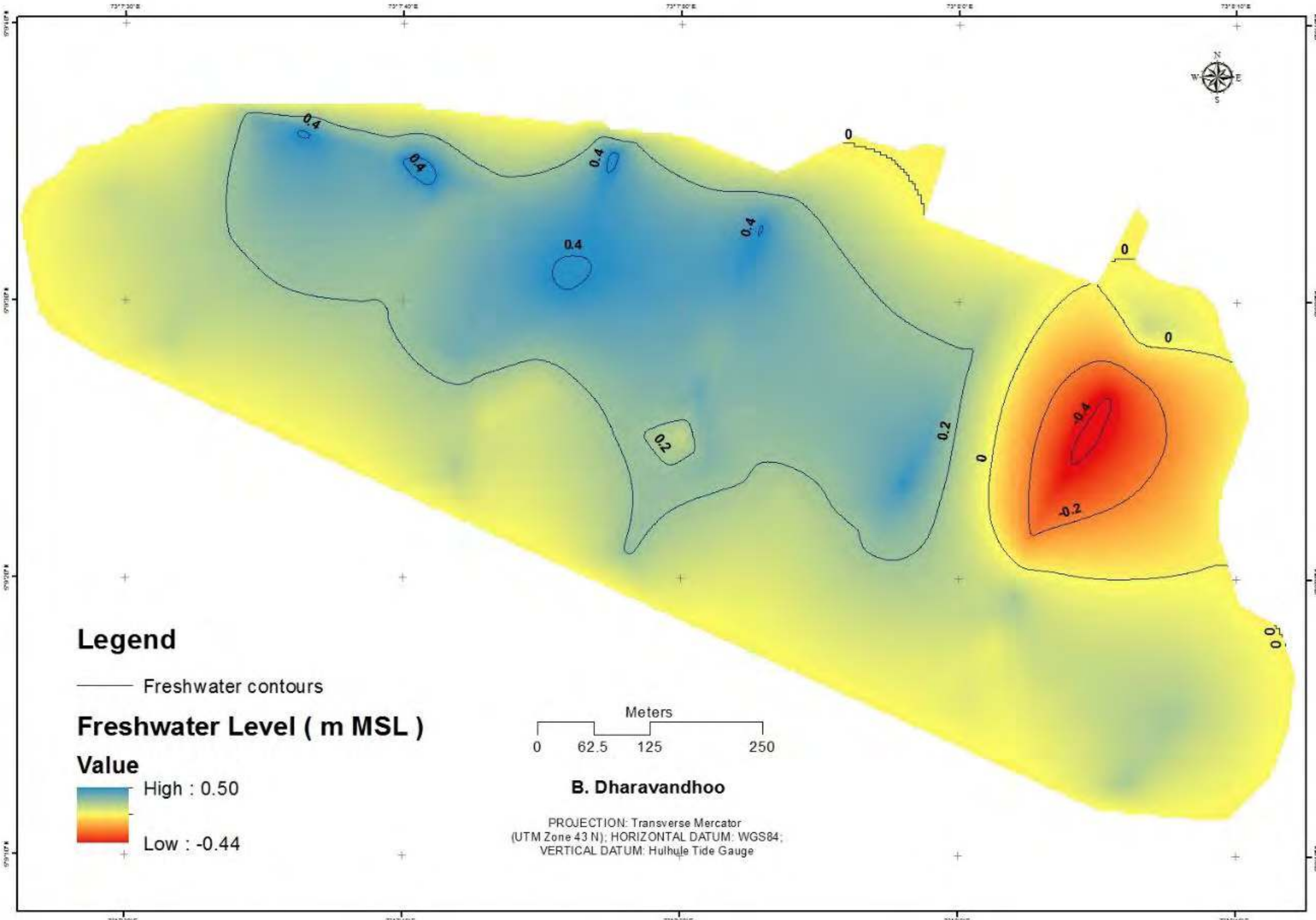


Figure 8.10: Freshwater Level in Dharavandhoo Island

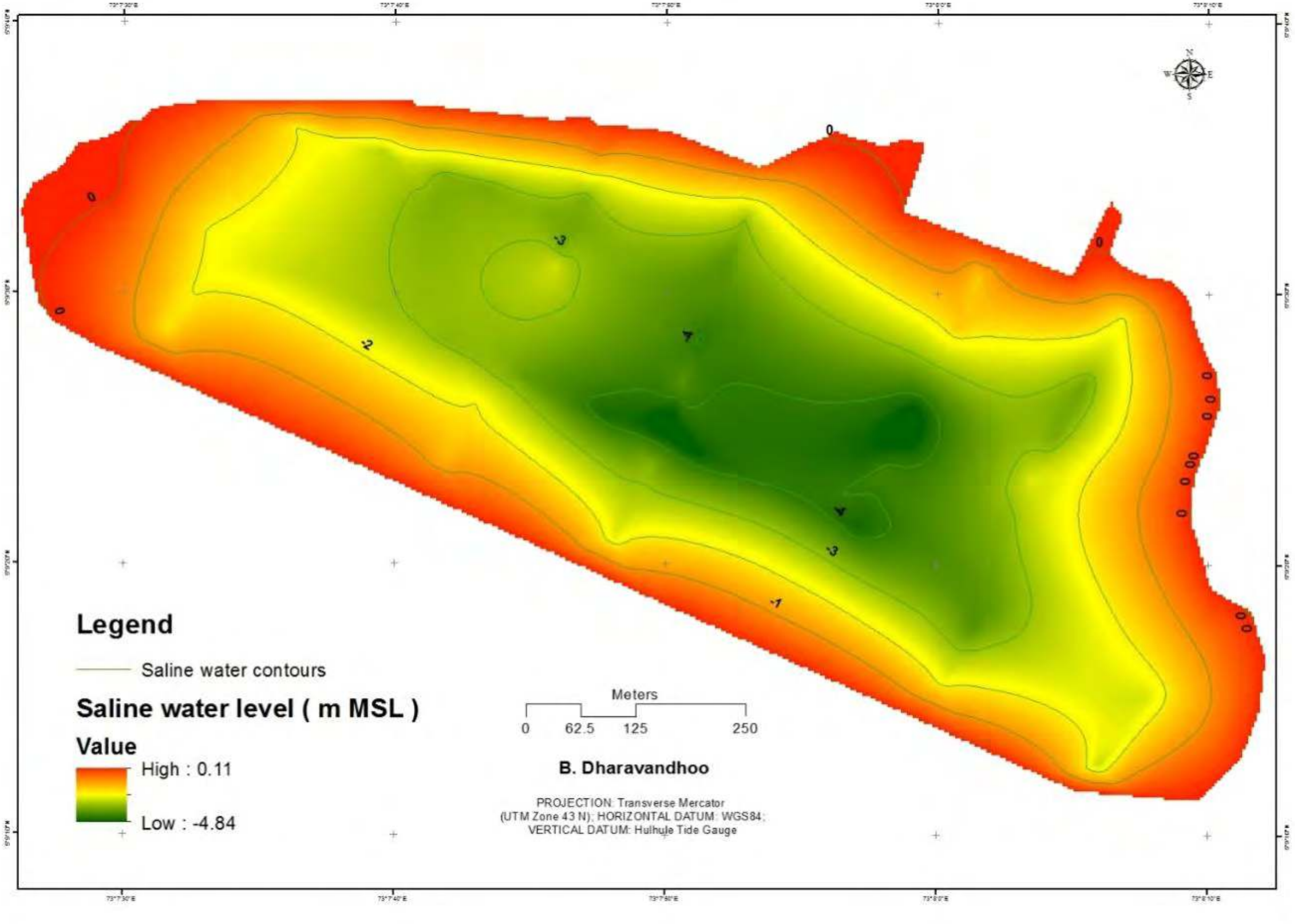


Figure 8.11: Saline water Level in Dharavandhoo Island

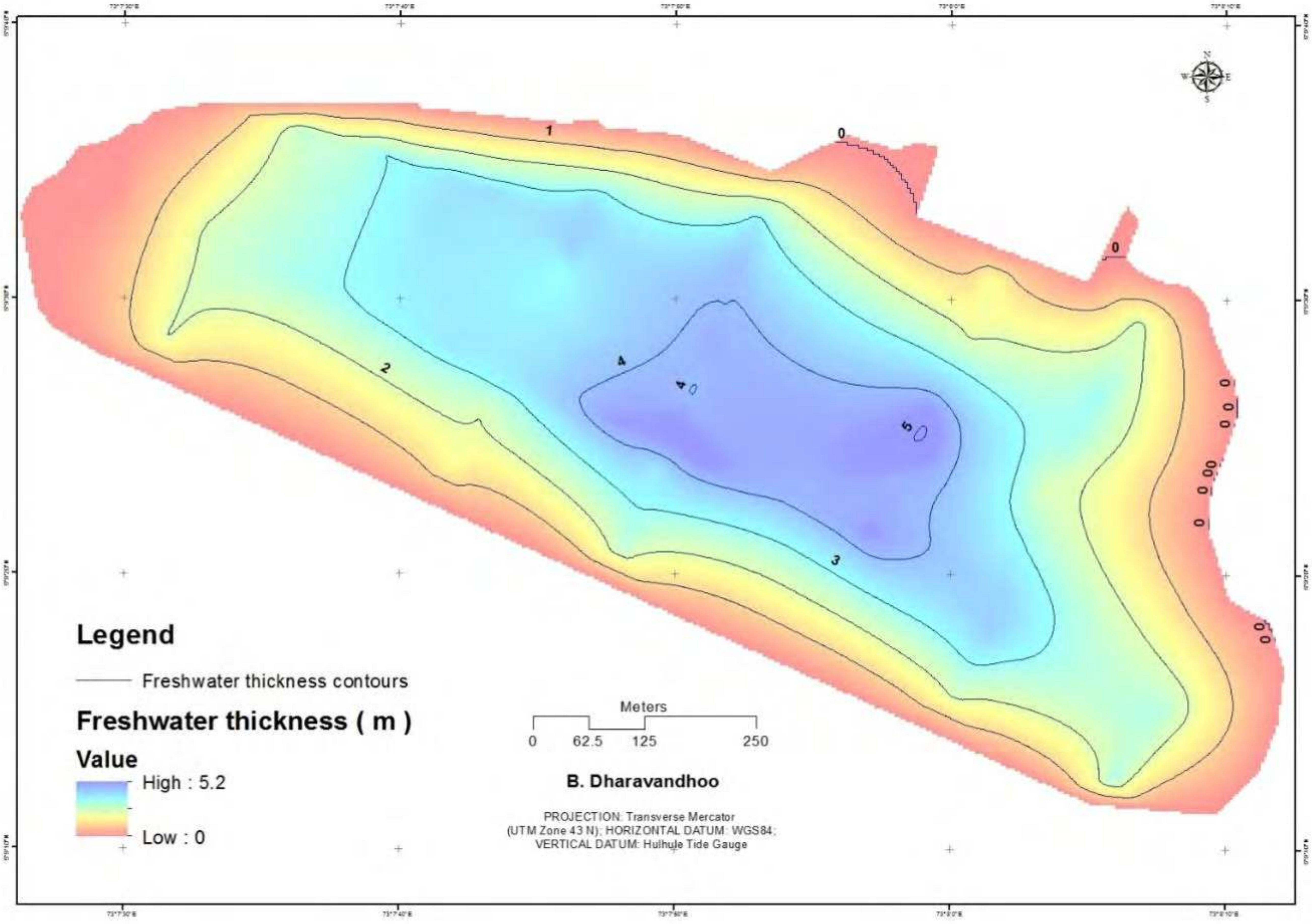


Figure 8.12: Freshwater thickness in Dharavandhoo Island

The maximum freshwater thickness of the island is 5.2 m (It is noted here that these readings were taken in April, which is the dry season and the hottest month of the year). According to Falkland, 1994, the freshwater level thickness of the island is 9 m. The relevant calculations are as follows;

Falkland , 1994

Average Annual Rainfall = 1900 mm/year

Width of the island = 525 m

Length of the island = 1497 m

Freshwater lens Thickness (m)

= (6.94*log(width of the island)-14.38)*Average Annual Rainfall = 9 m

8.8.1 Water balance and recharge

An annual estimation is carried out based on water balance method. Rainwater harvesting is calculated using number of rainwater harvesting units in the island. According to the spatial mean annual rainfall of Maldives, the island is reported as 1900 mm/year. Evapotranspiration was estimated using crop water requirement for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. The groundwater extractions were estimated from amount of water usage in different sectors (residential, resorts, restaurants, agriculture and farming).The difference between recharge and groundwater extraction is taken to estimate different in storage.

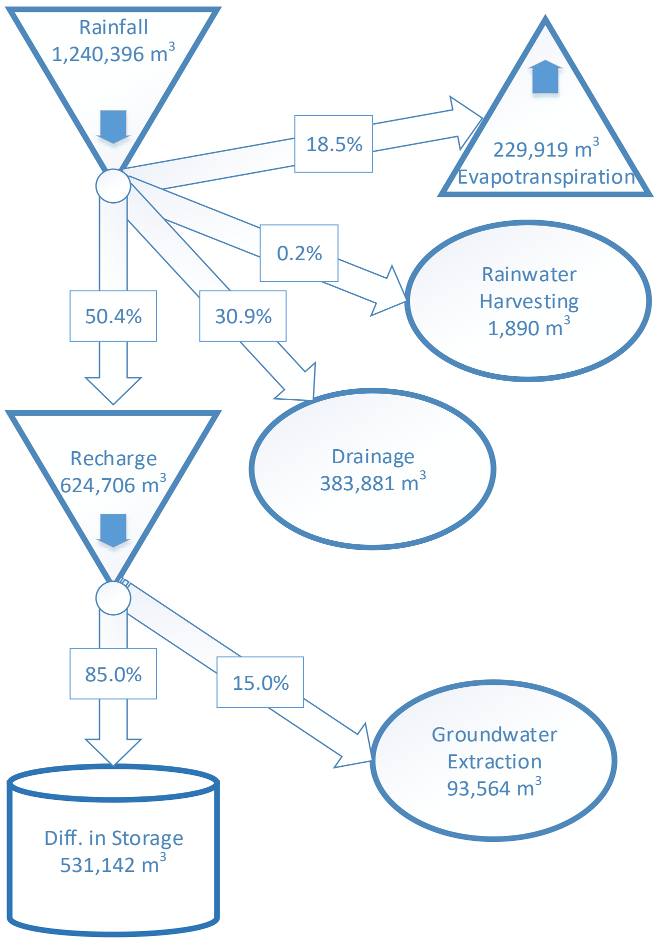


Figure 8.13: Schematic of water balance in Dharavandhoo Island

8.8.2 Sustainable yield of the lens

Sustainable yield of the water lens refers to the safe extraction potential of a given groundwater aquifer without significantly affecting its quality or quantity. This parameter is an important factor in the sustainable development of islands as it allows planning and design of water and sanitation intervention in islands.

The island has a sustainable yield of 1455 m^3 per day which was calculated subtracting groundwater extraction from recharge volume derived from water balance

Figure 8.13. According to Metai & Unit, n.d., based on geophysical investigations and drilling programme concluded that the safe sustainable yield was about 10% of mean annual rainfall. Such that the expected sustainable yield for the island should be 340 m^3 per day.

8.8.3 Permeability test

Permeability tests were carried out in the locations as outlined in Figure 8.14.

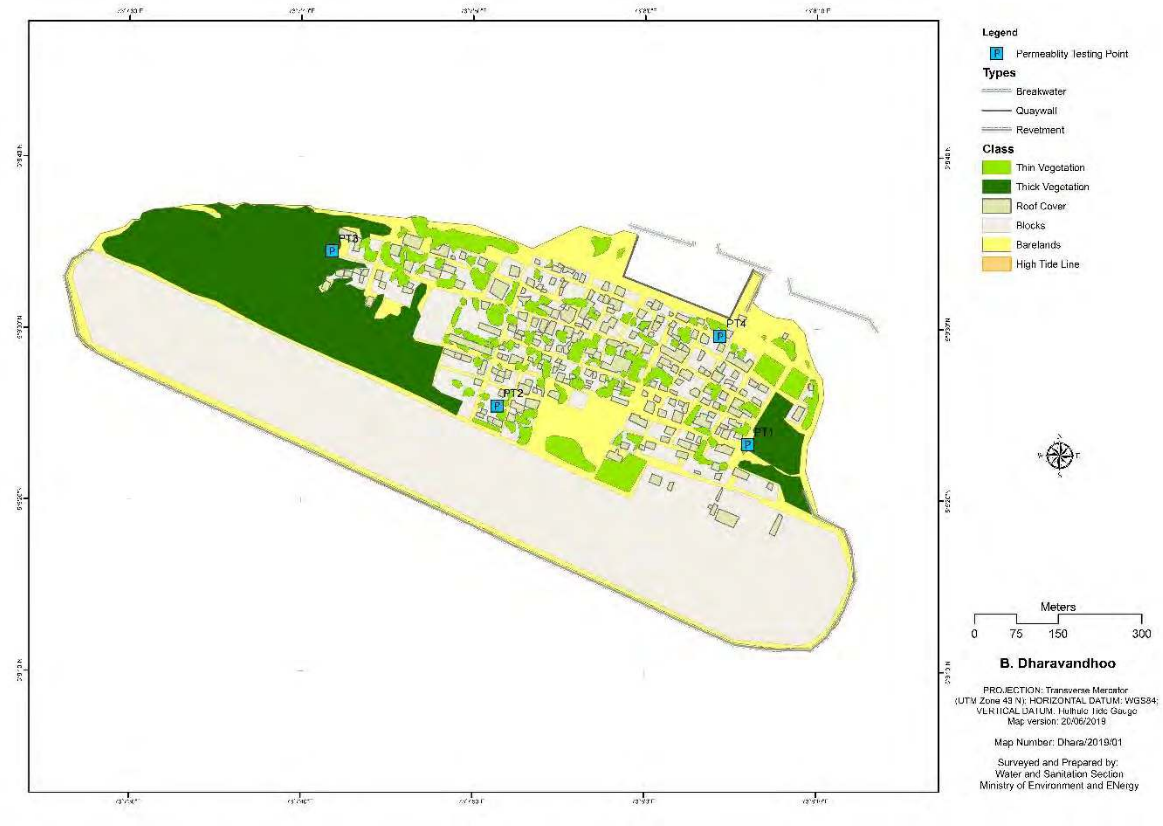


Figure 8.14: Locations of permeability tests in Dharavandhoo Island

The estimated permeability values for the above test locations are presented below.

Table 8.11: The estimated permeability Values

r_e		0.0260
r_1		0.0285

Point	H	Tu	Cs	H/r_e	Q	K (m/s)	K (m/day)	Q (l/min)	Q (m^3/s)
DVPT1	0.7	1.0	50	26.9	1.3E-04	1.77E-04	15.28	7.5	0.00013
DVPT2	0.7	1.0	50	26.9	8.3E-06	1.18E-05	1.02	0.5	0.00001
DVPT3	0.8	0.9	50	30.8	2.0E-04	3.14E-04	27.16	12.0	0.00020
DVPT4	0.7	1.1	50	26.9	2.9E-04	3.75E-04	32.40	17.5	0.00029
DVPT5	0.7	1.2	50	26.9	5.0E-04	5.89E-04	50.92	30.0	0.00050

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m^3/s), H = Height of water in well (m), l = length of perforated section (m), r_1 = outside radius of casing (radius of hole in consolidated material) (m), r_e = effective radius of well = r_1 (area of perforations) / (outside area of perforated section of casing) : $r_1 = r_e$ in consolidated material that will stand open and is not cast, C_u and C_s =Conductivity Coefficients, and T_u = distance from water level in casing to water table (m).

8.8.4 Groundwater availability

1) The selected Dharavandhoo island has dimensions of width = 525 m and length = 1497 m, with a total land area of 65.00 ha, a population of 857 persons, and a land use of built-up area 4.36 ha (6.7%), thick vegetation 10.89 ha (16.8%), light vegetation 4.92 ha (7.5%), and barelands 45.20 ha (69.0%).

2) To recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of freshwater lens and its associated recharge-discharge characteristics, 50 Electrical Resistivity (ER) location readings along 4 representatively selected transects were collected.

3) Soil overburden permeability tests (constant head) were carried out at 05 locations. Groundwater level was also recorded at 10 locations where groundwater water quality samples were tested.

4) Permeability tests were carried out at representatively selected 05 number of locations. The measured permeability (K m/day) values ranged from a minimum of 1.02 m/day to a maximum of 50.92 m/day, with an average of 25.35 ± 18.71 m/day (Mean ± 1 Standard Deviation).

5) The ground elevation values ranged from a minimum of 0.48 m MSL to a maximum of 1.74 m MSL, with an average of 1.28 ± 0.20 m MSL (Mean ± 1 Standard Deviation).

6) The upper boundary of the freshwater lens (FWL) varied from a minimum of -0.44 m MSL to a maximum of 0.53 m MSL, with an average of 0.20 ± 0.20 m MSL (Mean ± 1 Standard Deviation).

7) The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -4.86 m MSL to a maximum of 0.12 m MSL, with an average of -2.90 ± 1.03 m MSL (Mean ± 1 Standard Deviation).

8) Accordingly, the freshwater lens (FWL) thickness values ranged from a minimum of -0.12 m to a maximum of 4.86 m, with an average of 2.92 ± 1.07 m (Mean ± 1 Standard Deviation).

9) The groundwater profile in the island is characterized by a relatively Low (0.15%) Rainwater Harvesting, relatively High (30.95%) Drainage, relatively Very High (50.36%) Recharge, while the water use shows relatively Very Low (14.98%) Groundwater extraction, leading to relatively Very High (85.02%) Difference in Balance Storage.

10) The freshwater lens (FWL) volume calculated based on ER transect test data is 285,925 m^3 with a maximum FWL thickness of 4.86 m. The potential maximum FWL volume and thickness estimated based on Falkland (1994) method are 97,998 m^3 and 8.55 m.

8.8.5 Conclusive Comments and Recommendations

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 1,455 m^3 per day, while it is 340 m^3 per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 264 m^3 per day and this is about 78% of the allowable Safe Yield in the island with minor up-coning and slight drawdown in freshwater lens cross-sections. At present, there exists no island-wide sewerage network or water supply network. The water samples tested were found to be Odorous with 69.2% or 9/13 samples tested producing odour. The Hydrological condition of the freshwater lens aquifer can be categorized as Good based on above measurements and findings while Water quality aspects can be regarded as Contaminated with an Average Electrical Conductivity (EC) of 1,008.57 ± 399.20 µS/cm with measured values ranging from a minimum of 621.30 µS/cm to a maximum of 2,094.20 µS/cm, and an Average Ammonia Concentration of 1.43 ± 1.24 mg/L with measured values ranging from a minimum of 0.36 mg/L to a maximum of 4.46 mg/L. The Availability of space for incorporating recharge measures and related infrastructure is High while therefore the Potential for Recharging is considered to be High. Overall recommendation for groundwater recharging would be to use recharging trenches in roads and recharging pits in individual households and land blocks.

9 AA. BODUFULHADHOO ISLAND

9.1 General overview of the island

The island of Bodufolhudhoo is located at 04°11'05"N and 72°46'25"E in the Alif Administrative Atoll. It is 414 m long and 389 m wide, giving it an area of 11.92 Hectares. According to the 2014 Census it has a population of 608 people. The island has a harbour on its northern side. In addition to this there is a jetty located on the western side of the island. Bodufolhudhoo Reef is located to the east of the island. The island does not have a water supply network. The main way of waste disposal is via one local outfall pipe to which the houses are connected to.

Table 9.1: Basic statistical information on Bodufolhudhoo Island in AA Atoll.

Name of the island	AA.Bodufolhudhoo
Longitude and Latitude	04°11'05"N, 72°46'25"E
Area	11.4 ha
Population (Census, 2014)	608
Distance from Atoll Capital (AA. Rasdhoo)	25.8km
Distance from Male'	81.64
Harbour	Present
Island sewerage network	No
Water supply network	Yes (Local)

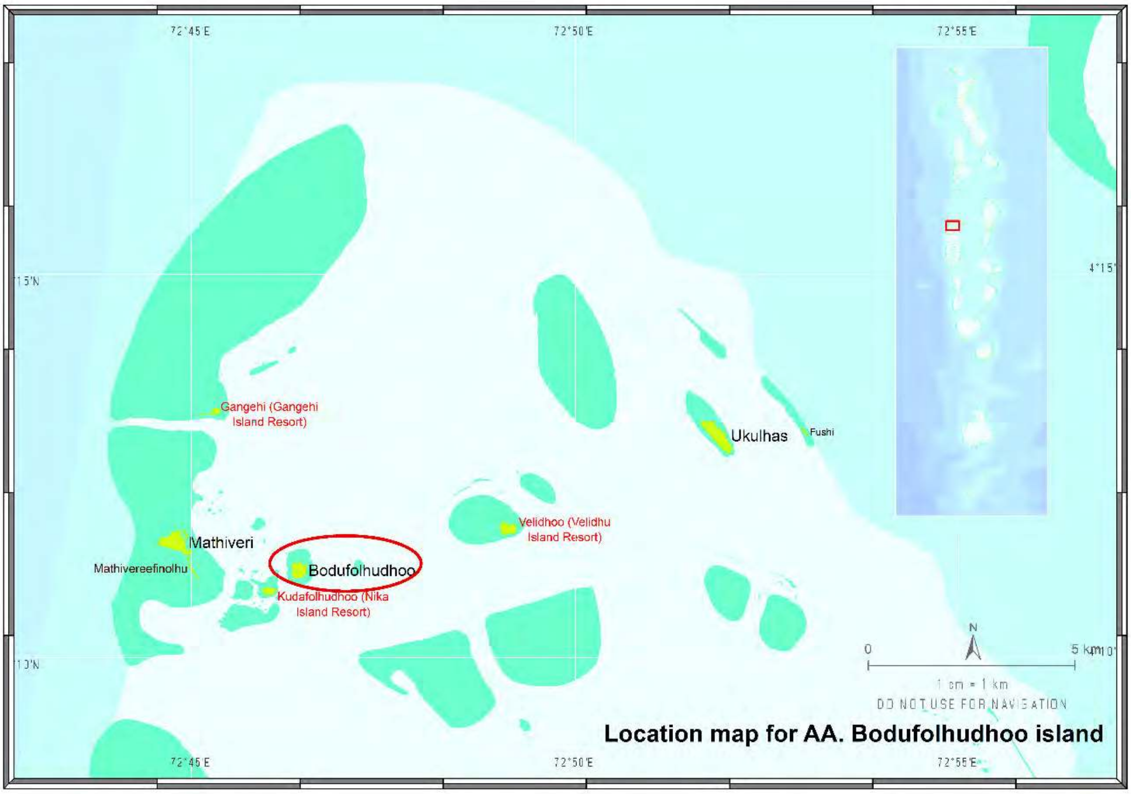


Figure 9.1: Location map for Bodufolhudhoo Island in AA Atoll.

9.2 Geology and vegetation

The island is around 0.4kilometers in both length and width, and has an area of around 11.4 hectares. Vegetation covers around a tenth of the island. The vegetation is mostly concentrated around the football field on the southern side of the island, while the rest is scattered throughout the island. A harbor has been built on the northern side of the island. No farming takes place on the island with the exception of home gardens.

9.3 Topography

The island has a topography that ranges from an elevation of 0.76 meters to 1.55 meters above Mean Sea Level, with an average elevation of 1.01 meters above MSL. Figure 9.2 shows map of Utheemu Island showing spot heights and digital surface model (DSM).

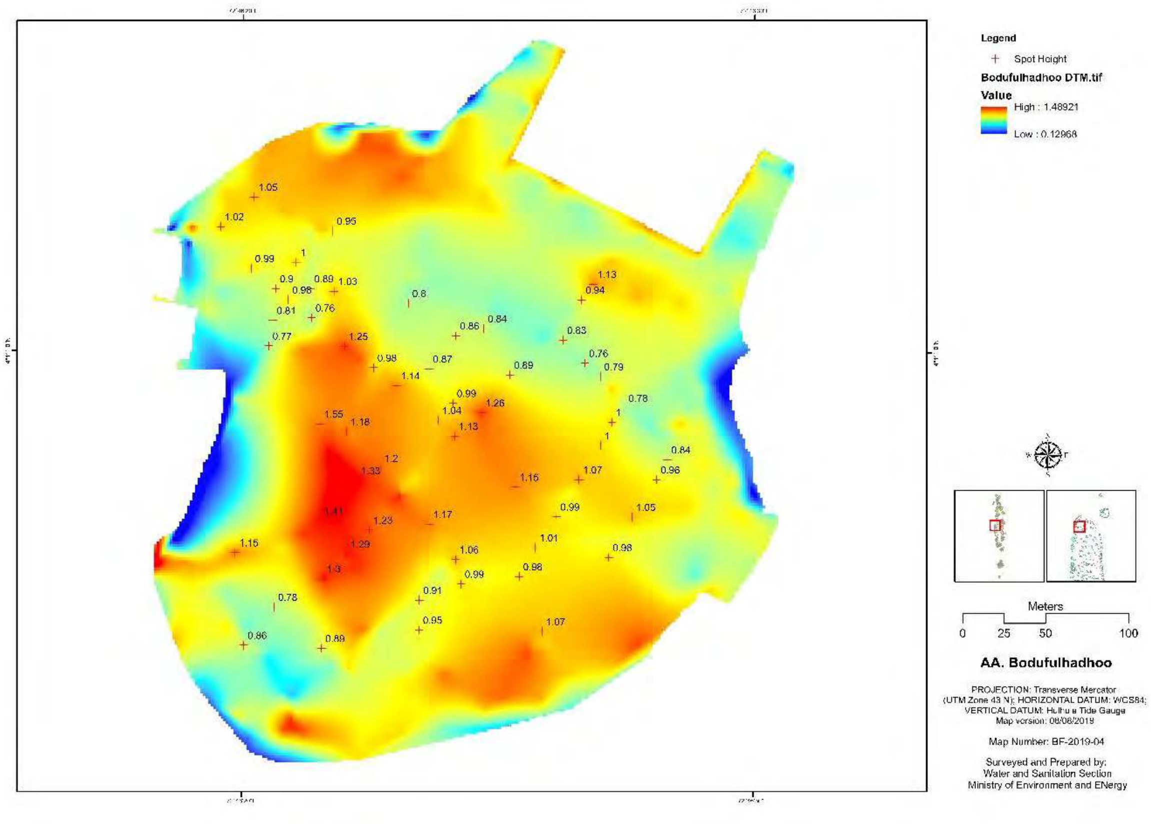


Figure 9.2: Digital Terrain Model of Bodufulhadhoo showing spot heights

9.4 Climate

Bodufulhadhoo experiences the typical two monsoons namely, north east monsoon from November to April and South-west monsoons from April to November. There are no specific wind and rainfall data available for Bodufolhudhoo as there are no weather monitoring stations on the island.

9.5 Demography

Bodufulhadhoo island has a population of 608 people via the 2014 Census, of which 584 are locals and 24 are foreigners. However this figure may be inaccurate as the island council reports a higher population of 811 people as of 2019. When looking at the total population there are 14 more males than females (51:49 percent). However, when only the local population is taken there are an equal number of males and females at 292. This is because the foreign population has 19 males to 5 females. The following graphs and table illustrate the demographic breakdown.

Table 9.2: Demographic Breakdown of Bodufulhadhoo Island

Atoll	locality	Resident population (Census, 2014)								
		Total			Maldivians			Foreigners		
		Both sexes	Male	Female	Both sexes	Male	Female	Both sexes	Male	Female
AA	Bodufulhadhoo	608	311	297	584	292	292	24	19	5

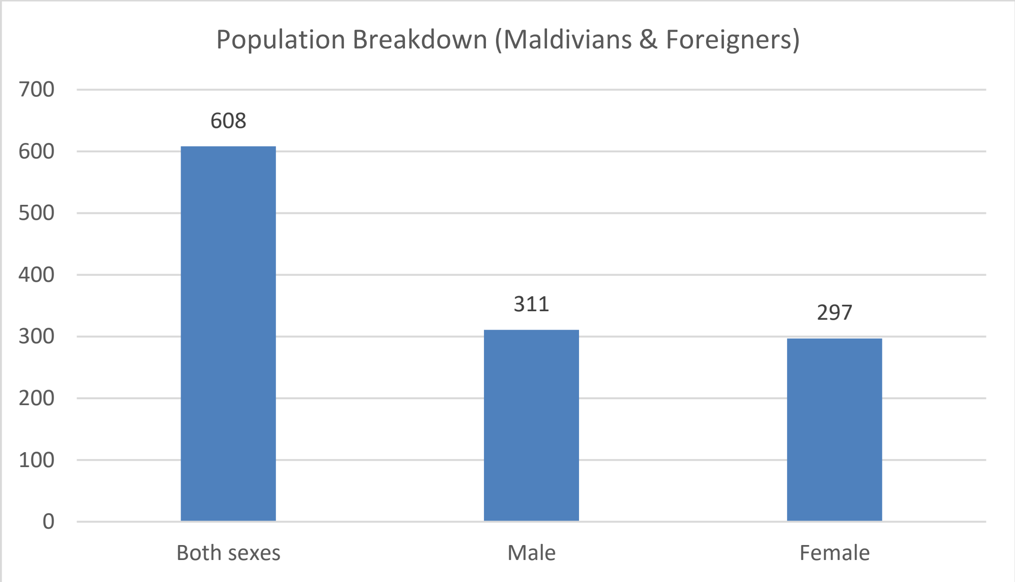


Figure 9.3: Population breakdown of Bodufulhadhoo (Maldivians & Foreigners)

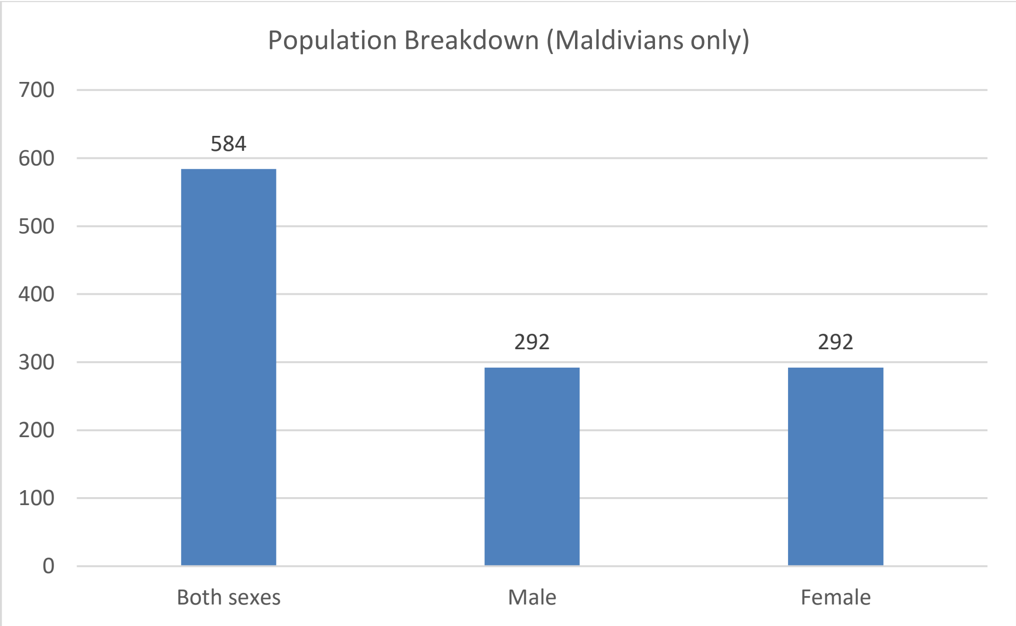


Figure 9.4: Population breakdown of Bodufulhadhoo (Maldivians)

9.6 Socio-economic condition

Bodufolhudhoo was formerly supported from mostly fishing. Currently the economy is supported by people working in the tourism industry. The island has over 5 guesthouses with more under development. There are tourist shops on the island and many people are employed at nearby resorts. The Sunset Beach is very popular among tourists visiting the island. Aside from tourism people on the island have occupations in education, restaurants, health centers and other essential jobs.

9.7 Existing water and sanitation situation

The island does not have a water supply system and has a local outfall pipe for waste disposal, to which the households on the island are connected.

The primary source of drinking water on the island is rainwater collected in community and household tanks and bottled water. Rainwater is the main source for cooking. When the rainwater tends to run out during the dry season, well water and bottled water is sometimes used for cooking. There are plans to build both a water supply network and a sewerage network in the island.

9.8 Results

9.8.1 Water sources and water use

Based on domestic, commercial, institutional and industrial water usage, a total of 175,589 liters of groundwater are estimated to be used every day. Otherwise stated, 289 liters of groundwater are used per capita per day. The respective water use situations are detailed in the following sections.

9.8.1.1 Domestic water use situation

Based on the questionnaire to collect data on domestic water consumption, a summary of results are present in this section.

According to the survey, 100% of the households surveyed uses HDPE rainwater tanks as their main storage for water. A total of 73% households use rainwater for drinking and 100% use it for cooking. None of the surveyed houses use rainwater for bathing or washing.

0% of the households use groundwater as drinking. Groundwater is mainly used for non-potable use in all the households surveyed.

The following table 4.3 summarizes the data for Bodufulhadhoo island.

Table 9.3: Groundwater and rainwater use data for Bodufulhadhoo

Rainwater	
Households with rainwater tanks	11 of 11 i.e. 100%
Rainwater use for drinking	73%
Rainwater use for cooking	100%
Rainwater use for bathing and washing	0%
Groundwater	
Groundwater as drinking source	0%
Groundwater for cooking	0%
Groundwater for non-potable use	100%
Total number of household wells surveyed	11 (10%)
Percentage of wells surveyed fitted with pumps	100%

Based on the survey questionnaire, average daily water demand per capita for domestic purposes has been estimated based on the average amount of water used per person for showering, toilet flushing, laundry and gardening, this data is shown in table 9.4. The total domestic water use is estimated to be 267.08 liters per capita per day.

Table 9.4: Domestic Water Usage in Bodufulhadhoo

Shower/ Liters per capita per day	Toilet/ Liters per capita per day	Laundry/ Liters per capita per day	Gardening/ Liters per capita per day	**Total/ Liters per capita per day**
200.21	13.22	22.20	31.46	**267.08**

9.8.1.2 Commercial water use situation

Based on the questionnaire to collect data on commercial water consumption, a summary of results are present in this section. A total of 2 restaurants and 6 guesthouses were surveyed.

For the guesthouses, the main use of groundwater was for showers, toilet flushing, gardening and dish washing for those guesthouses which contained restaurants. The following table presents a summary. A total of 9309.48 liters of groundwater are used by 6 guesthouses in Bodufulhadhoo.

Table 9.5: Groundwater usage for commercial institutes

Name of Guesthouse	Number of rooms	Average occupancy throughout the year	Total Volume of water per day (Liters)	Total Volume of water per guest per day (Liters)
Manta	5	<50%	1474	369
Holiday Village Retreat	4	40%	1336	417
Surf Retreat	4	40%	1257	393
Lagoon View Maldives	9	40%	2315	322
Yonder Retreat	6	40%	1832	382
Castle Inn	4	40%	1096	342
		Total:	9309	

For the restaurants, the main use of groundwater was for dishwashing and toilet use. A total of 2 restaurants were surveyed and from this data, the total groundwater consumption for the 4 restaurants on this island was estimated to be 2042 liters.

9.8.1.3 Institutional water use situation

Based on the questionnaire to collect data on institutional water consumption, a summary of results are present in this section. Three instituions were surveyed for this study namely the council office, health center and school. Groundwater in the institutions in Bodufulhadhoo Island are mainly used for gardening, mopping floors and flushing toilets. A total of approximately 1815.58 liters of groundwater are estimated to be used per day by the institutions. Therefore, a total of approximately 3.05 liters of groundwater are estimated to be used per capita per day by the institutions of Bodufulhadhoo Island.

Table 9.6: Water Usage in Institutions in Bodufulhadhoo

	Water Flushed (Liters per day)	Gardening (Liters per day)	Mopping (Liters per day)	Total Water Usage (Liters)	Total Water Usage (Liters)	Institutional Groundwater Usage (Liters per capita per day)
Council	73	270	-	343	1852	3.05
Health Center	73	-	-	73		
School	327	1080	30.00	1436		

9.8.2 Groundwater quality

Groundwater quality measurements were made at selected wells in Bodufulhadhoo for both physical and microbiological testing.

The following table summarizes the water quality results.

Table 9.7: Summary of groundwater quality tests from Bodufulhadhoo, April 2019

Sample No	Odour	Physical Appearance
gw1	yes	Pale yellow with particles
gw2	yes	Clear with particles
gw3	yes	Pale yellow with particles
gw4	yes	Clear with particles
gw5	yes	Clear
gw6	yes	Clear
gw7	yes	Clear with particles
gw8	yes	Clear
gw9	yes	Clear with particles
gw10	yes	Pale yellow with particles

Sample No	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (FNU)	DO (mg/L)	Temp (°C)	Sal (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
gw1	11511	6683	7.2	7.76	1.29	31.28	5.75	25.7	0.95	0.28		
gw2	10599	6248	7.32	5.45	1.34	30.39	5.35	14.2	0.54	0.18		
gw3	6388	3701	7.44	0.17	1.27	31.39	3.05	14.2	0.22	0.58		
gw4	1524	871	7.56	6.11	4.02	32.17	0.66	6.2	0.06	0.1		
gw5	2239	1276	7.4	0	3.77	32.33	0.99	7.1	0.02	0.12		
gw6	8094	4693	7.27	2.7	3.54	31.33	3.93	36.3	0.1	0.23	0	0
gw7	5069	2863	7.53	3.27	2.37	32.89	2.31	17.7	0.31	0.27	>2420	0
gw8	2259	1384	7.47	0	6.02	28.17	1.08	19.5	0.04	0.08	24	24
gw9	3956	2294	7.77	1.31	6.16	31.33	1.83	15.9	0.15	0.14		
gw10	10188	5925	7.31	4.34	3.68	31.17	5.05	27.4	0.71	0.71	>2420	>2420

	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)
WHO Standards	Suggested maximum limit of freshwater for potable purposes = 1500 µS/cm Suggested maximum limit of freshwater for non-potable purposes = 2500 µS/cm	-	-	-	-	-

	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
WHO Values	-	Guideline Value = 50 mg/L-NO3	Natural Level of Ammonia < 0.2 mg/L Threshold odour concentration = 1.5 mg/L Taste threshold = 35 mg/L	-	-	-

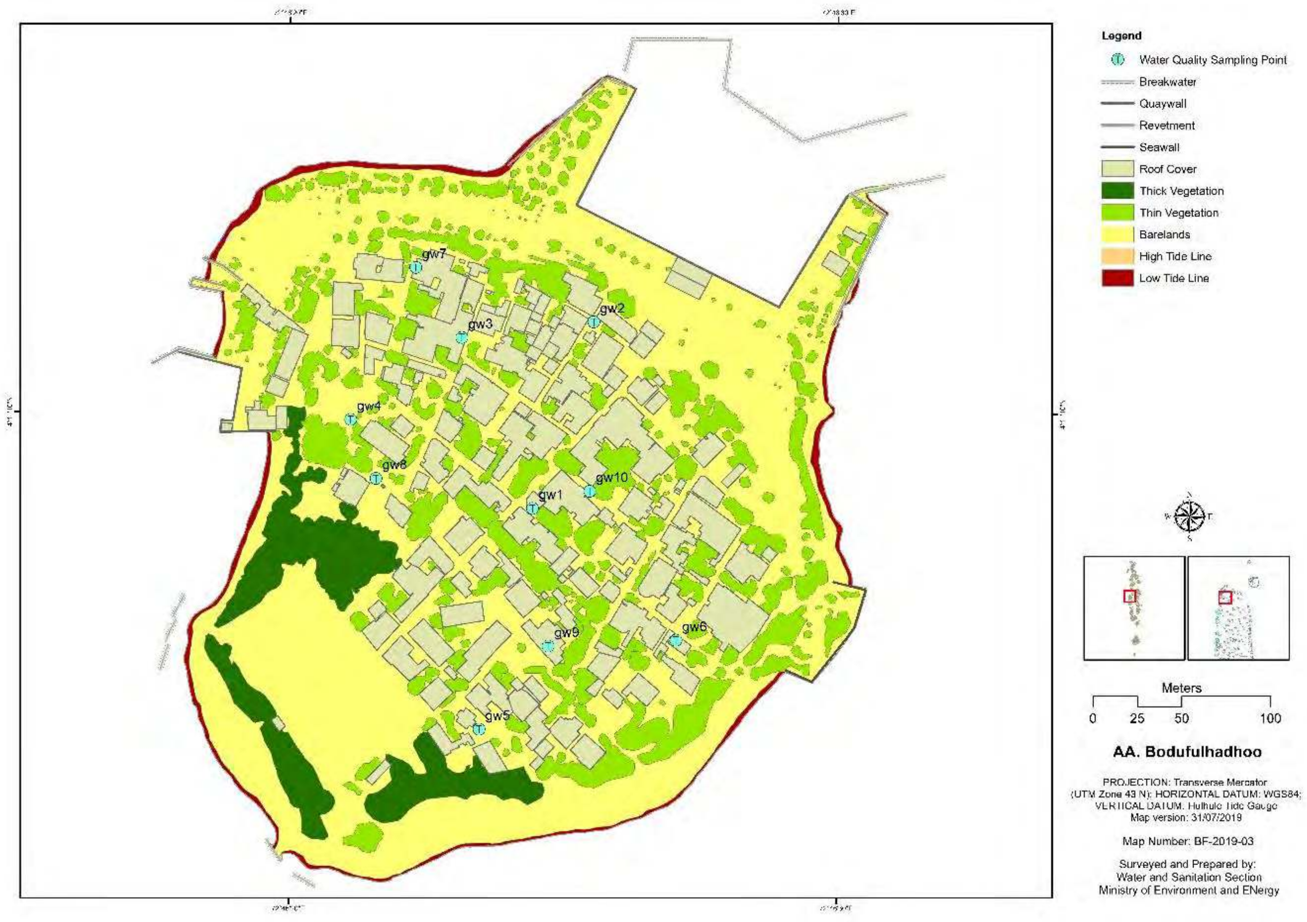


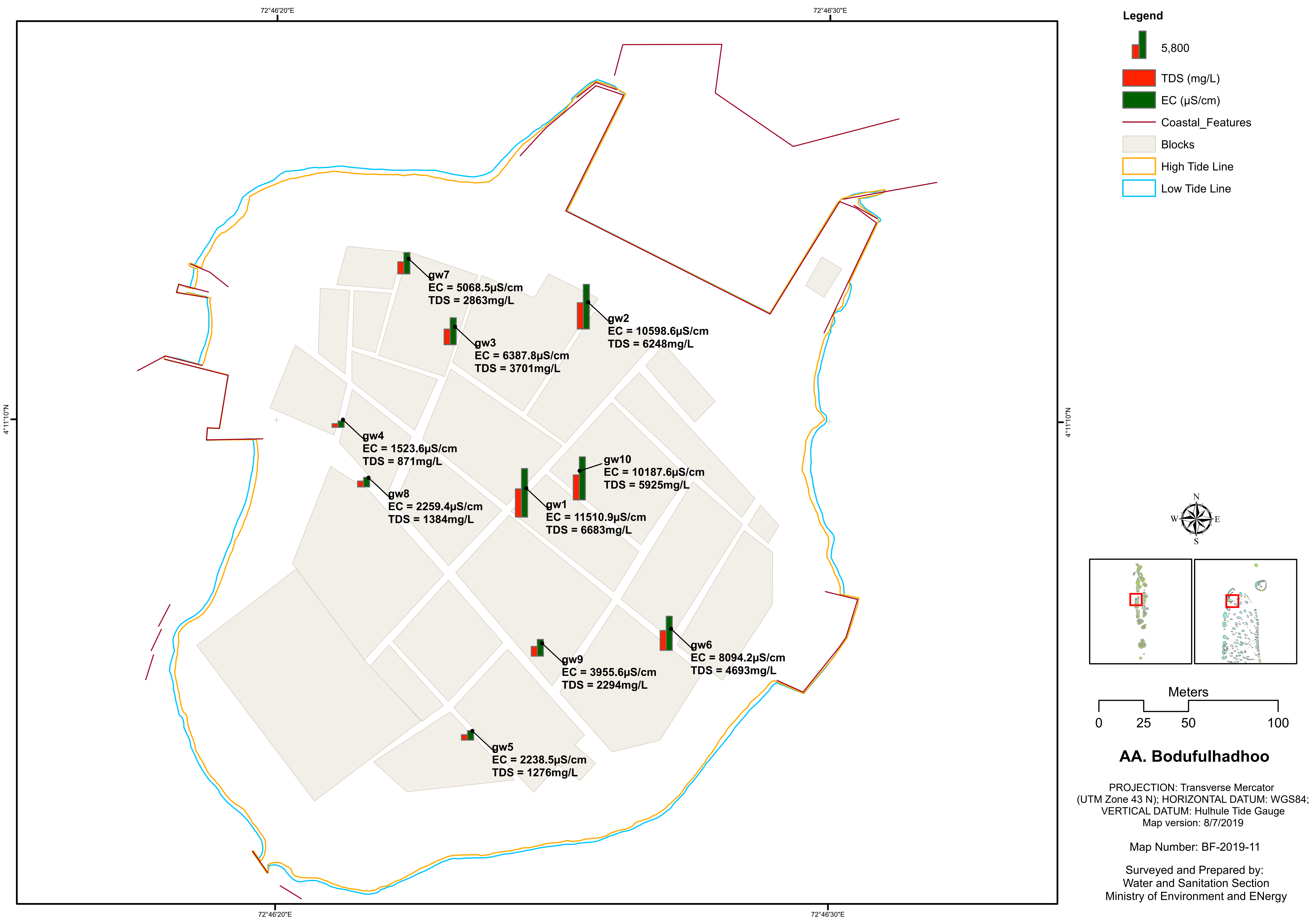
Figure 9.5: Location of groundwater sampling points in Bodufulhadhoo Island

Based on the full results and the summary shown in Table 4.5, the following observations are made:

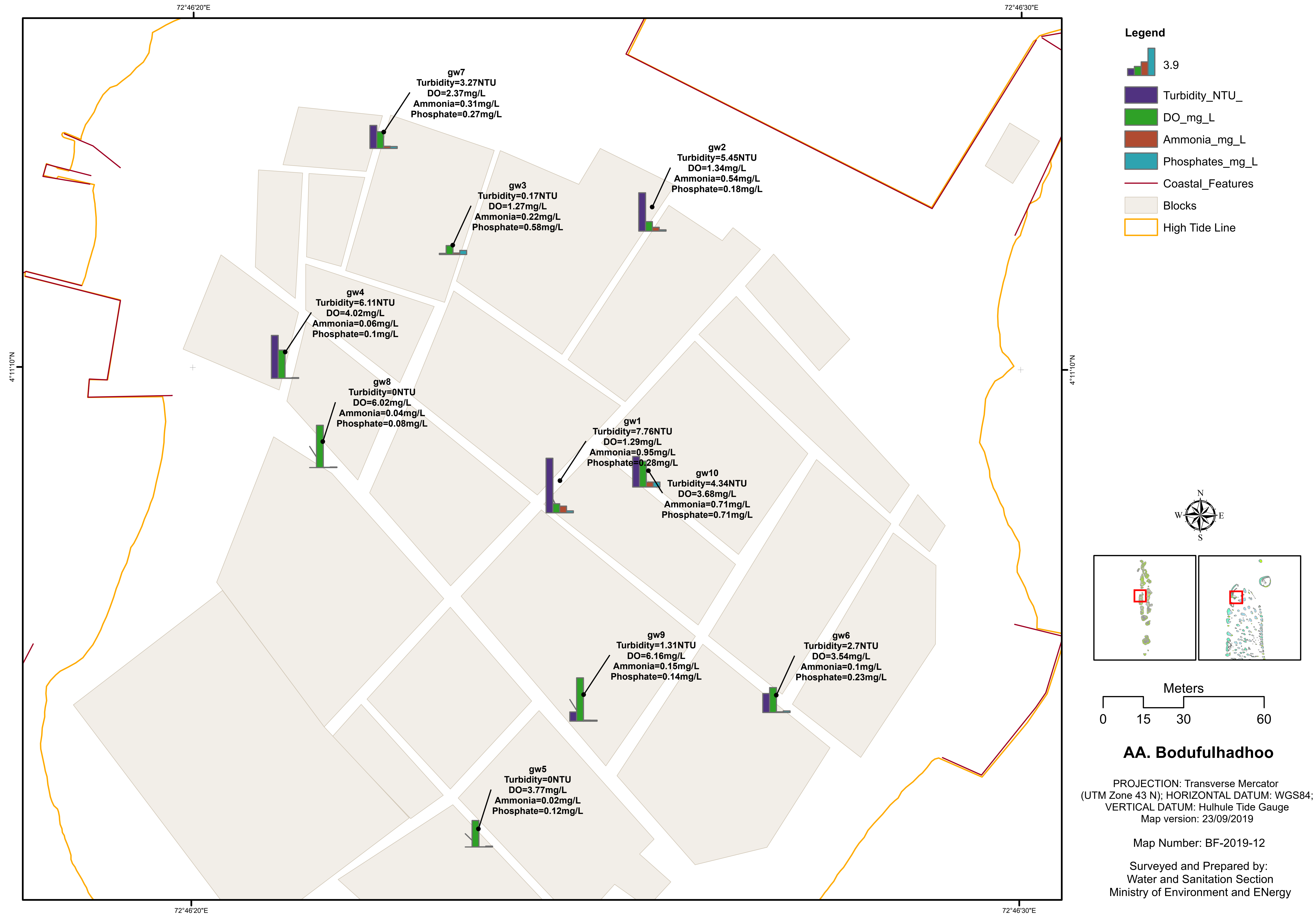
- The Electrical Conductivity (EC) of the groundwater is high. The average EC reading of 6182.5 μS/cm is significantly higher than the acceptable limit for potable water of 1,500 μS/cm and the acceptable limit for freshwater for non-potable purposes of 2500 μS/cm (refer section 2.2). All 10 of the tested water samples (100%) exceeded the limit for potable water, with the lowest EC being 1524 μS/cm and the highest EC being 11511 μS/cm. 7 samples (70%) exceeded the acceptable limit for freshwater for non-potable purposes.Total dissolved solids were generally high and ranged from 871 mg/L to 6683 mg/L with an average of 3593.8 mg/L. As TDS readings are calculated from Specific Conductance and Conductivity, the trends shown in TDS readings are similar to EC.
- The pH ranged from 7.2 to 7.77 with an average pH of 7.43.
- Turbidity ranged from 0 NTU to 7.76 NTU with an average of 3.11 NTU. As a guide, “crystal-clear” water has a turbidity below 1 NTU, and water becomes visibly cloudy at 4 NTU and above.
- Dissolved oxygen levels ranged from 1.27 to 6.16 mg/L. The average value was 3.35 mg/L.
- The salinity of groundwater ranged from 0.66 PSU to 5.75 PSU with an average salinity of 3 PSU.
- The average Nitrate concentration was 18.4 mg/L which is below the WHO guideline limit of 50 mg/L. The Nitrate concentrations ranged from lowest concentration of 6.2 mg/L to the highest concentration of 36.3 mg/L. It should be noted that none of the tested water samples exceeded the WHO guideline limit for Nitrate concentrations.
- The average ammonia concentration was 0.31 mg/L. This is well below the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. It was found that none of the tested water samples exceeded the WHO guideline. Natural levels of ammonia are generally below 0.2 mg/L (WHO, 1993) and 5 of the tested water samples showed concentrations below this level. There is no apparent correlation between increasing levels of ammonia and other nutrients.
- Phosphate concentrations ranged from 0.08 mg/L to 0.71 mg/L with an average concentration of 0.27 mg/L. There is no WHO drinking water guideline value for phosphate. However, it would normally be expected that phosphate concentrations in groundwater are less than 0.1 mg/L, where there are no impacts from human wastewater (e.g. effluent from septic tanks and ‘greywater’ from kitchens and bathrooms). Only 1 tested water sample showed concentration below 0.1 mg/L.
- Total coliform levels were found to be high and vary significantly between samples with the lowest concentration being 24 MPN/100mL and the highest concentrations exceeding 2420 MPN/100mL, with the average concentration being 1216 MPN/100mL. Faecal Coliform levels were also found to be high and vary significantly ranging from lowest count of 24 MPN/100mL to the highest count of more than 2420 MPN/100mL with an average estimated to be greater than 611 MPN/100mL. As expected, the groundwater layer is contaminated with effluent from septic tanks.

In conclusion, Bodufulhadhoo Island contains groundwater with generally high Electrical Conductivity with a higher average than WHO guidance value for potable and non-potable water and high TDS. Nitrate concentration was lower than WHO maximum guidance value, average Ammonia concentration lower than expected in natural, undisturbed groundwater but average Phosphate concentration higher than expected in natural, undisturbed groundwater. In terms of microbiological contamination, Bodufulhadhoo Island shows variable patterns where one water sample tested had zero contamination but others have high contamination.

Additionally, the following pages contain maps which show the main physiochemical parameters displayed on map of the island.



72°46'20"E
72°46'30"E
4°11'10"N
gw7
EC = 5068.5μS/cm
TDS = 2863mg/L
gw2
EC = 10598.6μS/cm
TDS = 6248mg/L
gw3
EC = 6387.8μS/cm
TDS = 3701mg/L
gw4
EC = 1523.6μS/cm
TDS = 871mg/L
gw10
EC = 10187.6μS/cm
TDS = 5925mg/L
gw8
EC = 2259.4μS/cm
TDS = 1384mg/L
gw1
EC = 11510.9μS/cm
TDS = 6683mg/L
gw6
EC = 8094.2μS/cm
TDS = 4693mg/L
gw9
EC = 3955.6μS/cm
TDS = 2294mg/L
gw5
EC = 2238.5μS/cm
TDS = 1276mg/L
Legend
5,800
TDS (mg/L)
EC (μS/cm)
Coastal_Features
Blocks
High Tide Line
Low Tide Line
N
W
E
S
Meters
0 25 50 100
AA. Bodufulhadhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/7/2019
Map Number: BF-2019-11
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy



AA. Bodufulhadhoo

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 23/09/2019

Map Number: BF-2019-12

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

9.8.3 Geophysical survey

The Resistivity tests were carried out in the locations as outlined in Figure 9.6 below.

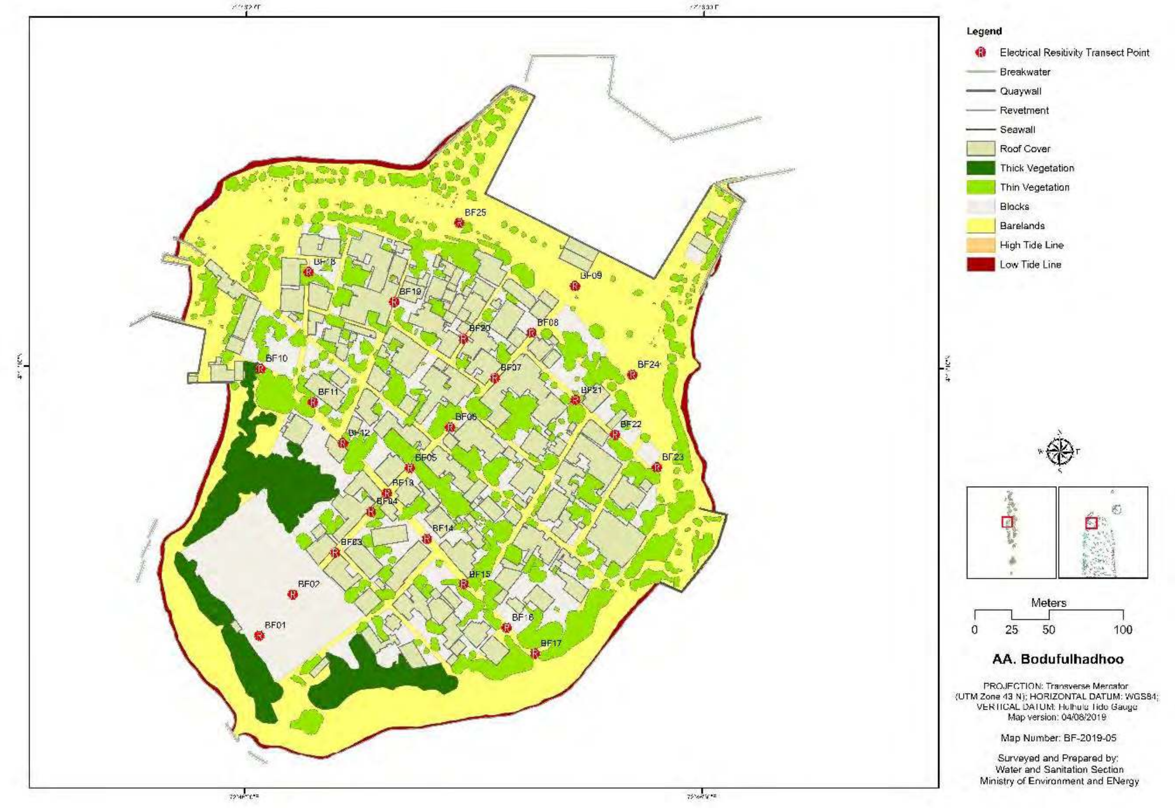


Figure 9.6: Location of ER points in Bodufulhadhoo Island

9.8.4 Aerial surveys

Based on the aerial survey, a multiple dataset consisting of roof cover, thick vegetation area, thin vegetation area, bare lands and shorelines were extracted. This data is shown in Figure 9.7 and the Table 9.8 shows the different area distribution.

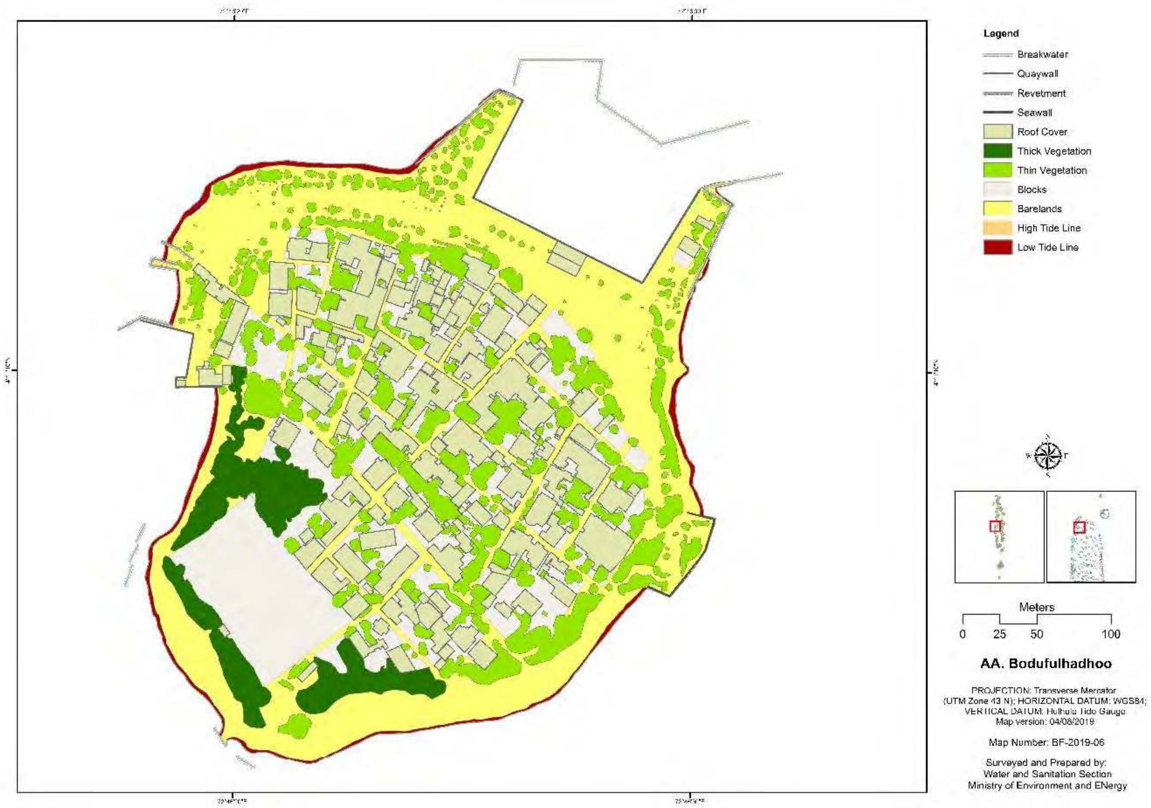


Figure 9.7: Area Distribution in Bodufulhadhoo Island

Table 9.8: Area Distribution in Bodufulhadhoo

	Area (Square Meters)	% of total area
Roof cover	25,268.49	21.2%
Vegetation (Thick)	7,669.83	6.4%
Vegetation (Light)	23,700.17	19.9%
Bare lands	62,624.52	52.5%
Farm Lands	-	-
Wetlands (Inland)	-	-

9.8.5 Freshwater lens

Based on the ER survey the depth to groundwater level and the freshwater-saline water interface was determined for a set of transverse transects as shown in Figure 9.8. Plots in the Figure 8.9 shows the cross sections of each transect line. The dotted lines in the plots indicating a simple interpolation of levels to mean sea level in the island boundaries. These cross sections were used to identify the spatial extent and volume of the freshwater lens while they were also useful in deriving implications on the stress level of the aquifer based on the observed, localized drawdown effect in the groundwater table and up-coning in the freshwater-saline interface, defining the upper and lower boundaries of the freshwater lens in an island.

The Table 9.9 illustrate the freshwater volume calculation for the island. The area covered by freshwater for each transect line has been calculated. To estimate the total volume of available freshwater lens, the cross-section area of freshwater extent under each transect was multiplied by the distance between two transects. The sum of these lengths represents the cumulative length of the island

and thus, the above estimation could represent the total volume of the freshwater lens sandwiched between the groundwater table on top and freshwater-saline water interface in the bottom. Then the actual groundwater storage within this freshwater lens was calculated by multiplying the estimated total lens volume with the porosity of the topsoil in the island.

This estimation represents the total available freshwater volume within the freshwater lens at any given time (time of the measurement). The measurements were carried out towards the end of the dry period and the freshwater lens is presumed to be undergoing a 'stressed' condition due to continued groundwater abstractions despite reduced recharge in the dry period. Falkland (1994) method can be used to estimate the freshwater lend thickness under salient conditions using average annual rainfall, length and width of the island, and the comparison was used as a measure of stress level of the freshwater lens

Table 9.9: Freshwater Volume Calculation for Bodufulhadhoo Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
3	Start		0	0	0	0			
			19	0.208	0	0	0		
	BF18	ER	83	0.887	0.008	-0.463	15		
	BF19	ER	143	0.851	0.049	-0.449	29		
	BF20	ER	195	0.844	-0.063	-0.063	13		
	BF07	ER	228	0.788	-0.054	-1.052	16		
	BF21	ER	282	1.031	-0.539	-0.539	27		
	BF22	ER	316	0.793	-0.037	-0.037	0		
	BF23	ER	352	0.964	-0.006	-0.006	0		
			370	0.464	0	0	0		
	End		390	0	0	0	0		
	Total						100	139	13886
4	Start		0	0	0	0			
			19	0.170	0	0	0		
	BF10	ER	74	0.669	-0.081	-0.081	0		
	BF11	ER	115	1.345	0.135	-0.395	11		
	BF12	ER	149	1.150	0.12	-0.7	23		
	BF13	ER	193	1.065	0.149	-1.195	48		
	BF14	ER	234	1.043	0.127	-0.217	34		
	BF15	ER	273	0.985	0.107	-0.755	24		
	BF16	ER	315	1.082	-0.018	-0.708	32		
	BF17	ER	340	1.057	-0.083	-0.083	9		
			355	0.468	0	0	0		
	End		374	0	0	0	0		
	Total						181	208	37604
									51,490

Table 9.10: ER Survey Results of Longitudinal Sections for Bodufulhadhoo Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)
1	Start		0		0	0
			17		0	0
	BF11	ER	158	1.345	0.135	-0.395
	BF19	ER	245	0.851	0.049	-0.449
	BF25	ER	314	1.017	0.017	0.017
			323		0	0
	End		340		0	0
2	Start		0		0	0
			20		0	0
	BF01	ER	48	0.805	-0.295	-0.295
	BF02	ER	84	0.898	-0.172	-1.682
	BF03	ER	124	1.239	0.169	-0.991
	BF04	ER	161	1.158	0.088	-0.752
	BF13	ER	177	1.065	0.149	-1.195
	BF05	ER	200	1.059	0.16	-0.45
	BF06	ER	239	1.104	0.264	-0.989
	BF07	ER	284	0.788	-0.054	-1.052
	BF08	ER	323	0.787	-0.07	-0.24
	BF09	ER	366	1.048	-0.042	-0.042
			376		0	0
	End		396		0	0

Volume of lens = 51,490 m^3

Groundwater Storage = Porosity (20%) x Lens volume (m^3) = 10,298 m^3

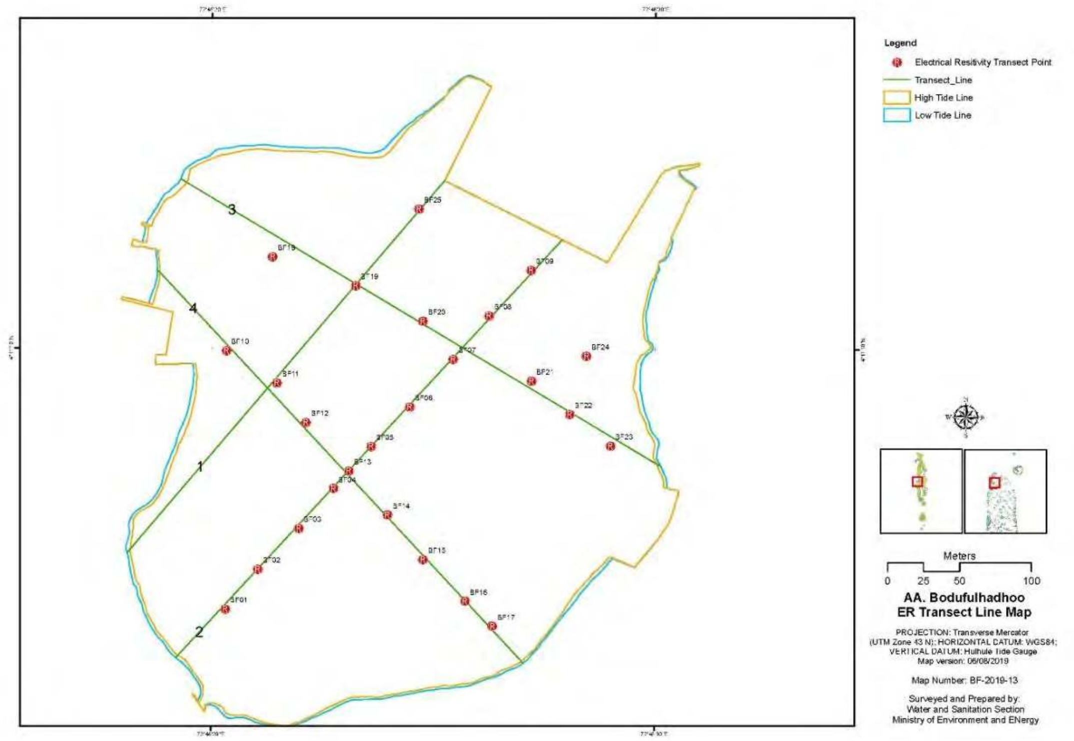
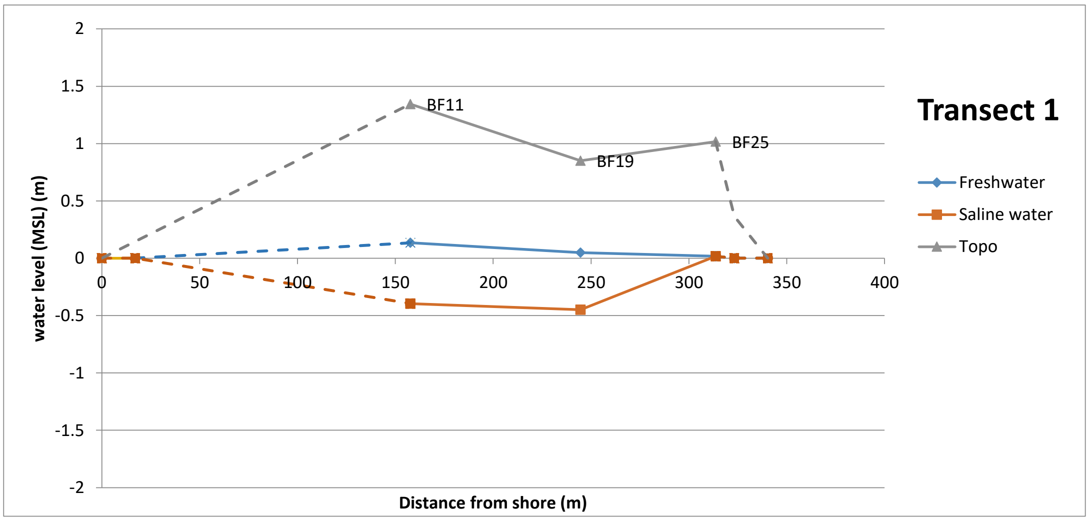
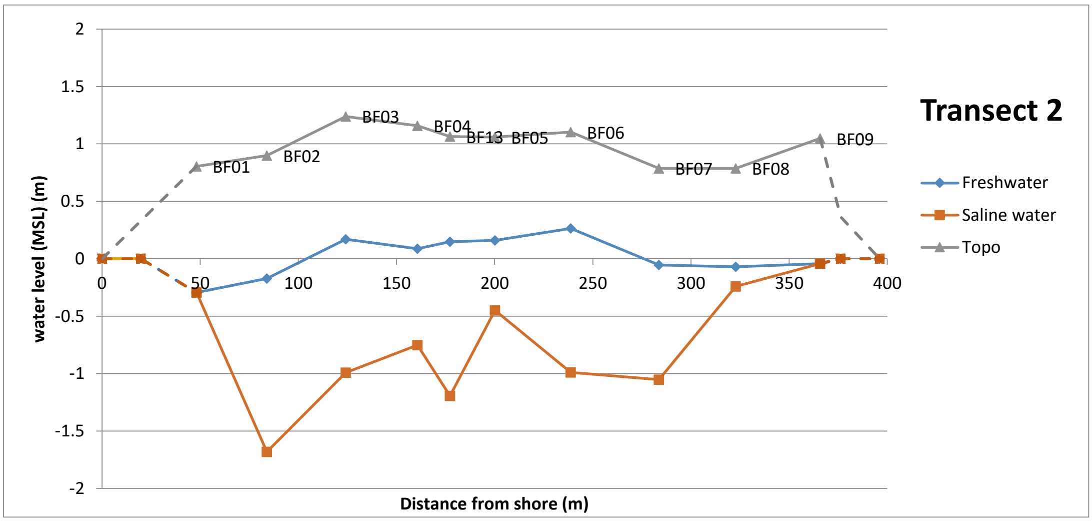
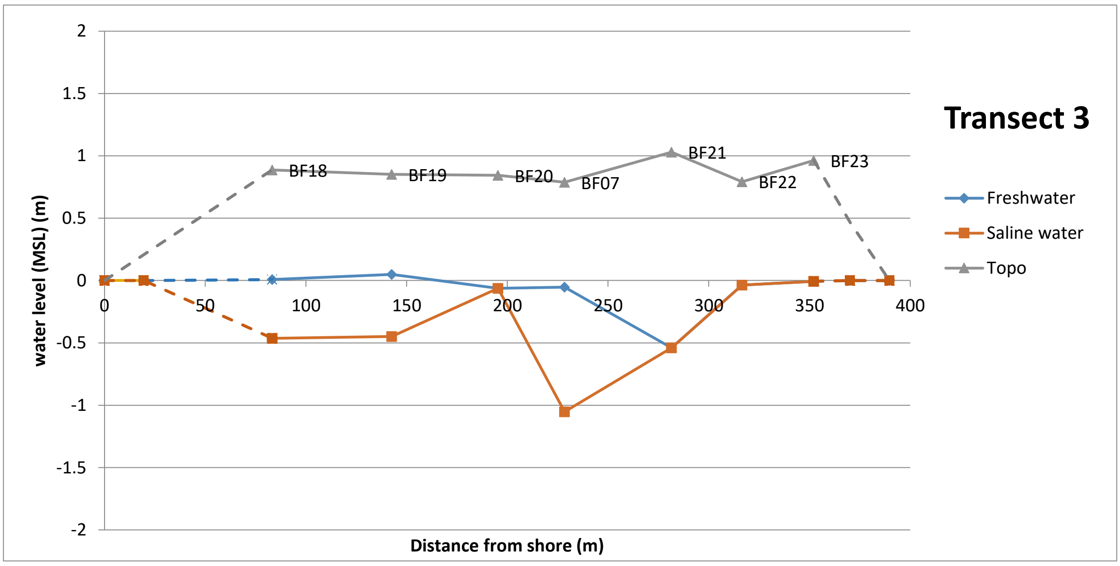


Figure 9.8: ER transect lines in Bodufulhadhoo Island







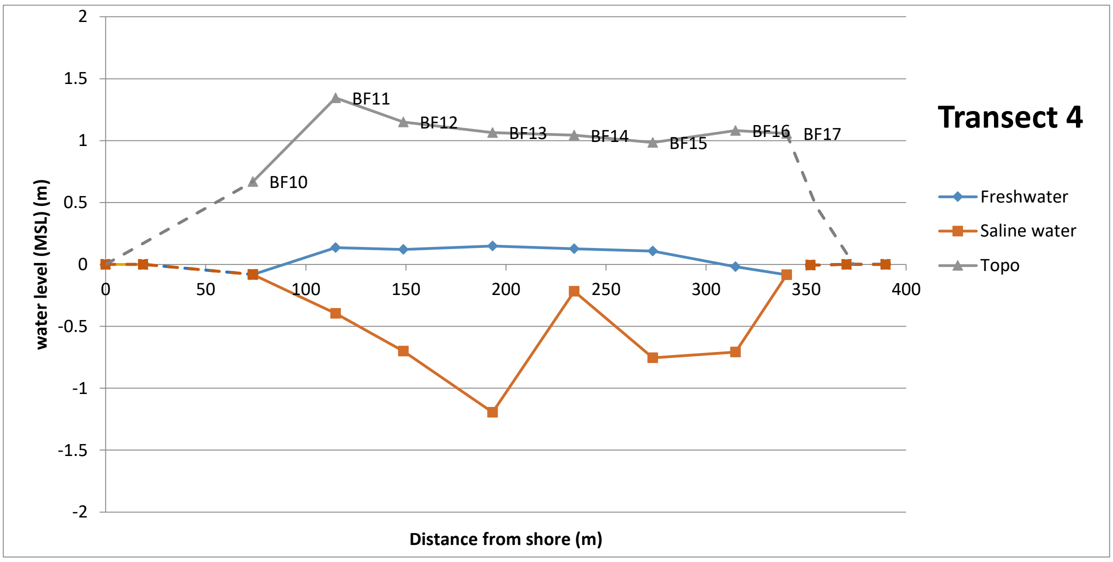


Figure 9.9: Cross-sections of transect lines in Bodufulhadhoo Island

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented below.

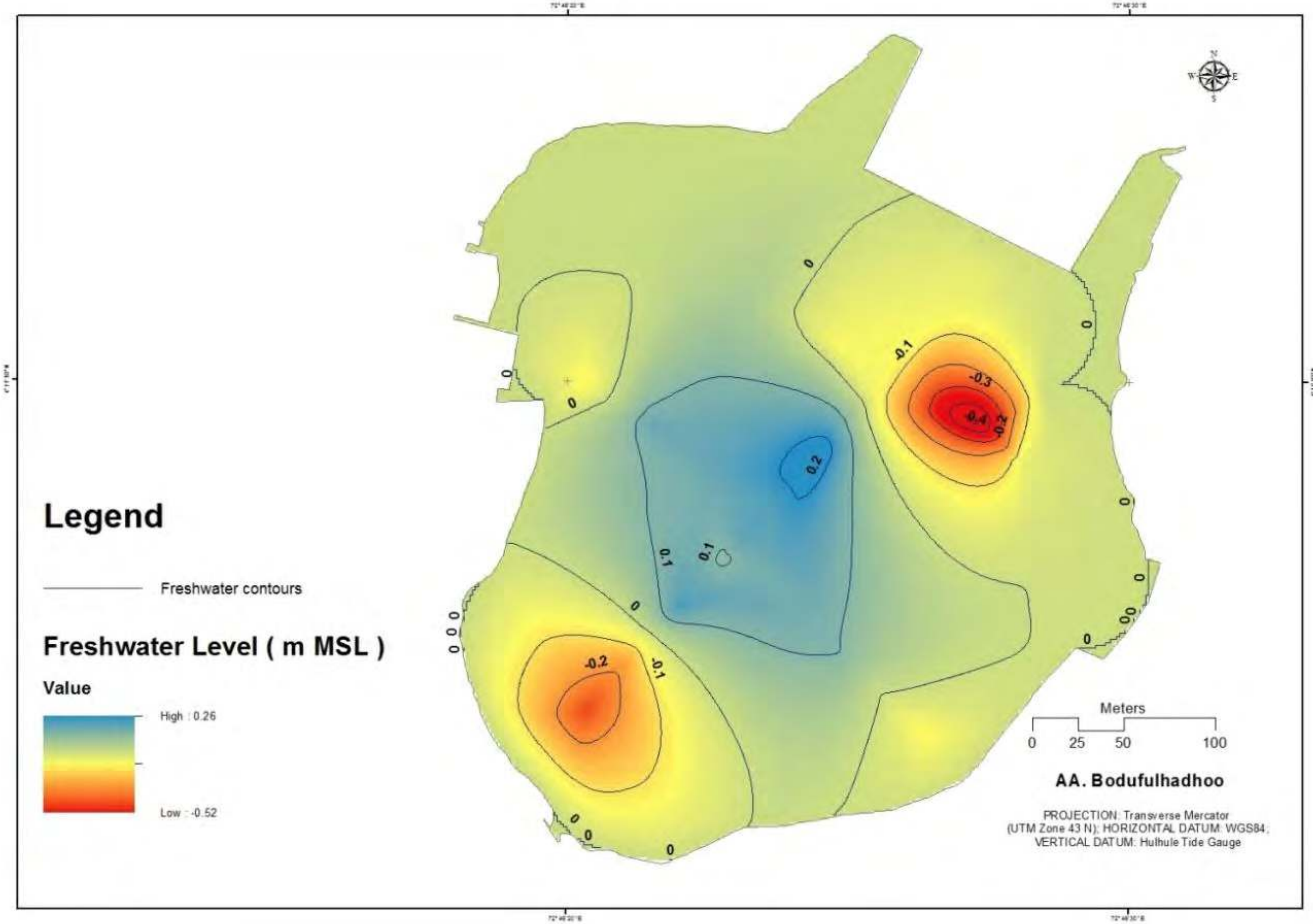


Figure 9.10: Freshwater Level in Bodufulhadhoo Island

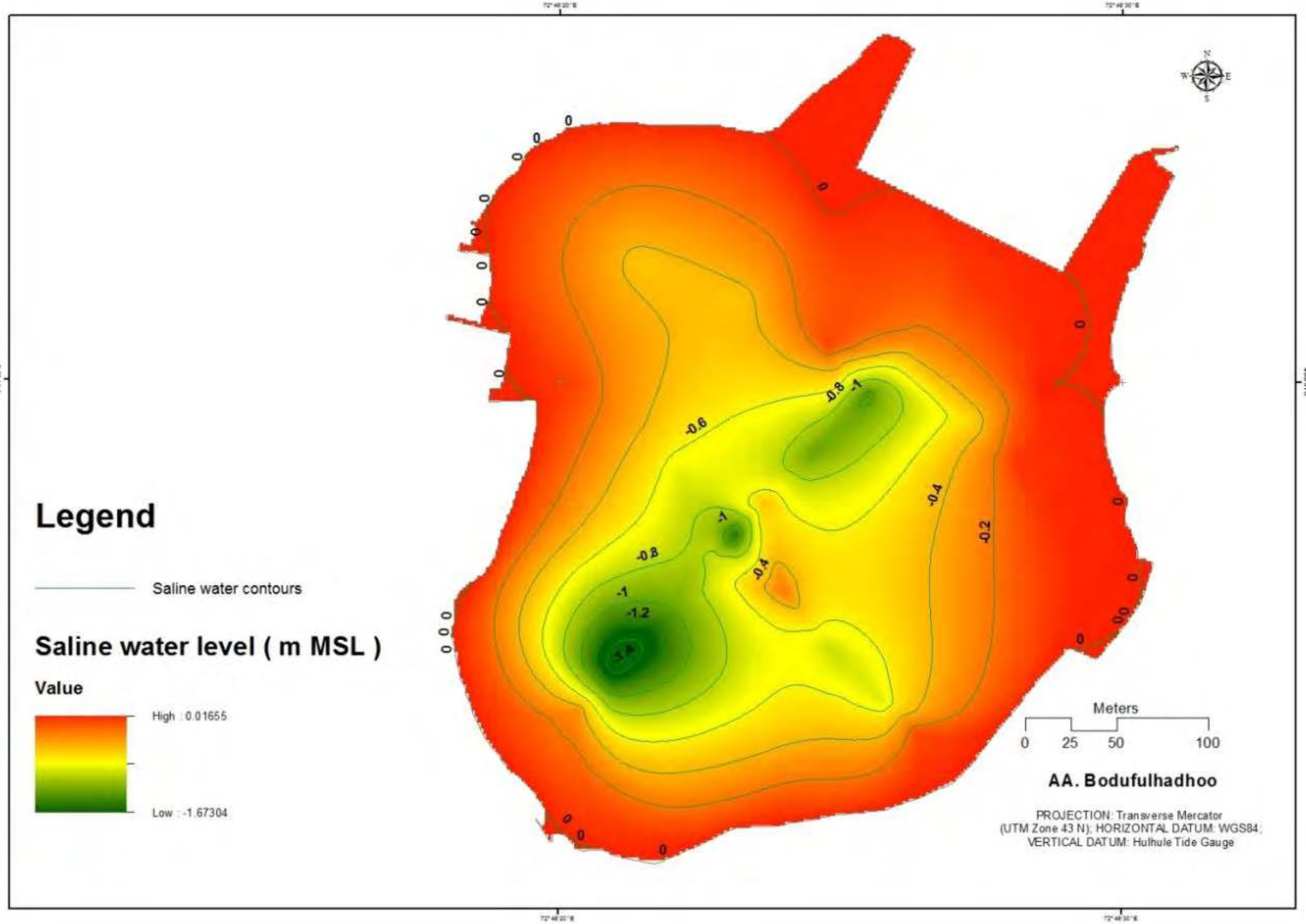


Figure 9.11: Saline water Level in Bodufulhadhoo Island

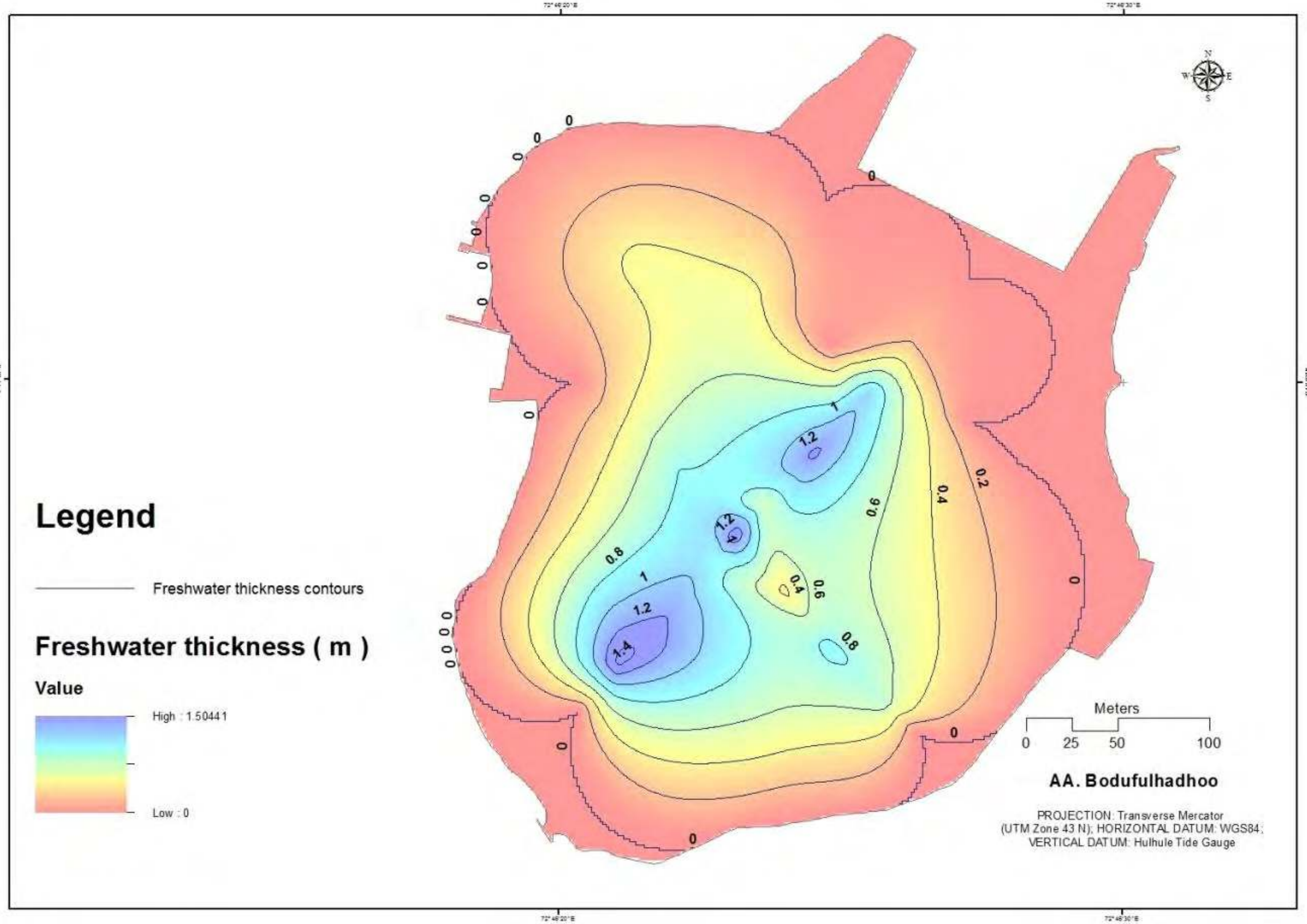


Figure 9.12: Freshwater thickness in Bodufulhadhoo Island

The maximum freshwater thickness of the island is 1.5 m. According to Falkland, 1994, the freshwater level thickness of the island is 7 m. The relevant calculations are as follows;

Average Annual Rainfall = 2050 mm/yr

Width of the island = 374 m

Length of the island = 385 m

Freshwater lens Thickness (m)

= (6.94*log (width of the island)-14.38)*Average Annual Rainfall = 7 m

9.8.1 Water balance and recharge

An annual estimation is carried out based on water balance method. Rainwater harvesting is calculated using number of rainwater harvesting units in the island. According to the spatial mean annual rainfall of Maldives, the island is reported as 2050 mm/year. Evapotranspiration was estimated using crop water requirement for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. The groundwater extractions were estimated from amount of water usage in different sectors (residential, resorts, restaurants, agriculture and farming).The difference between recharge and groundwater extraction is taken to estimate different in storage.

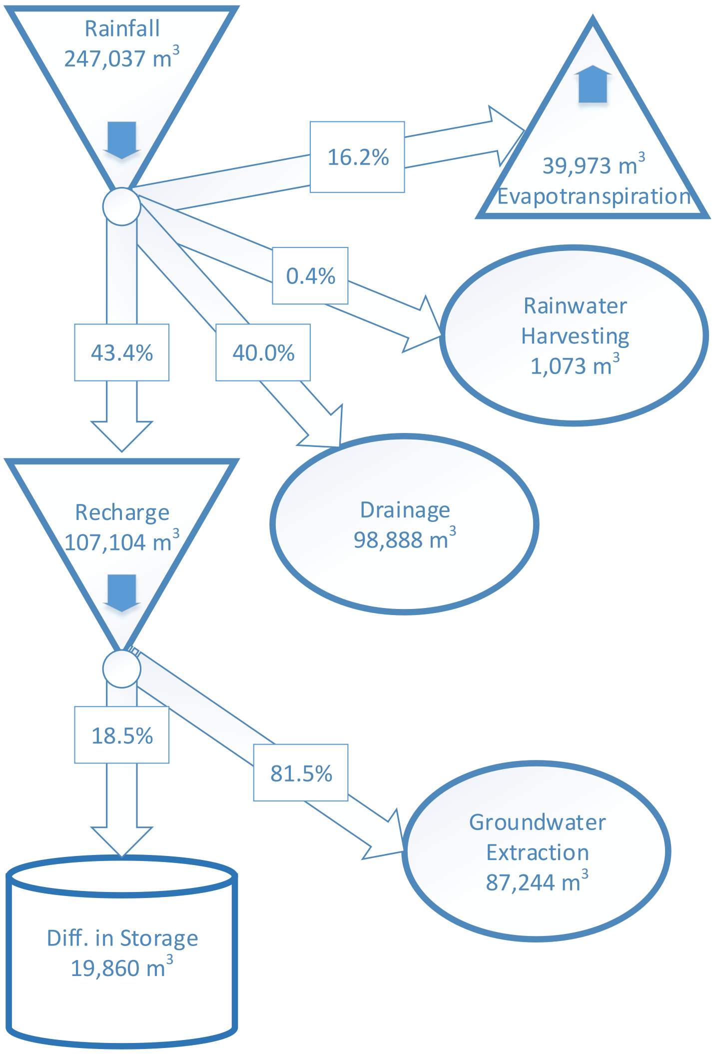


Figure 9.13: Schematic of water balance in Bodufulhadhoo Island

9.8.2 Sustainable yield of the lens

Sustainable yield of the water lens refers to the safe extraction potential of a given groundwater aquifer without significantly affecting its quality or quantity. This parameter is an important factor in the sustainable development of islands as it allows planning and design of water and sanitation intervention in islands.

The island has a sustainable yield of 54 m^3 per day which was calculated subtracting groundwater extraction from recharge volume derived from water balance (

Figure 8.13). According to Metai & Unit, n.d., based on geophysical investigations and drilling programme concluded that the safe sustainable yield was about 10% of mean annual rainfall. Such that the expected sustainable yield for the island should be 68 m^3 per day.

9.8.3 Permeability test

Permeability tests were carried out in the locations as outlined in Figure 9.14.

Figure 9.14: Permeability Testing Locations

The estimated permeability values for the above test locations are presented below.

Table 9.11:The estimated permeability Values

r_e		0.026
r_1		0.0285

Point	H	Tu	Cs	H/re	Q	K (m/s)	K (m/day)
PT1	0.6	1.55	43	23.1	1.2E-05	1.22E-05	1.06
PT2	0.7	1.36	50	26.9	1.3E-05	1.39E-05	1.20

Q (l/min)	Q (m^3/s)
0.7	1.17E-05
0.8	1.33E-05

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m^3/s), H = Height of water in well (m), l = length of perforated section (m), r_1 = outside radius of casing (radius of hole in consolidated material) (m), r_e = effective radius of well = r_1 (area of perforations) / (outside area of perforated section of casing) : $r_1 = r_e$ in consolidated material that will stand open and is not cast, C_u and C_s =Conductivity Coefficients, and T_u = distance from water level in casing to water table (m).

9.8.4 Groundwater availability

1) The selected Bodufulhadhoo island has dimensions of width = 389 m and length = 414 m, with a total land area of 11.92 ha, a population of 608 persons, and a land use of built-up area 2.52 ha (21.2%), thick vegetation 0.77 ha (6.4%), light vegetation 2.37 ha (19.9%), and barelands 6.26 ha (52.5%).

2) In order to recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of freshwater lens (FWL) and its associated recharge-discharge characteristics, 25 number of Electrical Resistivity (ER) location readings along 04 representatively selected transects were collected.

3) Soil overburden permeability tests (constant head) were carried out at 02 locations. In addition, groundwater level was also recorded at 04 locations where groundwater water quality samples were tested.

4) Permeability tests were carried out at representatively selected 02 number of locations. The measured permeability (K m/day) values ranged from a minimum of 1.06 m/day to a maximum of 1.20 m/day, with an average of 1.13 ± 0.10 m/day (Mean ± 1 Standard Deviation).

5) The ground elevation values ranged from a minimum of 0.76 m MSL to a maximum of 1.55 m MSL, with an average of 1.01 ± 0.17 m MSL (Mean ± 1 Standard Deviation).

6) The upper boundary of the freshwater lens (FWL) varied from a minimum of -0.17 m MSL to a maximum of 0.26 m MSL, with an average of 0.07 ± 0.11 m MSL (Mean ± 1 Standard Deviation).

7) The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -1.68 m MSL to a maximum of 0.02 m MSL, with an average of -0.49 ± 0.45 m MSL (Mean ± 1 Standard Deviation).

8) Accordingly, the freshwater lens (FWL) thickness values ranged from a minimum of 0.17 m to a maximum of 1.51 m, with an average of 0.81 ± 0.39 m (Mean ± 1 Standard Deviation).

9) The groundwater profile in the island is characterised by a relatively Low (0.43%) Rainwater Harvesting, relatively Very High (40.03%) Drainage, relatively Very High (43.36%) Recharge, while the water use shows relatively Very High (81.46%) Groundwater extraction, leading to relatively Very Low (18.54%) Difference in Balance Storage.

10) The freshwater lens (FWL) volume calculated based on ER transect test data is 10,298 m^3 with a maximum FWL thickness of 1.51 m. The potential maximum FWL volume and thickness estimated based on Falkland (1994) method are 14,956 m^3 and 7.12 m.

9.8.5 Conclusive Comments and Recommendations

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 54 m^3 per day, while it is 68 m^3 per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 176 m^3 per day and this exceeds the allowable Safe Yield in the island by 259% (Highly stressed) with severe up-coning and severe drawdown in freshwater lens cross-sections. The water samples tested were found to be Highly Odorous with 100.0% or 10/10 samples tested producing odour. The Hydrological condition of the freshwater lens aquifer can be categorised as Moderate to Low based on above measurements and findings while Water quality aspects can be regarded as Contaminated with an Average Electrical Conductivity (EC) of 6,182.47 ± 3,748.82 µS/cm with measured values ranging from a minimum of 1,523.60 µS/cm to a maximum of 11,510.90 µS/cm, and an Average Ammonia Concentration of 0.31 ± 0.32 mg/L with measured values ranging from a minimum of 0.02 mg/L to a maximum of 0.95 mg/L.

The ER test results indicate up-coning at several cross sections, indicating that the freshwater lens is stressed. The readings were taken towards the end of the dry period and the freshwater lens can be assumed to be depleted at the time of measurement. The Availability of space for incorporating recharge measures and related infrastructure is Low while therefore the Potential for Recharging is considered to be Low. Overall recommendation for groundwater recharging would be to use recharging pits in individual households and land blocks.

10 ADH. DHIGURAH ISLAND

10.1 General overview of the island

The island of Dhigurah is located at 03°31’35”N and 72°55’26”E in the Alif Dhaalu Administrative Atoll. The island is 3759 m long and 286 km wide, giving it an area of 52.1 Hectares. The population of the island is 610, via the 2014 Census. It is also a popular tourist destination with majority of the working population in the tourism sector. The island has a harbor at its northern side. The island does not have a water supply network. The houses are connected to one local outfall pipe for waste disposal.

Table 10.1: Basic statistical information on Dhigurah island in Alif Dhaal Atoll.

Name of the island	ADh.Dhigurah
Longitude and Latitude	03°31’35”N, 72°55’26”E
Area	41.96 ha
Population (Census, 2014)	610
Distance from Atoll Capital (Adh.Mahibadhoo)	25.55km
Distance from Male’	96.8km
Harbour	Present
Island sewerage network	Yes (Local)
Water supply network	No
Other infrastructure	No

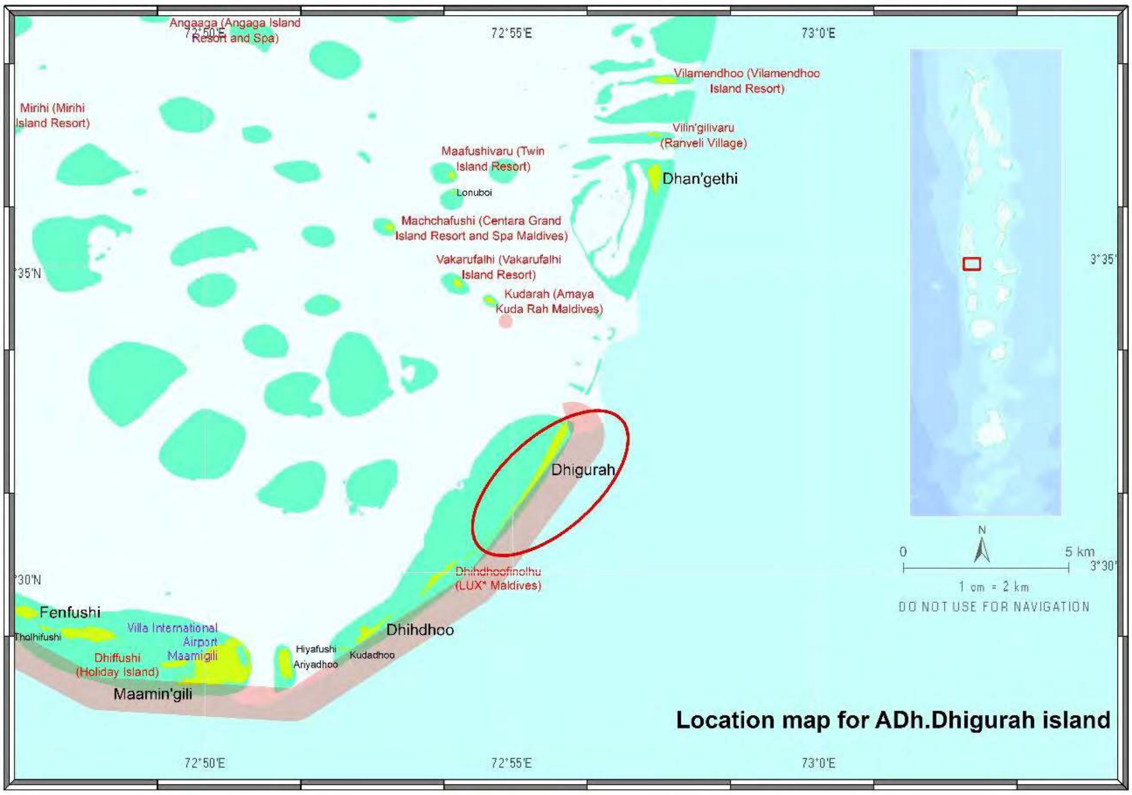


Figure 10.1: Location map for Dhigurah island in Alif Dhaal Atoll

10.2 Geology and vegetation

The island is around 3.1km long and 0.13km wide. Around 2/3 of the island is covered in vegetation. The southern half of the island is covered entirely by said vegetation. Some of the vegetation is also concentrated at the northern edge next to the harbor. Farming takes place on the southern half of the island. Only about a third of the island is populated, which is the northern end of the island.

10.3 Topography

The island has a topography that ranges from an elevation of 0.76 meters to 2.22 meters above Mean Sea Level, with an average elevation of 1.51 meters above MSL. Figure 10.2 shows map of Dhigurah Island showing spot heights and digital terrain model (DSM).

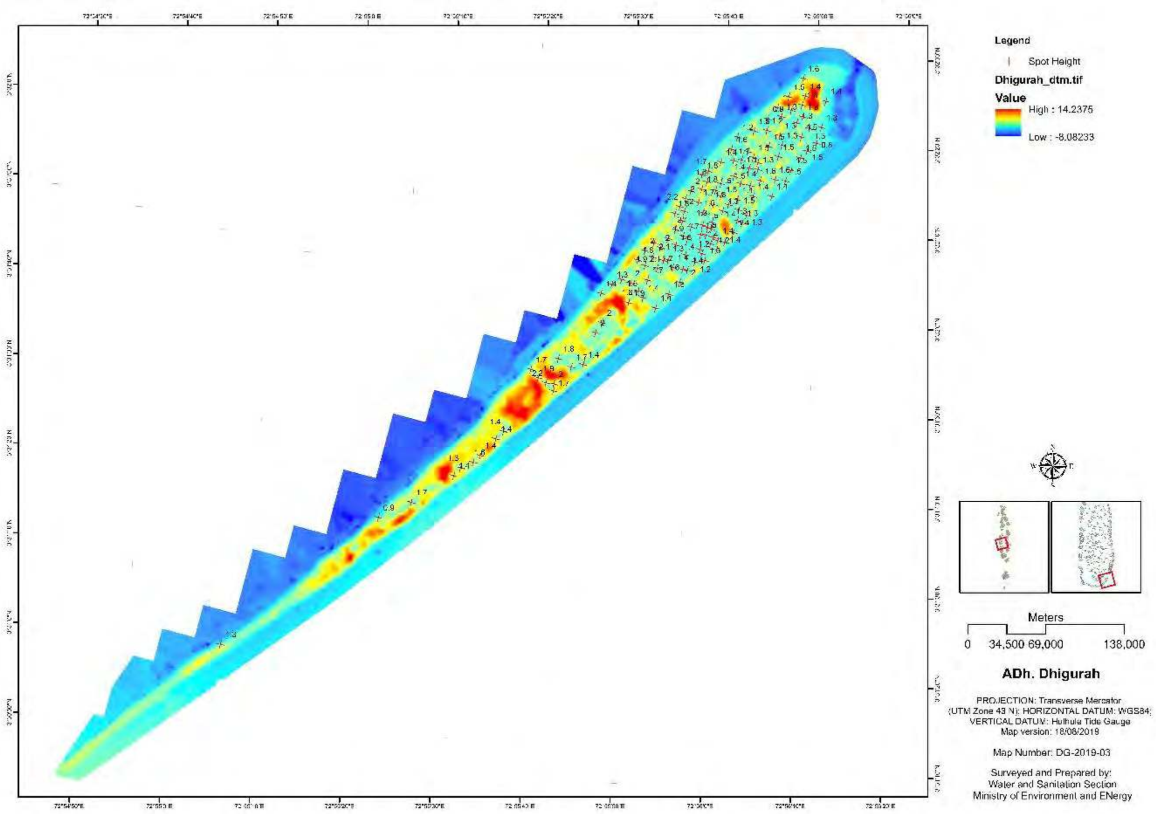


Figure 10.2: Digital Terrain Model of Dhigurah showing spot heights

10.4 Climate

Dhigurah experiences the typical two monsoons namely, north east monsoon from November to April and South-west monsoons from April to November. There are no specific wind and rainfall data available for Dhigurah as there are no weather monitoring stations on the island.

10.5 Demography

Dhigurah has a population of 610 via the 2014 Census, of which 522 are locals and 88 are foreigners. However this figure may be inaccurate as the island council reports a higher population of 685 people as of 2019. When looking at the total population there are 34 more males than females (53:47 percent). When only the local population is considered there are more females than males, with 32 more females than males (53:47 ratio). Amongst the foreigners there are significantly more males than females with 77 males and 11 females. The following graphs and table illustrate the demographic breakdown.

Table 10.2: Demographic Breakdown of Dhigurah Island

Atoll	locality	Resident population (Census, 2014)								
		Total			Maldivians			Foreigners		
		Both sexes	Male	Female	Both sexes	Male	Female	Both sexes	Male	Female
Adh	Dhigurah	610	322	288	522	245	277	88	77	11

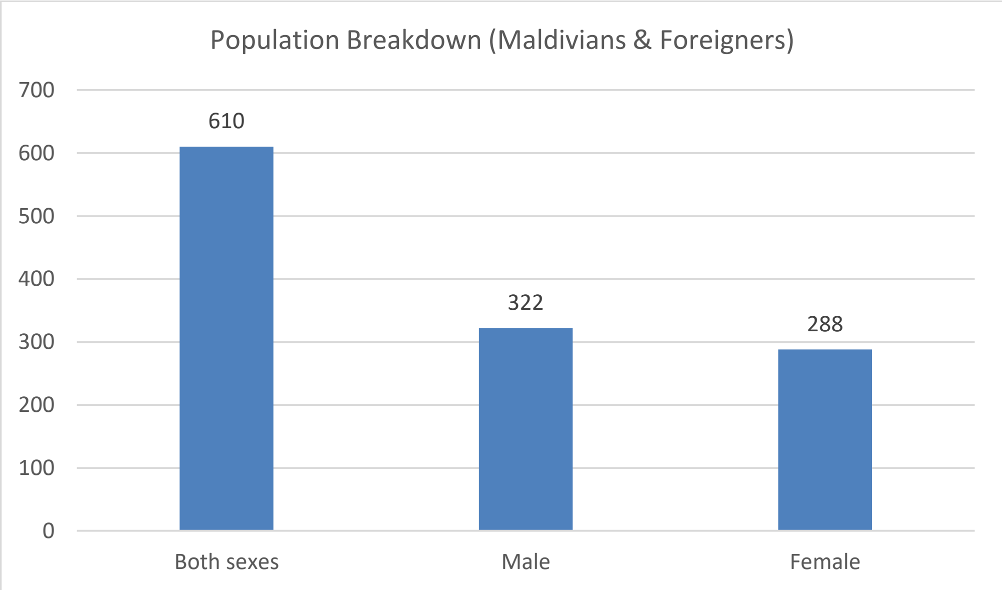


Figure 10.3: Population breakdown of Dhigurah (Maldivians & Foreigners)

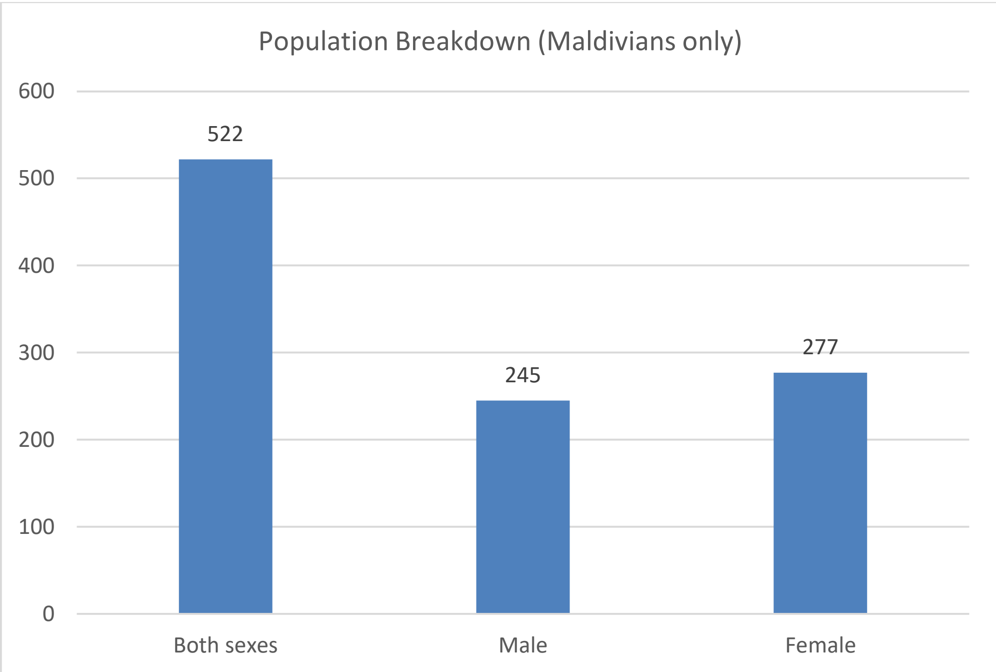


Figure 10.4: Population breakdown of Dhigurah (Maldivians)

10.6 Socio-economic condition

The island is an extremely popular tourist destination, as it's one of the few places where whale sharks are year round residents. As a result of this, majority of the working population is engaged in the tourism sector, with a few locals in the construction industry. The number of guest houses has been increasing drastically in the past three years. The island is also a popular diving destination, with a dive center on the island. Aside from the tourism sector, many residents find an occupation in the farming that takes place on the island.

10.7 Existing water and sanitation situation

The island does not have a water supply network. For sanitation the island has a local outfall pipe to which the households are connected to.

The primary source of drinking water in the island is from either or community or household rainwater tanks, and bottled water. When rainwater runs out during the dry season in many households, water is often taken from community tanks or other households for cooking purposes. There are plans in the 2019 budget to construct both a water supply network and sewerage network in the island.

10.8 Results

10.8.1 Water sources and water use

Based on domestic, commercial, institutional and industrial water usage, a total of 208,759.79 liters of groundwater are estimated to be used every day. Otherwise stated, 342.23 liters of groundwater are used per capita per day. It should be noted that out of the 8 islands surveyed, Dhigurah has the highest water usage per capita per day. The respective water use situations are detailed in the following sections.

10.8.1.1 Domestic water use situation

Based on the questionnaire to collect data on domestic water consumption, a summary of results are present in this section.

According to the survey, 94% of the households surveyed uses HDPE rainwater tanks as their main storage for water. A total of 35% households use rainwater for drinking and 100% use it for cooking. None of the surveyed houses use rainwater for bathing or washing.

0% of the households use groundwater as drinking. Groundwater is mainly used for non-potable use in all the households surveyed.

The following table summarizes the data for Dhigurah island.

Table 10.3: Groundwater and rainwater use data for Dhigurah Island

Rainwater	
Households with rainwater tanks	15 of 16 i.e. 94%
Rainwater use for drinking	35%
Rainwater use for cooking	100%
Rainwater use for bathing and washing	0%
Groundwater	
Groundwater as drinking source	0%
Groundwater for cooking	0%
Groundwater for non-potable use	100%
Total number of household wells surveyed	17 (10%)
Percentage of wells surveyed fitted with pumps	100%

Based on the survey questionnaire, average daily water demand per capita for domestic purposes has been estimated based on the average amount of water used per person for showering, toilet flushing, laundry and gardening, this data is shown in table 10.4 The total domestic water use is estimated to be 240.21 liters per capita per day.

Table 10.4: Domestic Water Usage in Dhigurah Island

Shower/ Liters per capita per day	Toilet/ Liters per capita per day	Laundry/ Liters per capita per day	Gardening/ Liters per capita per day	**Total/ Liters per capita per day**
120	16	48	56	**240**

10.8.1.2 Commercial water use situation

Based on the questionnaire to collect data on commercial water consumption, a summary of results are present in this section. A total of 1 restaurant and 14 guesthouses were surveyed. 11 of these guesthouses housed their own restaurants.

For the guesthouses, the main use of groundwater was for showers, toilet flushing, gardening and dish washing for those guesthouses which contained restaurants. The following table presents a summary. A total of 9309.48 liters of groundwater are used by 6 guesthouses in Dhigurah.

Table 10.5: Commercial Water Usage

Name of Guesthouse	Number of rooms	Average occupancy throughout the year	Total Volume of water per day (Liters)	Total Volume of water per guest per day (Liters)
Athiri Beach	16	>50%	5869.92	270.04
TME retreats, Dhigurah	21	Fully occupied throughout the year	10051.73	239.33
Dhiguveli	19	Fully occupied for the majority of the year	9747.28	256.51
White sand	24	>50%	10206.38	303.76
Ufa Escape	5	<50%	1045.84	298.61
Bliss Dhigurah	16	<50%	2914.68	303.61
Dhigurah Retreat Beach	4	66.7%	1626.00	304.86
Atollkey	6	66.7%	1989.00	248.61
Boutique Beach Guesthouse	6	66.7%	1828.99	228.61
BB Island House Dhigurah	7	66.7%	3283.86	351.82
Auge Dhigurah	1	66.7%	304.83	228.61
Holiday Home @Dhigurah	3	66.7%	914.50	228.61
Dhigurah Beach Inn	5	66.7%	1524.16	228.61
Dhivehi Experience	3	66.7%	1294.50	323.61
Total:			52,600.66	

For the restaurants, the main use of groundwater was for dishwashing and toilet use. A total of 1 restaurant was surveyed and from this data, the total groundwater consumption for the 2 restaurants on this island was estimated to be 2043.50 liters.

10.8.1.3 Institutional water use situation

Based on the questionnaire to collect data on institutional water consumption, a summary of results are present in this section. Five institutions were surveyed for this study namely the powerhouse, pre-school, school, health center and council office. Groundwater in the institutions in Dhigurah Island are mainly used for gardening, mopping floors and flushing toilets. A total of approximately 7585.82 liters of groundwater are estimated to be used per day by the institutions. Therefore, a total of approximately 12.44 liters of groundwater are estimated to be used per capita per day by the institutions of Dhigurah Island.

Table 10.6: Water Usage in Institutions in Dhigurah Island

	Water Flushed (Liters per day)	Gardening (Liters per day)	Mopping (Liters per day)	Total Water Usage (Liters)	Institutional Groundwater Usage (Liters per day)	Institutional Groundwater Usage (Liters per capita per day)
Powerhouse	35	540	-	575	7586	12.44
Pre-School	58	1.50	10	69		
School	249	2160	200	2609		
Health Center	70	2160	30	2260		
Council	47	2025	-	2072		

10.8.2 Groundwater quality

Groundwater quality measurements were made at selected wells in Dhigurah for both physical and microbiological testing. The following table summarizes the water quality results.

Table 10.7: Summary of groundwater quality tests from Dhigurah, April 2019

Sample No	Odour	Physical Appearance
gw1	no	Pale yellow
gw2	yes	Clear with particles
gw3	no	Clear with particles
gw4	no	Clear with particles
gw5	no	Clear with particles
gw6	no	Clear with particles
gw7	No	Clear with particles
gw8	no	Clear with particles
gw9	no	Clear
gw10	yes	Clear with particles
gw11	no	Clear
gw12	no	Clear
gw13	yes	Clear with particles
gw14	No	Clear with particles
gw15	No	Clear
gw16	no	Clear
gw17	no	Clear with particles
gw18	no	Clear with particles
gw19	no	Pale yellow with particles
gw20	no	Cloudy with particles

Sample No	EC (µS/cm)	TDS (mg/L)	pH	Turbidity	DO (mg/L)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
gw01	954.2	552	7.23	0.23	1.18	31.50	0.41	31.4	0.05	0.27		
gw02	2373.6	1394	7.38	6.25	1.32	30.61	1.08	198.2	6.2	0.28		
gw03	2839.8	1668	7.71	0.3	4.84	30.56	1.31	13.3	0.06	0.82		
gw04	767.2	427	7.55	0.84	3.23	33.83	0.31	46.0	0.14	0.5		
gw05	502.4	290	7.76	0.15	2.77	31.67	0.21	22.6	0.04	0.16		
gw06	2028.3	1239	7.66	0	6.03	28.39	0.96	36.3	0.1	0.23		
gw07	1170.5	700	7.93	0.88	1.99	29.56	0.53	59.7	0.06	0.14		
gw08	1392.7	824	7.36	1.69	1.99	30.17	0.63	56.2	0.05	0.21	866	27
gw09	1057.7	612	7.57	0.87	0.69	31.44	0.46	55.3	0.1	0.15		
gw10	2043.1	1193	7.32	10.83	3.31	30.94	0.92	19.9	0.64	0.14	>2420	55
gw11	955.7	559	7.38	0.66	1.51	30.83	0.42	54.0	0.04	0.17		
gw12	2000	1000	7.48	0.01	0.54	28.94	1.01	-	-	-		
gw13	1233	719	7.62	0.88	2.47	31.00	0.54	29.2	1.01	0.06		
gw14	851.4	501	7.74	0.11	3.18	30.44	0.37	16.8	0.02	0.12	1733	580
gw15	20685	11966	7.16	0.16	2.47	31.44	10.8	156.2	0.43	0.22		
gw16	997.4	594	7.65	0.11	3.51	29.78	0.44	15.5	0.03	0.13		
gw17	2191.2	1286	7.42	0.21	1.41	30.61	1	40.3	0.06	0.17		
gw18	2722.4	1634.67	7.28	1.61	1.2	29.33	1.29	-	-	-		
gw19	3074.7	1809	7.45	0.33	4.88	30.50	1.43	152.2	0.1	0.24		
gw20	4676	2338	7.27	-	-	1.4	27.43	-	-	-		

	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)
WHO Standards	Suggested maximum limit of freshwater for potable purposes = 1500 µS/cm Suggested maximum limit of freshwater for non-potable purposes = 2500 µS/cm	-	-	-	-	-

	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
WHO Values	-	Guideline Value = 50 mg/L-NO3	Natural Level of Ammonia < 0.2 mg/L Threshold odour concentration = 1.5 mg/L Taste threshold = 35 mg/L	-	-	-

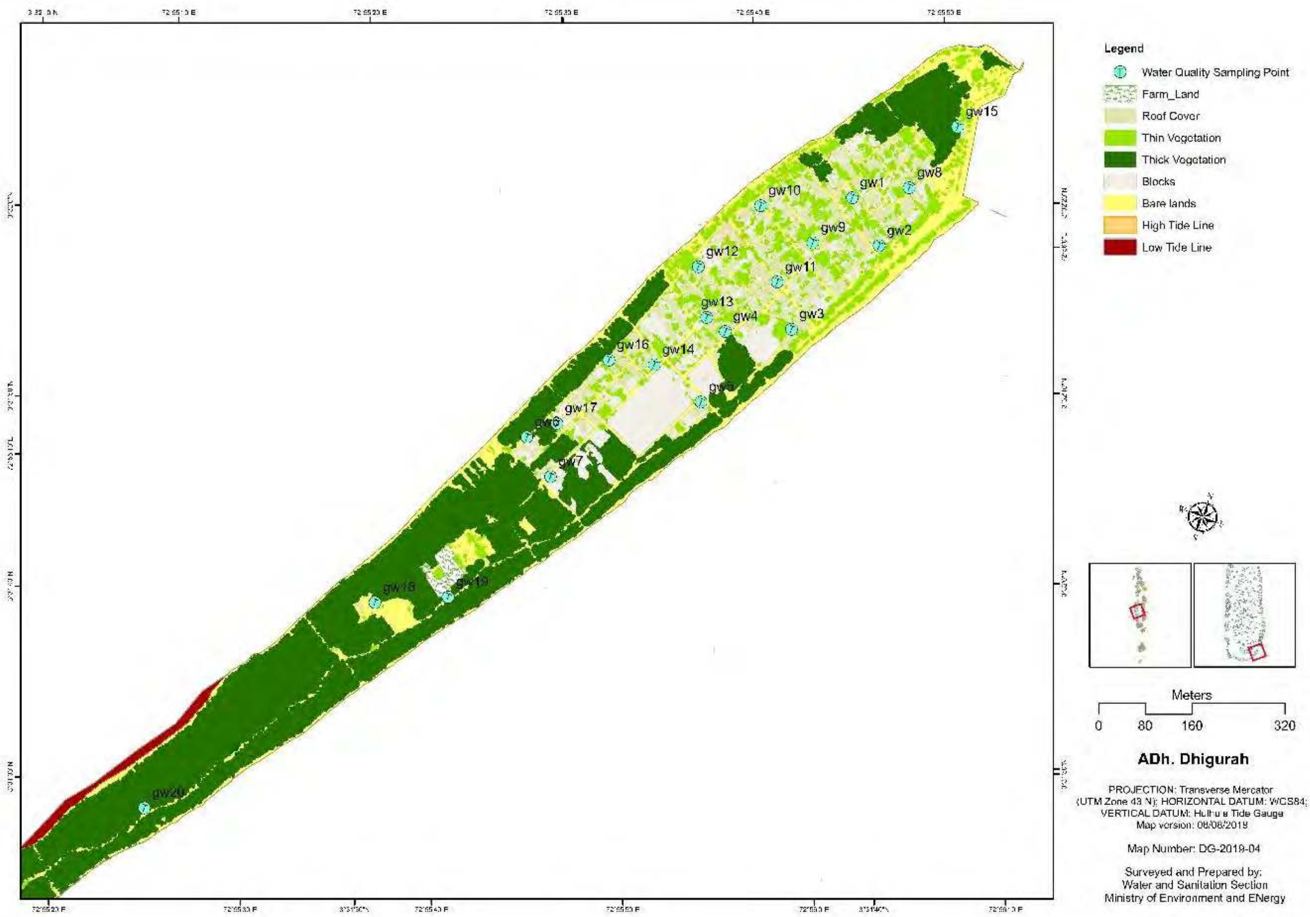


Figure 10.5: Location of groundwater sampling points in Dhigurah Island

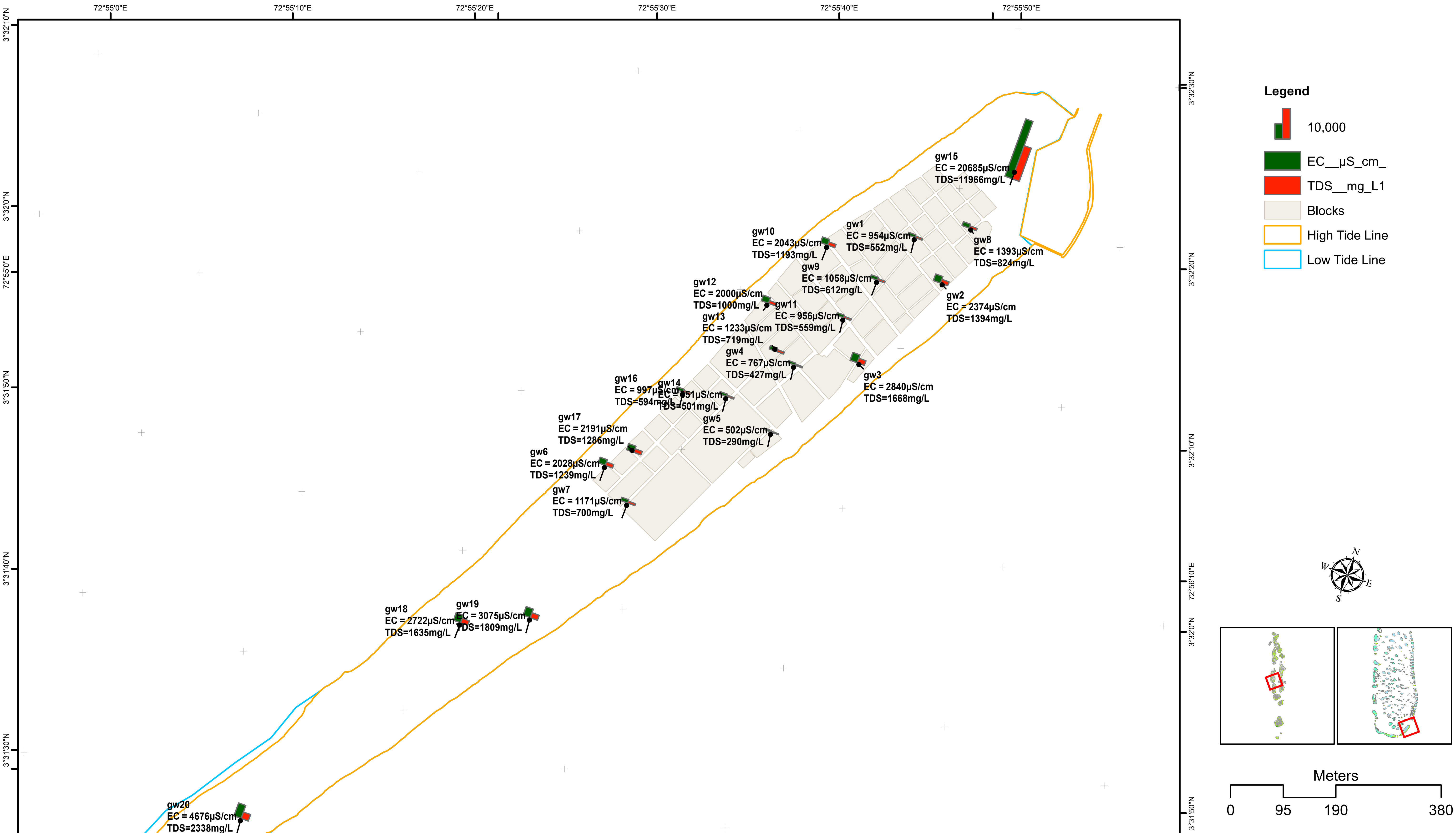
Based on the full results and the summary shown in Table 10.7, the following observations are made:

- The Electrical Conductivity (EC) of the groundwater is generally high with an average EC of 2725.81µS/cm which exceeds the acceptable limit for potable water of 1,500 µS/cm and the acceptable limit for freshwater for non-potable purposes of 2500 µS/cm (refer section 2.2). The EC ranged from 502.4 µS/cm to 20684.8 µS/cm. 8 of the tested 18 water samples (44.4%) exceed the WHO acceptable limit for potable water and 5 of the tested 18 samples (27.8%) exceeded the acceptable limit for freshwater for non-potable purposes of 2500 µS/cm. The sample with the highest EC (gw15) was taken 30m from the harbor as can be seen from Figure 10.5, therefore the high EC was as expected. As the island decreases in width towards the Southwest, the EC increases. The samples with the lower EC were observed in the center of the island while the samples taken from the periphery of the island generally have a higher EC.
- Total Dissolved Solids ranged from 290 mg/L to 11966 mg/L with an average of 1565.28 mg/L. As TDS readings are calculated from Specific Conductance and Conductivity, the trends shown in TDS readings are similar to EC.
- The pH ranged from 7.16 to 7.93 with an average pH of 7.50. The pH of all samples were within the WHO permissible limits of 6.5-8.5.
- Turbidity ranged from 0 NTU to 10.83 NTU with an average of 1.45 NTU. As a guide, "crystal-clear" water has a turbidity below 1 NTU, and water becomes visibly cloudy at 4 NTU and above.
- Dissolved oxygen levels ranged from 0.54 mg/L to 6.03 mg/L. The average value was 2.50 mg/L.

- The salinity of groundwater ranged from 0.21 PSU to 10.8 PSU with an average salinity of 1.33 PSU. Only sample gw15 with a salinity of 10.8 PSU is the only sample with a higher salinity than 1.7 PSU.
- The average Nitrate concentration was 59.0 mg/L which exceeds the WHO guideline limit of 50 mg/L. The Nitrate concentrations ranged from lowest concentration of 13.3 mg/L to the highest concentration of 198.2 mg/L. 7 of the tested 17 tested water samples (41.2%) exceeded the WHO Nitrate concentration guideline limit. Sample gw15 with a high Nitrate concentration of 156.2 mg/L has a high Nitrate concentration as the sample was taken from a thickly vegetated area. Nitrate reaches groundwater as a consequence of natural vegetation. Sample gw19 which was taken from the farming area also has a high Nitrate concentration of 152.2 mg/L as groundwater often gets contaminated with Nitrate due to the application of inorganic nitrogenous fertilizers and manures.
- The average ammonia concentration was 0.54 mg/L. This falls below the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. The ammonia concentrations ranged from the lowest concentration of 0.02 mg/L to the highest concentration of 6.2 mg/L. Only 1 of the tested water samples had ammonia concentration higher that the WHO guideline value. Natural levels of ammonia are generally below 0.2 mg/L (WHO, 1993) and 13 of the 18 tested water samples showed concentrations below this level. There is no apparent correlation between increasing levels of ammonia and other nutrients.
- Phosphate concentrations ranged from 0.06 mg/L to 0.82 mg/L with an average concentration of 0.24 mg/L. There is no WHO drinking water guideline value for phosphate. However, it would normally be expected that phosphate concentrations in groundwater are less than 0.1 mg/L, where there are no impacts from human wastewater (e.g. effluent from septic tanks and ‘greywater’ from kitchens and bathrooms). Only 1 sample tested (5.55%) had a concentration lower than 0.1 mg/L.
- Total coliform levels were found to be significant and ranged from lowest count of 866 MPN/100 mL to the highest count of more than 2420 MPN/100 mL with an average of 1673 MPN/100mL. Faecal Coliform levels were found to be significant and ranged from lowest count of 27 MPN/100mL to the highest count of 580 MPN/100mL with an average of 719 MPN/100mL. Compared to other islands surveyed as part of this project, the groundwater of Dhigurah has low faecal coliform levels as this island has a local sewerage network. However the groundwater layer is still contaminated with effluent.

In conclusion, Dhigurah Island contains groundwater with Electrical Conductivity higher than WHO acceptable limit for potable water and high TDS but low turbidity. Nitrate concentration was higher than WHO maximum guidance value, Ammonia concentration was lower than expected in natural, undisturbed groundwater but Phosphate concentration was higher than expected in natural, undisturbed groundwater. In terms of microbiological contamination, an island wide contamination is observed.

Additionally, the following pages contain maps which show the main physiochemical parameters displayed on map of the island.

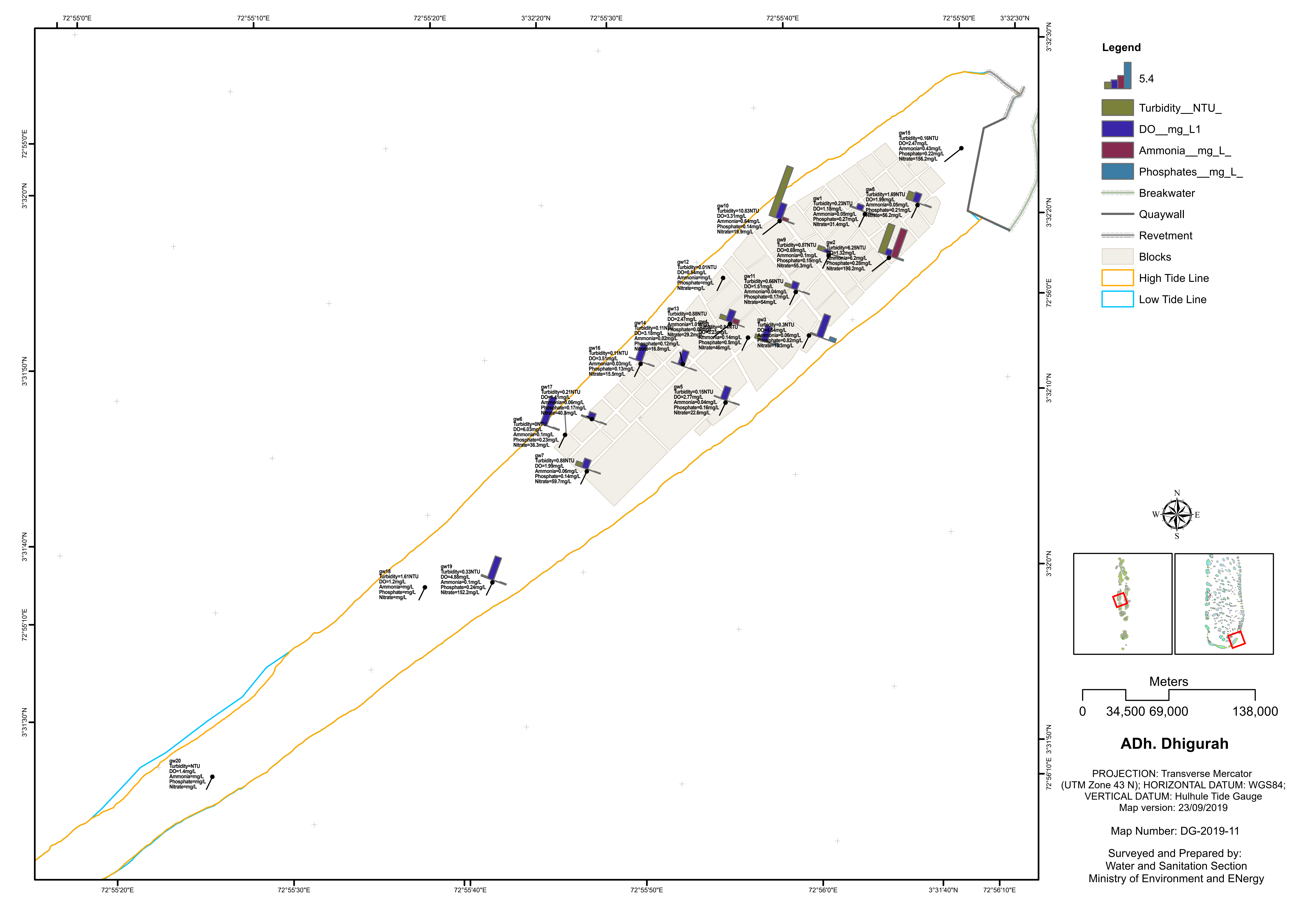


ADh. Dhigurah

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 07/08/2019

Map Number: DG-2019-11

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy



Legend
5.4
Turbidity__NTU_
DO__mg_L1
Ammonia__mg_L_
Phosphates__mg_L_
Breakwater
Quaywall
Revetment
Blocks
High Tide Line
Low Tide Line
N
S
E
W
Meters
0 34,500 69,000 138,000
ADh. Dhigurah
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 23/09/2019
Map Number: DG-2019-11
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

10.8.3 Geophysical survey

The Resistivity tests were carried out in the locations as outlined in Figure 10.6 below.

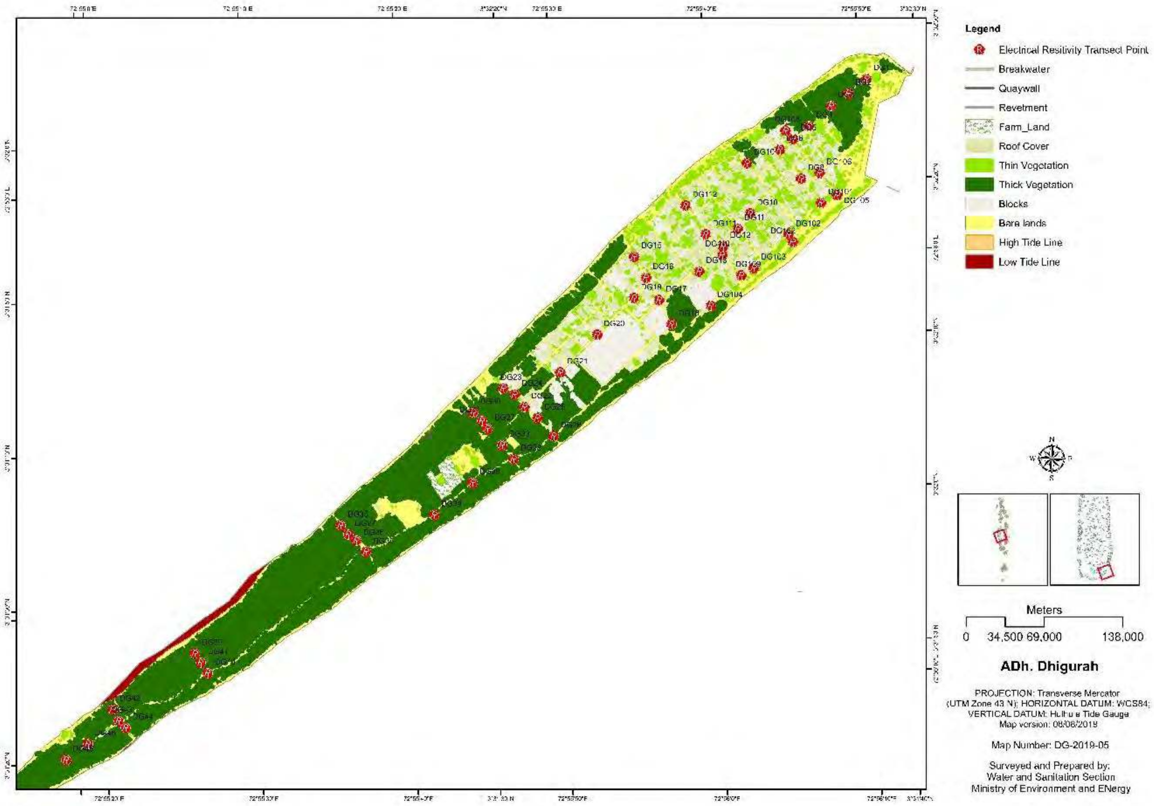


Figure 10.6: Location of ER points in Dhigurah Island

10.8.4 Aerial Surveys

Based on the aerial survey, a multiple dataset consisting of roof cover, thick vegetation area, thin vegetation area, bare lands and shoreline were extracted. This data is shown in Figure 10.7 and the table 10.8 shows the different area distribution.

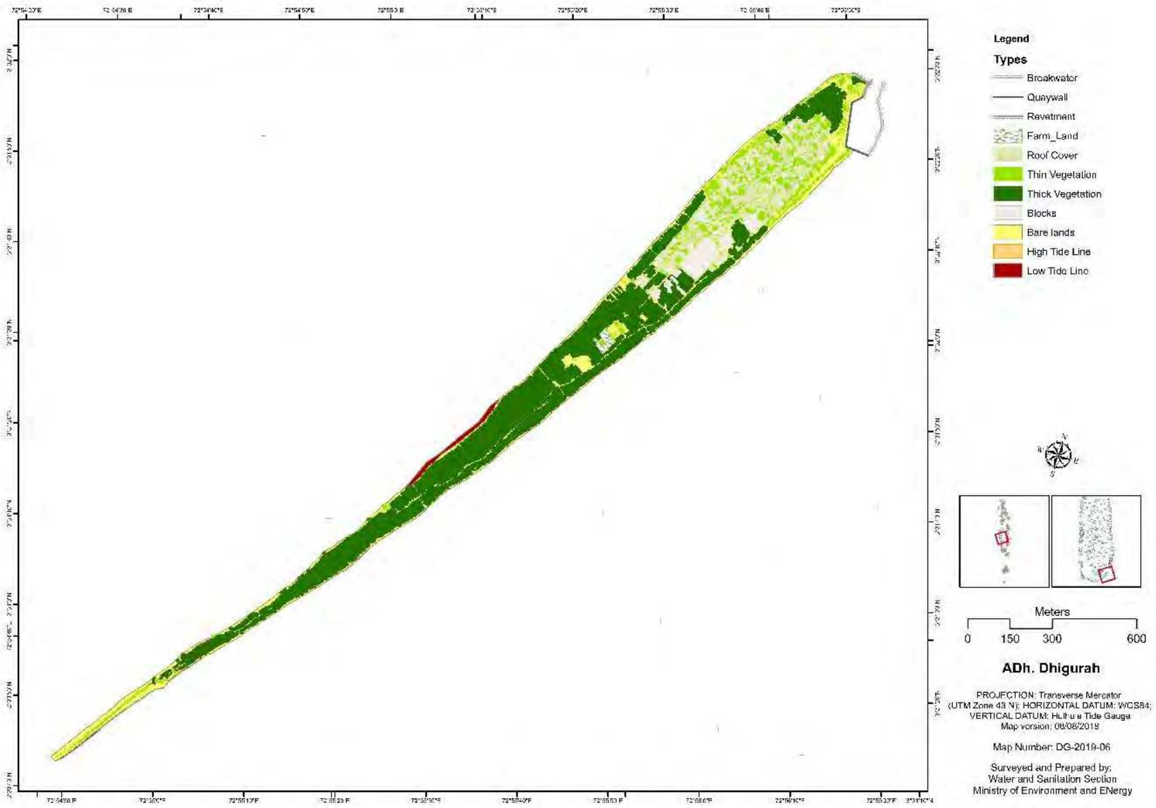


Figure 10.7: Area Distribution in Dhigurah Island

Table 10.8: Area Distribution in Dhigurah

	Area (Square Meters)	% of total area
Roof cover	39,471	7.6%
Vegetation (Thick)	266,021	51.3%
Vegetation (Light)	63,450	12.2%
Bare lands	149,343	28.8%
Farm Lands	2830	0.54%
Wetlands (Inland)	-	-

10.8.5 Freshwater lens

Based on the ER survey the depth to groundwater level and the freshwater-saline water interface was determined for a set of transverse transects as shown in Figure 10.8. Plots in the Figure 10.9 shows the cross sections of each transect line. The dotted lines in the plots indicating a simple interpolation of levels to mean sea level in the island boundaries. These cross sections were used to identify the spatial extent and volume of the freshwater lens while they were also useful in deriving implications on the stress level of the aquifer based on the observed, localized drawdown effect in the groundwater table and up-coning in the freshwater-saline interface, defining the upper and lower boundaries of the freshwater lens in an island.

The Table 10.9 illustrate the freshwater volume calculation for the island. The area covered by freshwater for each transect line has been calculated. To estimate the total volume of available freshwater lens, the cross-section area of freshwater extent under each transect was multiplied by the distance between two transects. The sum of these lengths represents the cumulative length of the island

and thus, the above estimation could represent the total volume of the freshwater lens sandwiched between the groundwater table on top and freshwater-saline water interface in the bottom. Then the actual groundwater storage within this freshwater lens was calculated by multiplying the estimated total lens volume with the porosity of the topsoil in the island.

This estimation represents the total available freshwater volume within the freshwater lens at any given time (time of the measurement). The measurements were carried out towards the end of the dry period and the freshwater lens is presumed to be undergoing a 'stressed' condition due to continued groundwater abstractions despite reduced recharge in the dry period. Falkland (1994) method can be used to estimate the freshwater lend thickness under salient conditions using average annual rainfall, length and width of the island, and the comparison was used as a measure of stress level of the freshwater lensgroundwater storage was calculated by multiplying total lens volume with porosity of the island.

Table 10.9: Freshwater Volume Calculation for Dhigurah Island

Transect Line	Location	Point ID	Distance from shore (m)	Elevation (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
1	Start		0		0	0			
			13		0	0			
	DG108	ER	50	1.08	0.18	-2.01	40		
	DG5	ER	74	1.255	0.16	-1.81	52		
	DG106	ER	165	1.466	0.38	-2.21	207		
	DG105	ER	225	1.433	0.13	-0.95	110		
			252		0	0	14		
	End		265		0	0	0		
	Total						423	46	19444
2	Start		0		0	0			
			13		0	0			
	DG6	ER	76	1.3	0.36	-2.26	83		
	DG8	ER	152	1.427	0.38	-2.5	207		
	DG101	ER	225	1.494	0.1	-0.86	140		
			252		0	0	13		
	End		266		0	0	0		
	Total						443	66	29456
3	Start		0		0	0			
			14		0	0			
	DG107	ER	65	1.805	0.4	-1.91	59		
	DG102	ER	259	1.45	0.27	-0.74	323		
			270		0	0	5		
	End		284		0	0	0		
	Total						387	88	33856
5	Start		0		0	0			
			15		0	0			
	DG11	ER	166	1.204	0.27	-4.5	362		
	DG103	ER	254	1.571	0.21	-0.34	234		

Transect Line	Location	Point ID	Distance from shore (m)	Elevation (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
			276		0	0	6		
	End		291		0	0	0		
	Total						602	50	30327
6	Start		0		0	0			
			14		0	0			
	DG112	ER	58	1.528	0.27	-1.97	48		
	DG111	ER	134	1.458	0.29	-2.95	209		
	DG110	ER	189	1.548	0.25	-3.35	190		
	DG109	ER	250	1.501	0.25	-0.42	130		
			275		0	0	8		
	End		289		0	0	0		
	Total						585	91	53451
7	Start		0		0	0			
			14		0	0			
	DG15	ER	59	2.09	0.48	-2.42	66		
	DG16	ER	111	1.479	0.27	-3.23	164		
	DG17	ER	166	1.414	0.27	-3.4	199		
	DG18	ER	223	1.601	0.17	-2.4	177		
			270		0	0	61		
	End		285		0	0	0		
	Total						666	258	172273
8	Start		0		0	0			
			12		0	0			
	DG23	ER	61	1.969	0.39	-2.33	67		
	DG24	ER	86	1.982	0.52	-3.9	91		
	DG22	ER	120	1.857	0.47	-2.5	124		
	DG25	ER	156	1.365	0.39	-3.54	124		
	DG26	ER	208	1.374	0.27	-2.16	167		
			223		0	0	18		
	End		235		0	0	0		
	Total						590	209	123606
9	Start		0		0	0			
			11		0	0			
	DG30	ER	52	1.452	0.35	-2.2	52		
	DG31	ER	78	2.121	0.38	-2.47	71		
	DG27	ER	98	2.143	0.42	-2.6	58		
	DG33	ER	144	1.741	0.4	-2.56	139		
	DG28	ER	183	1.067	0.28	-2.57	113		
			207		0	0	33		
	End		217		0	0	0		

Transect Line	Location	Point ID	Distance from shore (m)	Elevation (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
	Total						467	202	94476
10	Start		0		0	0			
			8		0	0			
	DG35	ER	31	1.587	0.24	-2.2	29		
	DG37	ER	56	1.751	0.24	-2.35	62		
	DG36	ER	78	1.961	0.23	-2.2	55		
	DG38	ER	109	1.942	0.2	-1.95	71		
			150		0	0	45		
	End		158		0	0	0		
	Total						261	350	91408
11	Start		0		0	0			
			6		0	0			
	DG39	ER	36	1.683	0.23	-1.95	33		
	DG41	ER	59	1.059	0.25	-2.1	53		
	DG40	ER	86	1.377	0.21	-2.02	60		
			115		0	0	33		
	End		121		0	0	0		
	Total						179	339	60667
12	Start		0		0	0			
			5		0	0			
	DG42	ER	27	1.731	0.25	-1.46	18		
	DG43	ER	54	1.833	0.28	-1.54	49		
	DG44	ER	75	2.331	0.22	-1.02	31		
			102		0	0	17		
	End		108		0	0	0		
	Total						115	145	16780
									725743

Volume of lens = 725,743 m^3

Groundwater Storage = Porosity (20%) x Lens volume (m^3) = 145,149 m^3

Table 10.10: ER Survey Results of Longitudinal Sections for Dhigurah Island

Transect Line	Location	Point ID	Distance from shore (m)	Elevation (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)
13	Start		0		0	0
			122		0	0
	DG106	ER	134	1.466	0.38	-2.21
	DG8	ER	179	1.427	0.38	-2.5
	DG10	ER	309	1.393	0.28	-4.7
	DG11	ER	353	1.204	0.27	-4.5
	DG12	ER	401	1.489	0.33	-2.31
	DG110	ER	470	1.548	0.25	-3.35
	DG13	ER	538	1.513	0.31	-3.6
	DG17	ER	648	1.414	0.27	-3.4
	DG20	ER	795	1.607	0.44	-4.9
	DG21	ER	906	1.742	0.43	-3.9
	DG22	ER	1011	1.857	0.47	-2.5
	DG27	ER	1102	2.143	0.42	-2.6
	DG37	ER	1470	1.751	0.24	-2.35
	DG41	ER	1888	1.059	0.25	-2.1
	DG43	ER	2098	1.833	0.28	-1.54
	DG46	ER	2183	1.207	0.2	-0.8
	DG45	ER	2241	2.042	0.19	-0.6
			2319		0	0
	End		2441		0	0
	Total					
14	Start		0		0	0
			45		0	0
	DG1	ER	69	1.531	0.18	0.18
	DG2	ER	119	1.422	0.22	0.22
	DG3	ER	165	1.481	0.19	-0.6
	DG4	ER	271	1.255	0.181	-1.73
	DG5	ER	376	1.255	0.16	-1.81
	DG6	ER	413	1.3	0.36	-2.26
	DG107	ER	487	1.805	0.4	-1.91
	DG112	ER	645	1.528	0.27	-1.97
	DG15	ER	801	2.09	0.48	-2.42
			856		0	0
	End		901		0	0
	Total					

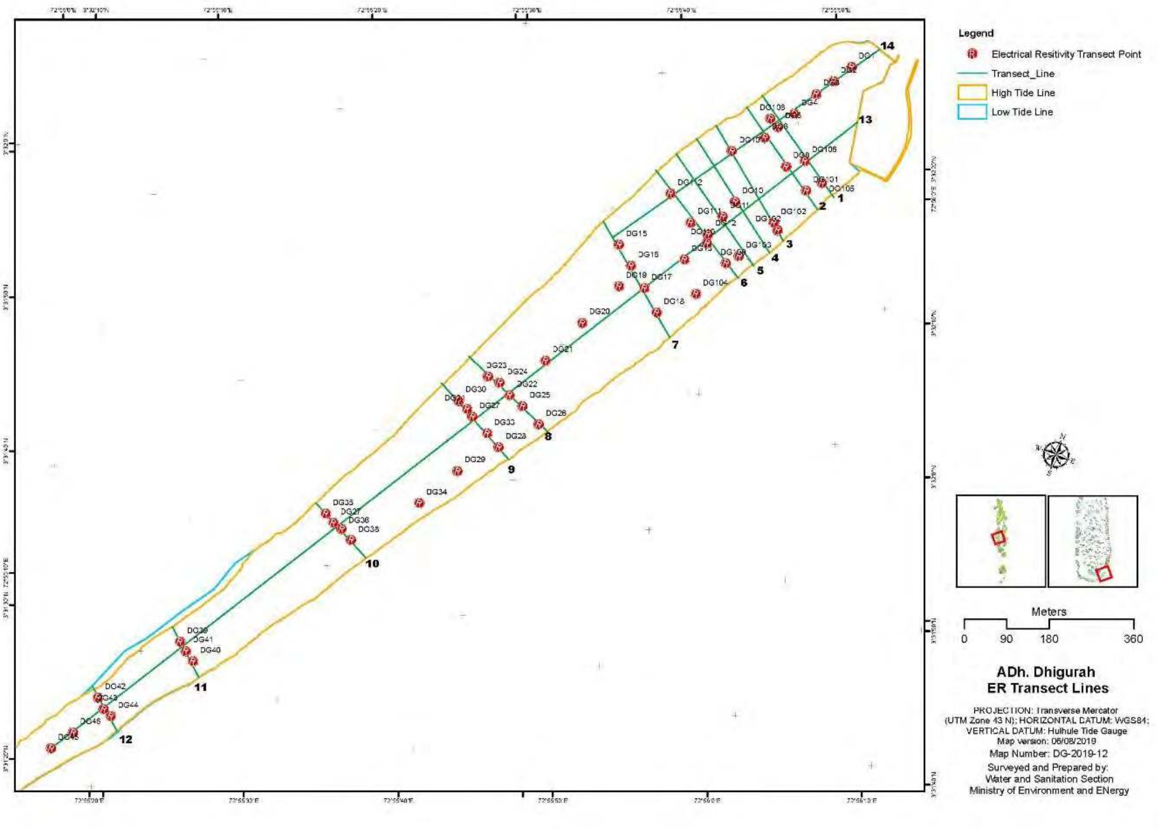
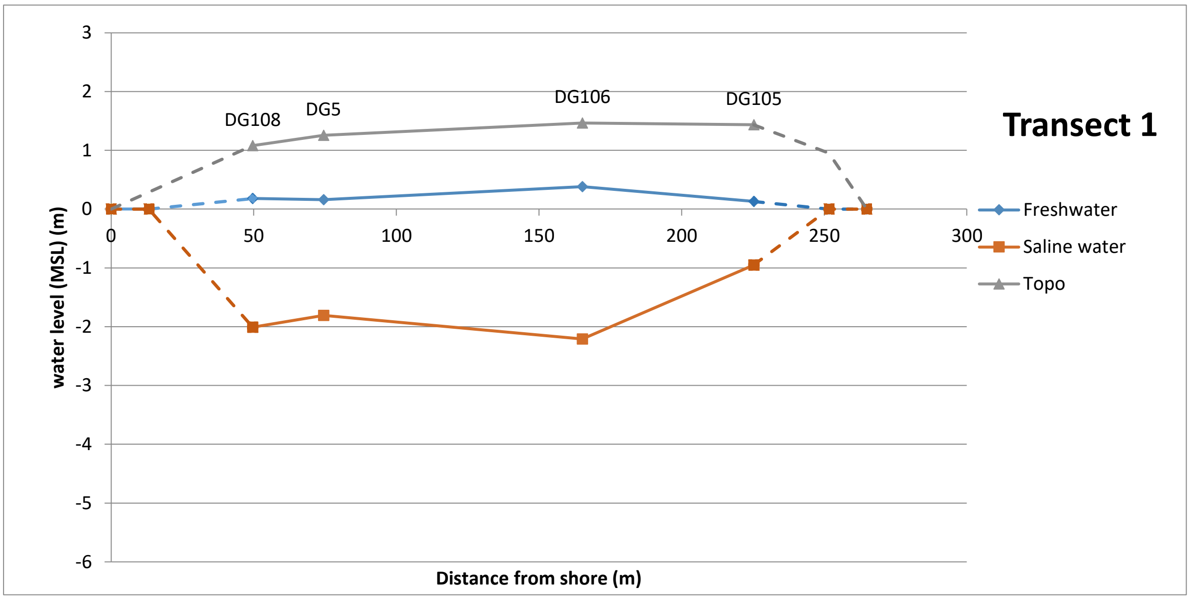
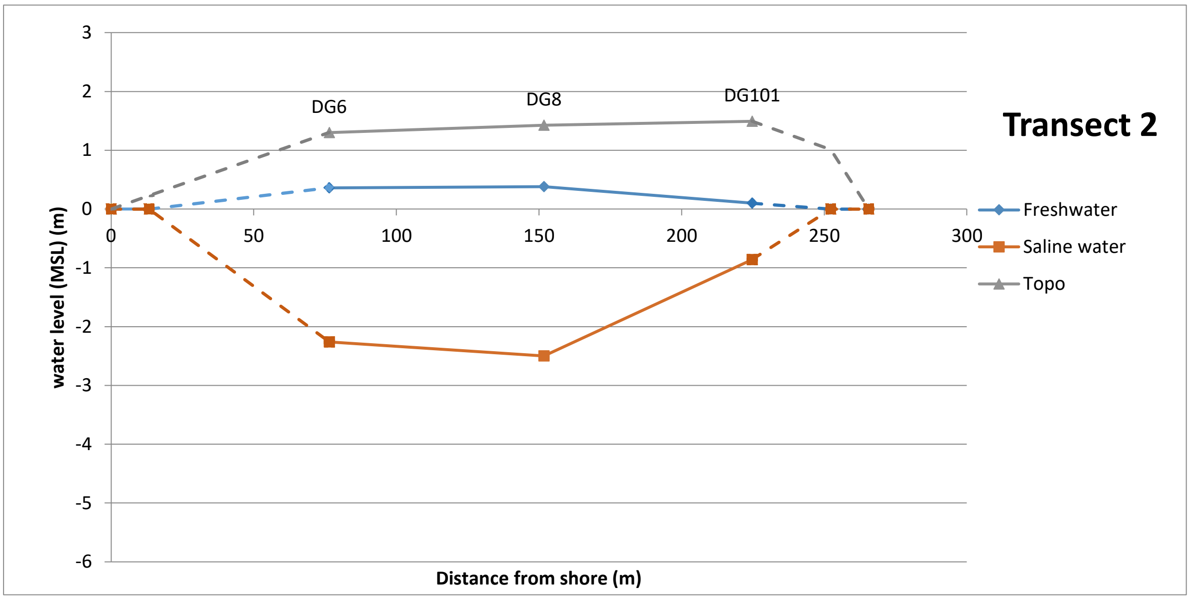
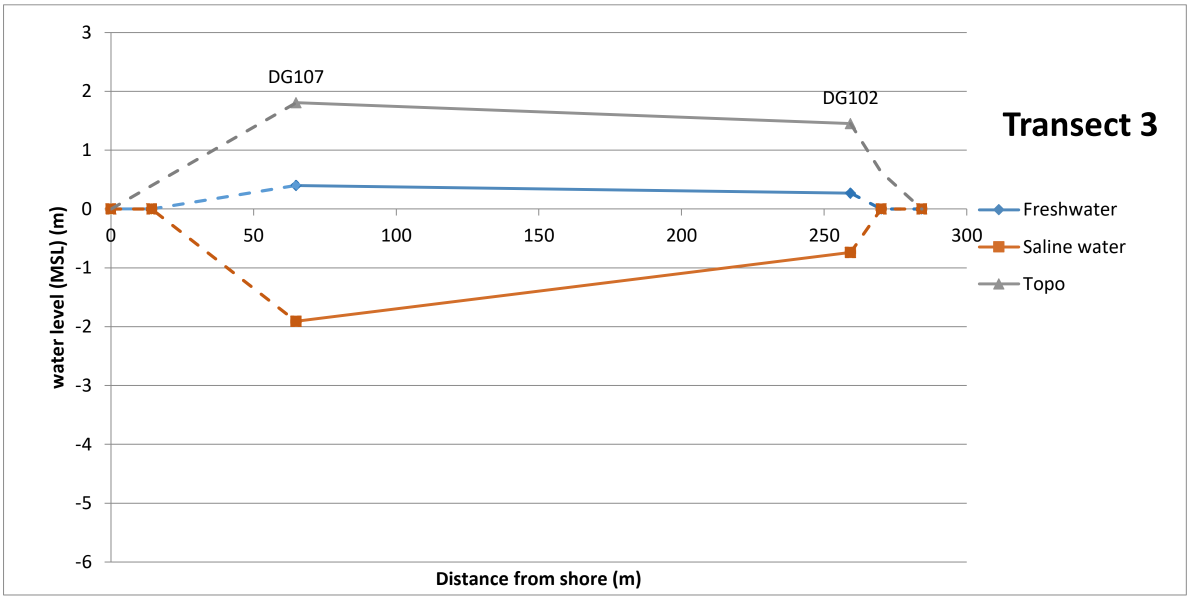
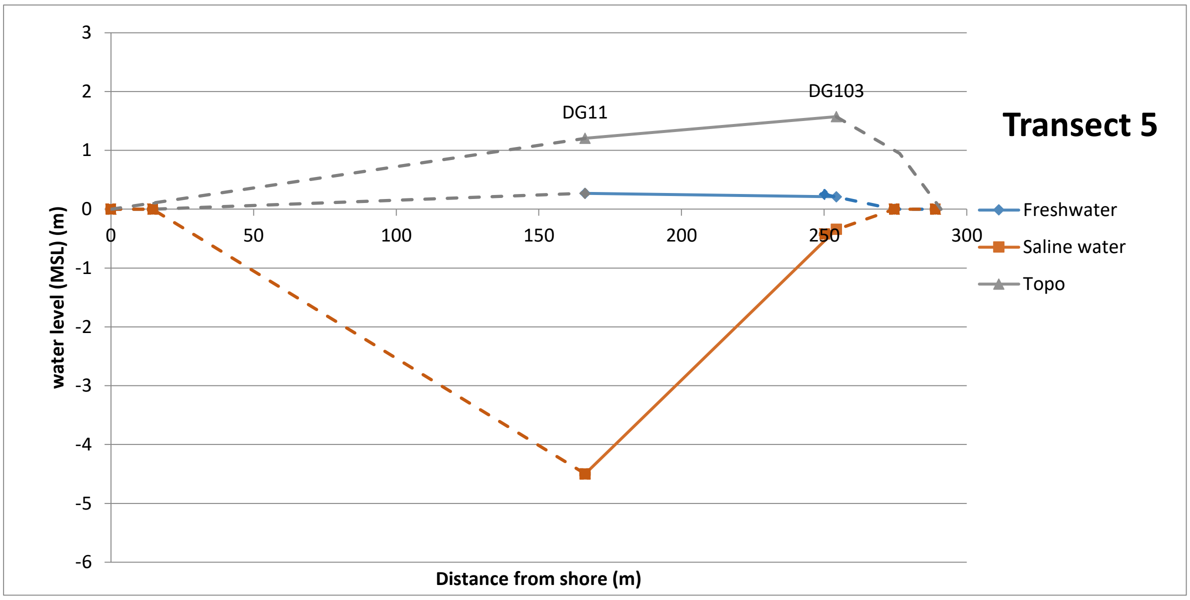


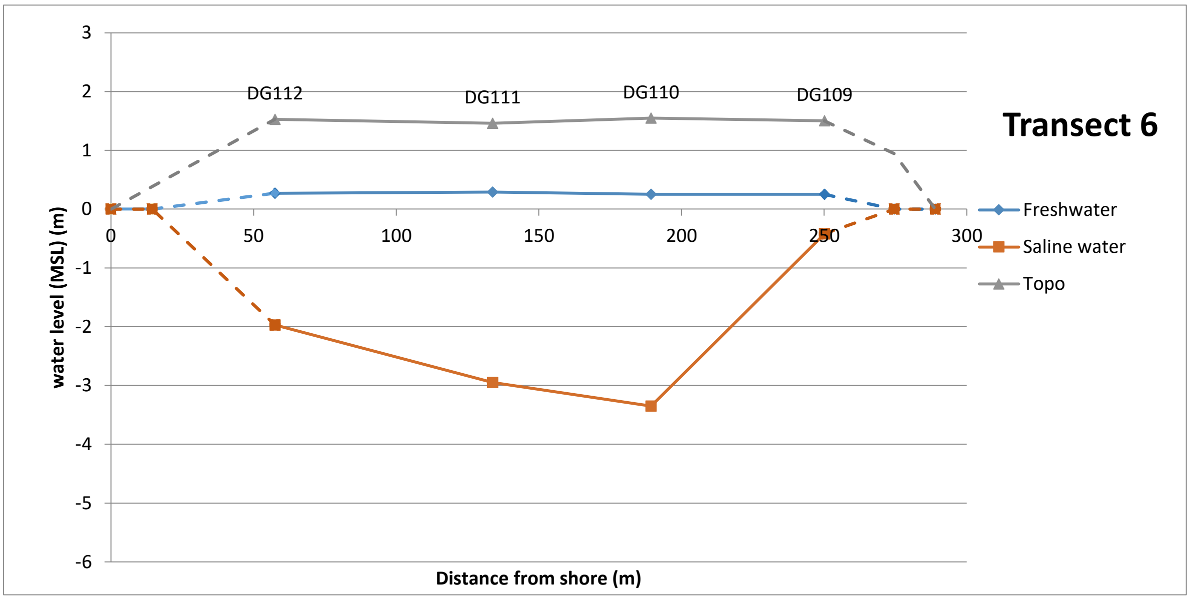
Figure 10.8: ER transect lines in Digurah Island

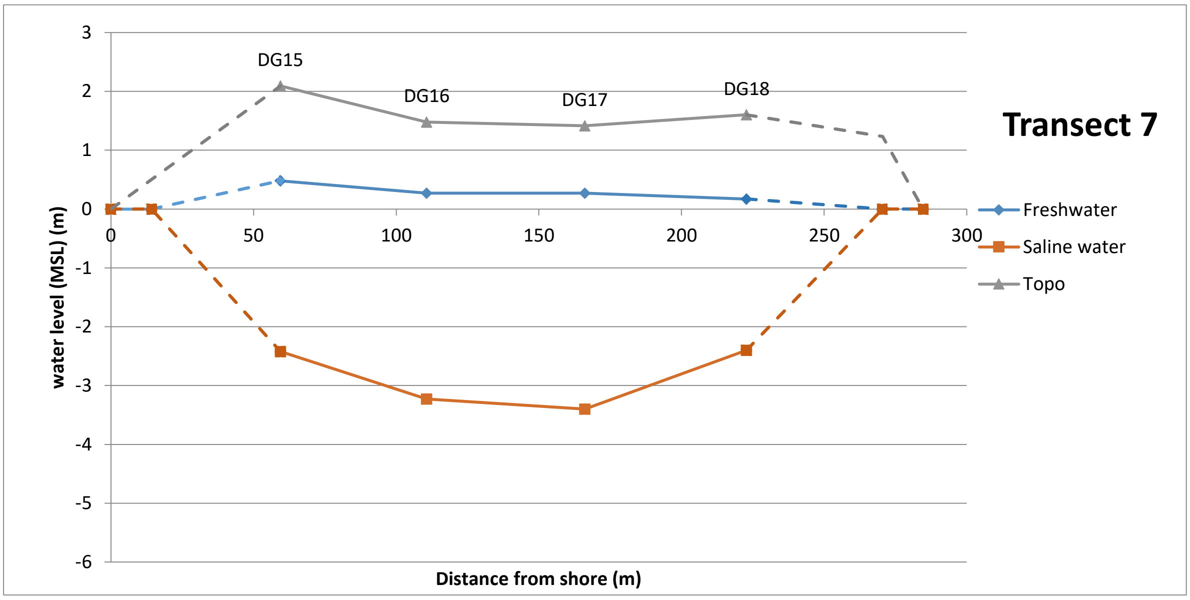


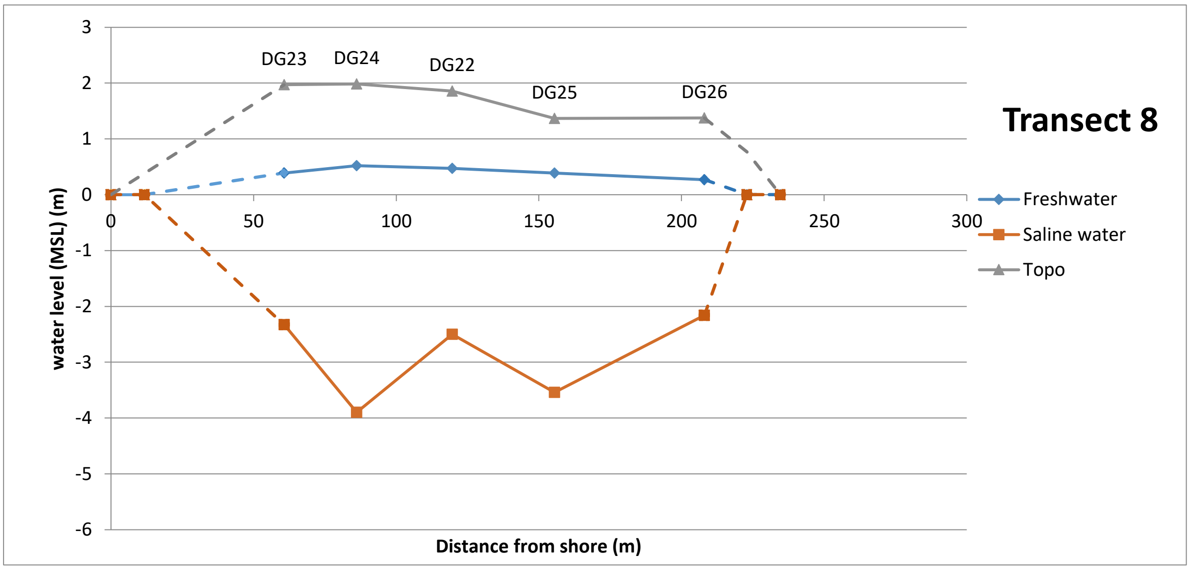

Transcect 2
DG6
DG8
DG101
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo
3
2
1
0
-1
-2
-3
-4
-5
-6
0
50
100
150
200
250
300

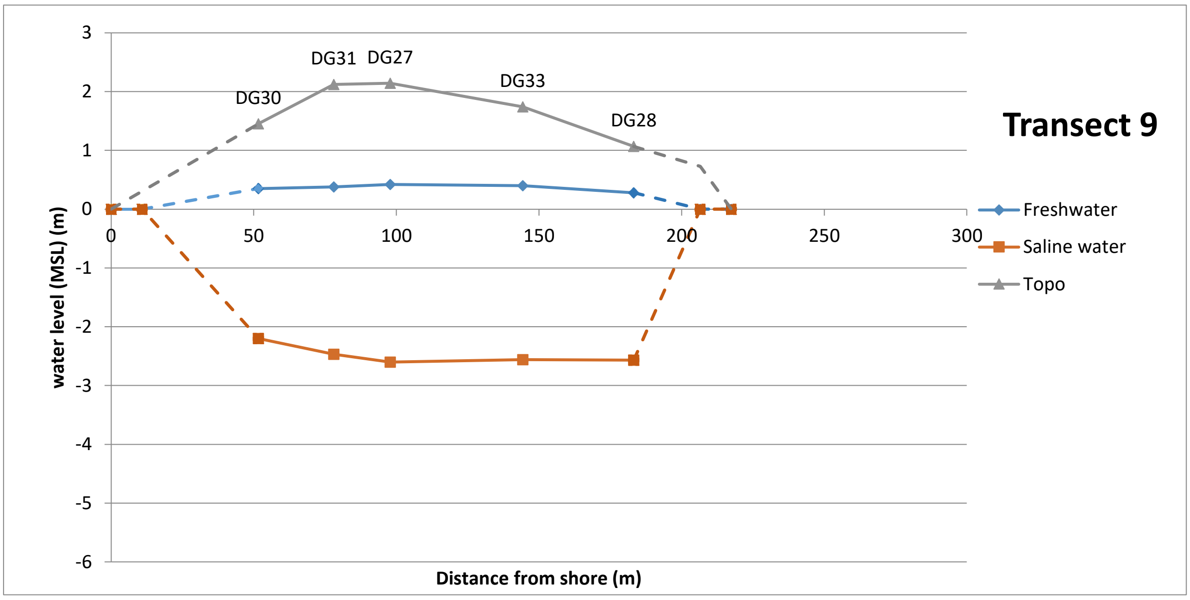

Transect 3
DG107
DG102
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo
3
2
1
0
-1
-2
-3
-4
-5
-6
0
50
100
150
200
250
300

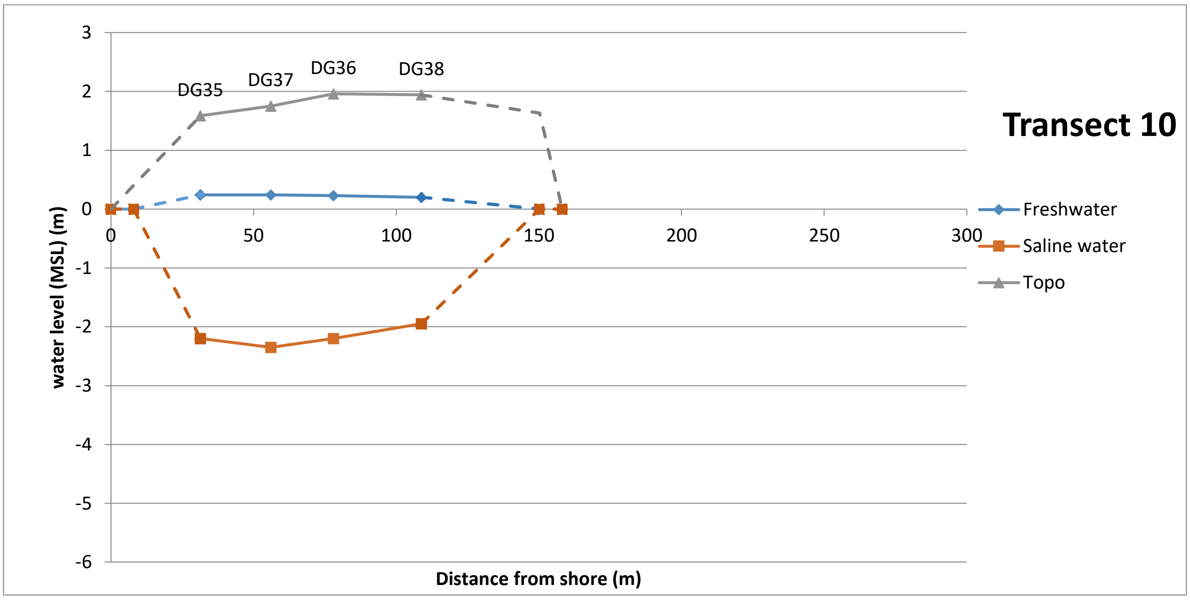

Transect 5
DG11
DG103
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo
3
2
1
0
-1
-2
-3
-4
-5
-6
0
50
100
150
200
250
300

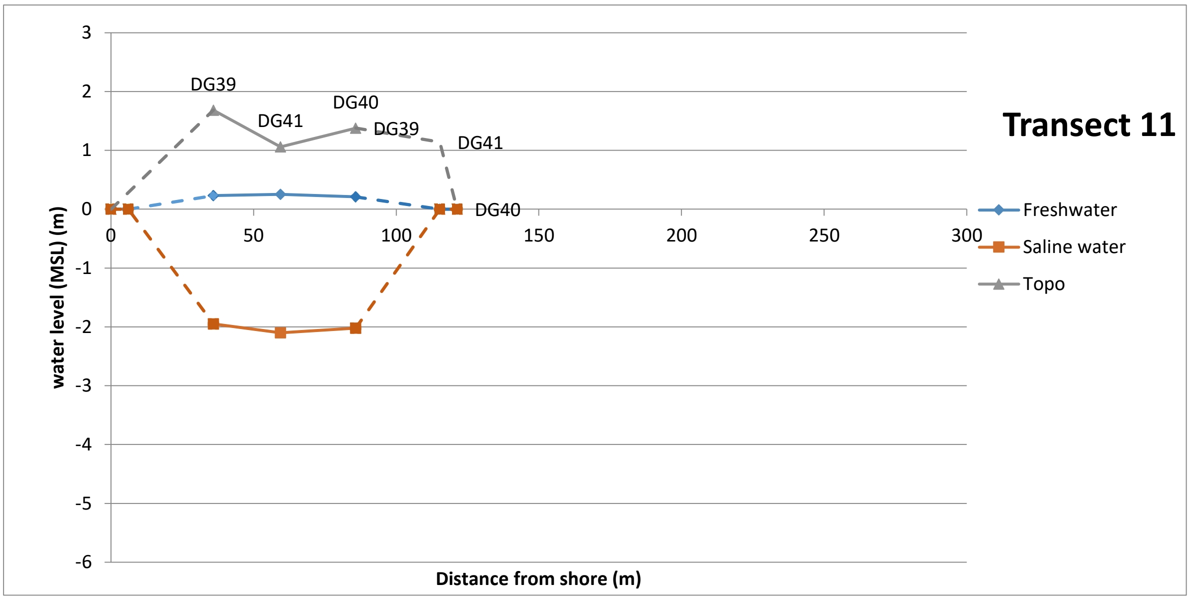

Transcect 6
DG112
DG111
DG110
DG109
water level (MSL) (m)
Distance from shore (m)
3
2
1
0
-1
-2
-3
-4
-5
-6
0
50
100
150
200
250
300
Freshwater
Saline water
Topo


Transect 7
DG15
DG16
DG17
DG18
water level (MSL) (m)
Distance from shore (m)
3
2
1
0
-1
-2
-3
-4
-5
-6
0
50
100
150
200
250
300
Freshwater
Saline water
Topo


Transect 8
DG23
DG24
DG22
DG25
DG26
water level (MSL) (m)
Distance from shore (m)
3
2
1
0
-1
-2
-3
-4
-5
-6
0
50
100
150
200
250
300
Freshwater
Saline water
Topo


Transcect 9
water level (MSL) (m)
Distance from shore (m)
DG30
DG31
DG27
DG33
DG28
Freshwater
Saline water
Topo
3
2
1
0
-1
-2
-3
-4
-5
-6
0
50
100
150
200
250
300


Transect 10
water level (MSL) (m)
Distance from shore (m)
DG35
DG37
DG36
DG38
Freshwater
Saline water
Topo
3
2
1
0
-1
-2
-3
-4
-5
-6
0
50
100
150
200
250
300


Transect 11
water level (MSL) (m)
Distance from shore (m)
DG39
DG41
DG40
DG39
DG41
DG40
Freshwater
Saline water
Topo
3
2
1
0
-1
-2
-3
-4
-5
-6
0
50
100
150
200
250
300

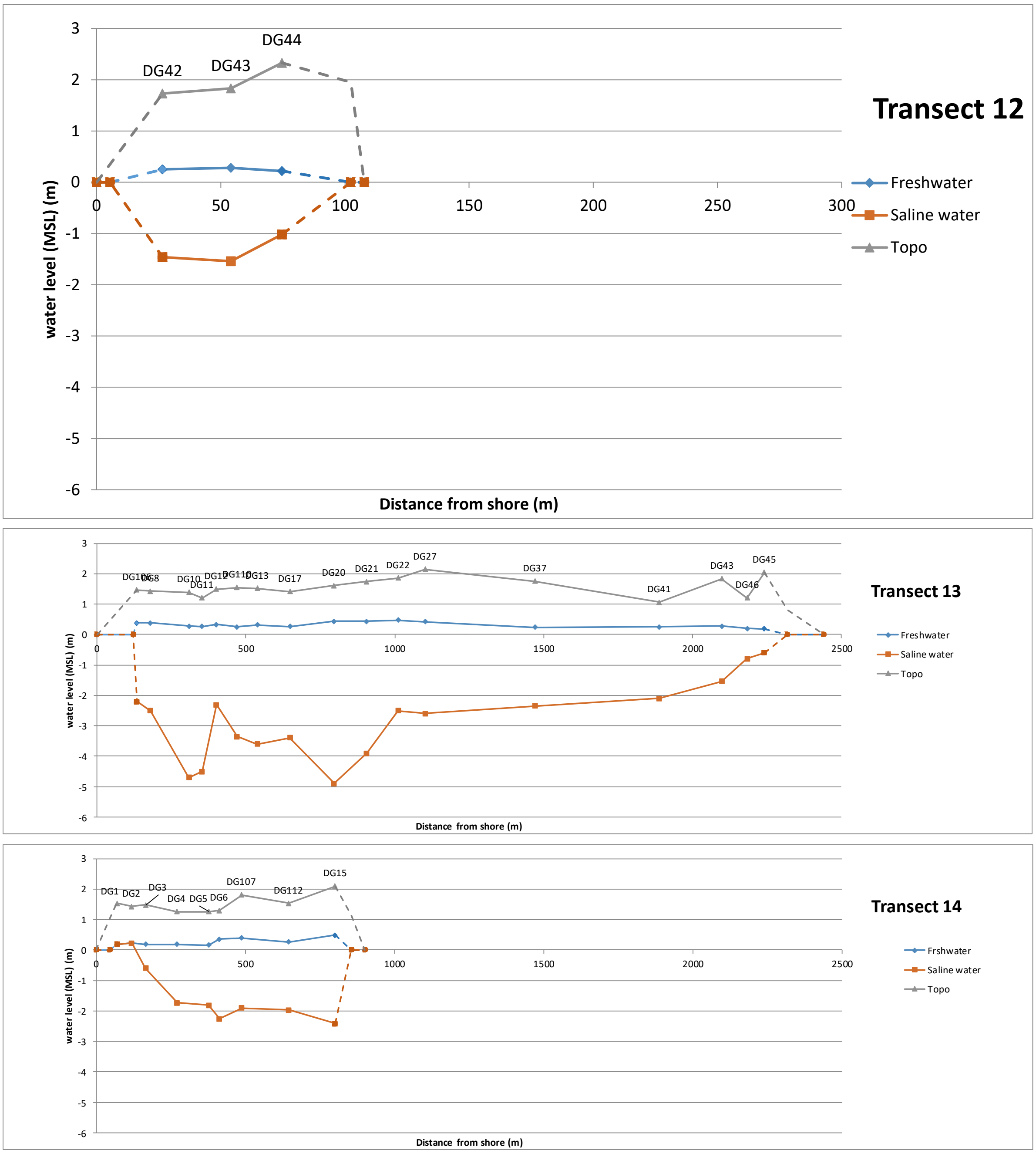


Figure 10.9: Cross-sections of transect lines in Digurah Island

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented below.

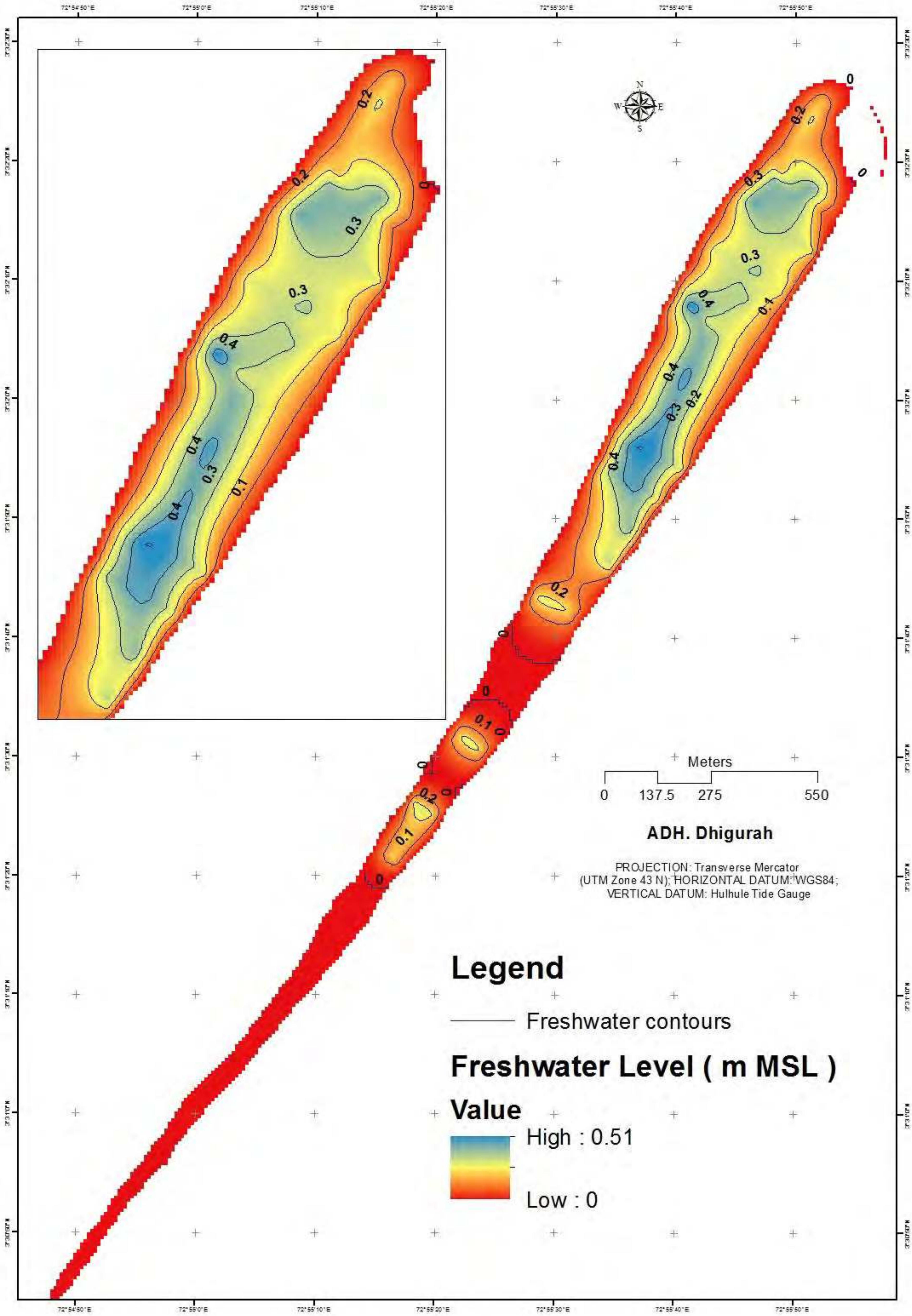

Meters
0 137.5 275 550
ADH. Dhigurah
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Legend
Freshwater contours
Freshwater Level (m MSL)
Value
High : 0.51
Low : 0

Figure 10.10: Freshwater Level in Digurah Island

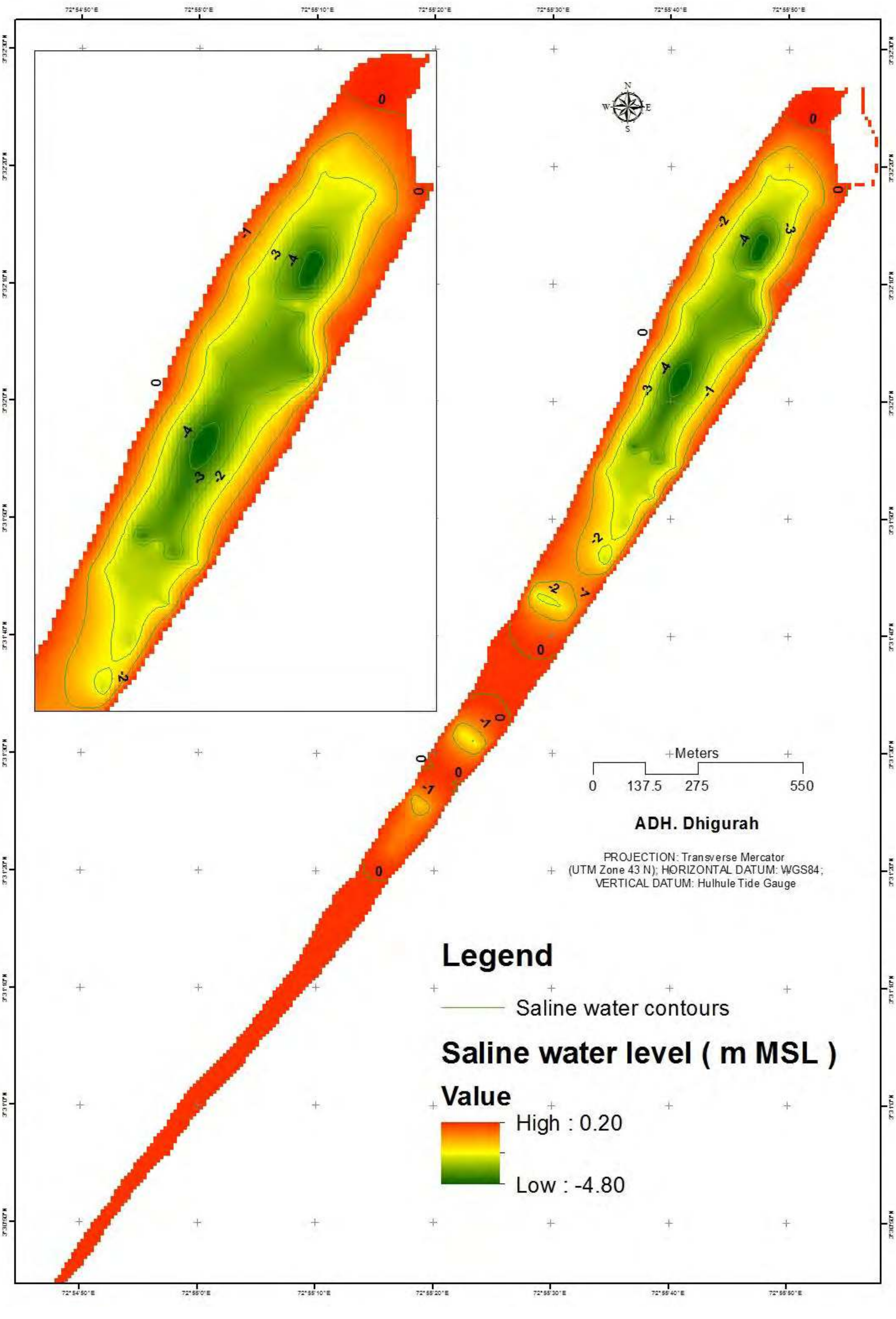


Figure 10.11: Saline water Level in Digurah Island

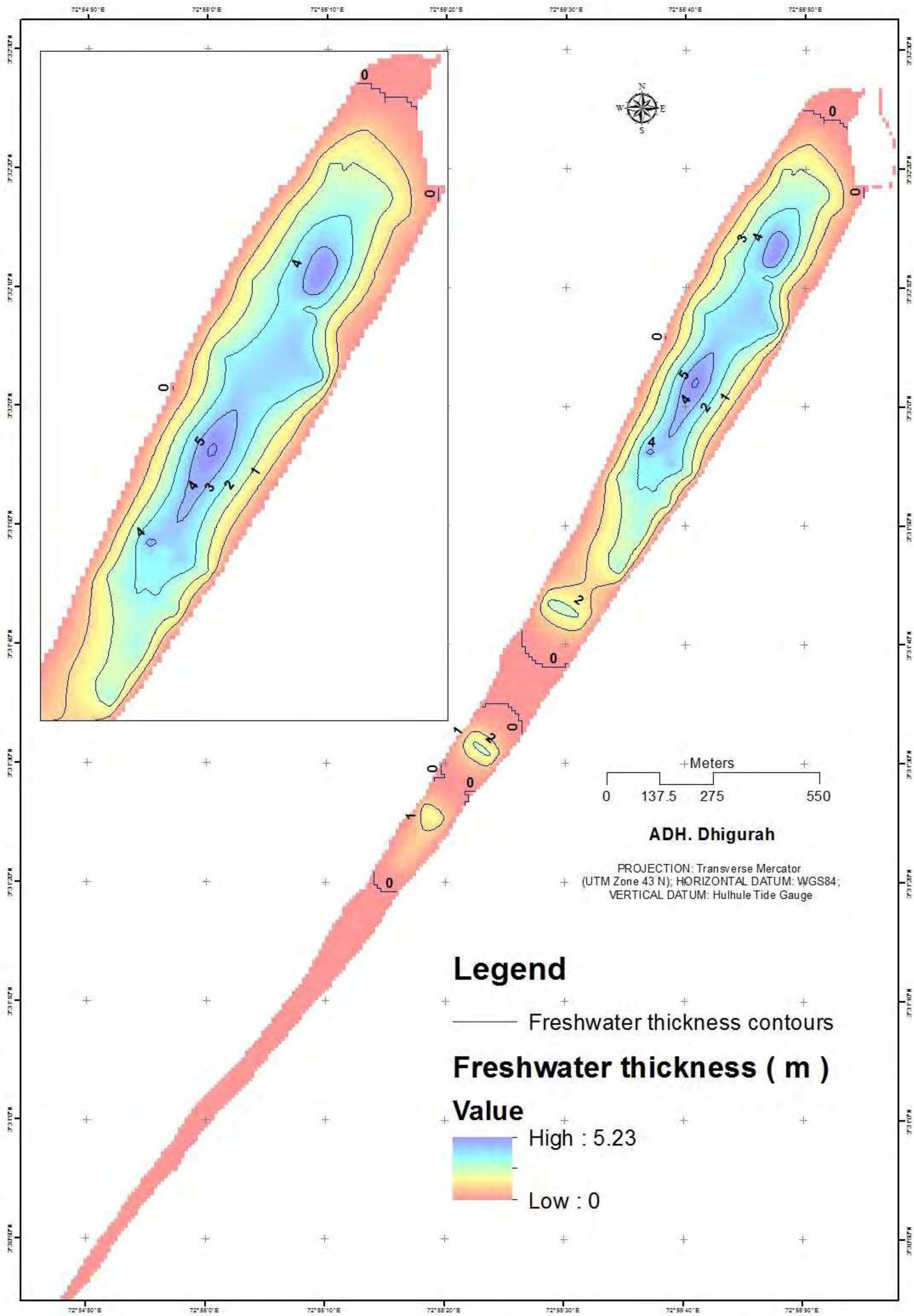


Figure 10.12: Freshwater thickness in Digurah Island

The maximum freshwater thickness of the island is 5.23 m. (It is noted here that these readings were taken in April, which is the dry season and the hottest month of the year). According to Falkland, 1994, the freshwater level thickness of the island is 9m. The relevant calculations are as follows;

Average Annual Rainfall =	2100	mm/yr
Width of the island =	285	m
Length of the island =	2172	m

Freshwater lens Thickness (m)

= (6.94*log (width of the island)-14.38)*Average Annual Rainfall = 6 m

10.8.6 Water balance and recharge

An annual estimation is carried out based on water balance method. Rainwater harvesting is calculated using number of rainwater harvesting units in the island. According to the spatial mean annual rainfall of Maldives, the island is reported as 2100 mm/year. Evapotranspiration was estimated using crop water requirement for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. The groundwater extractions were estimated from amount of water usage in different sectors (residential, resorts, restaurants, agriculture and farming).The difference between recharge and groundwater extraction is taken to estimate different in storage.

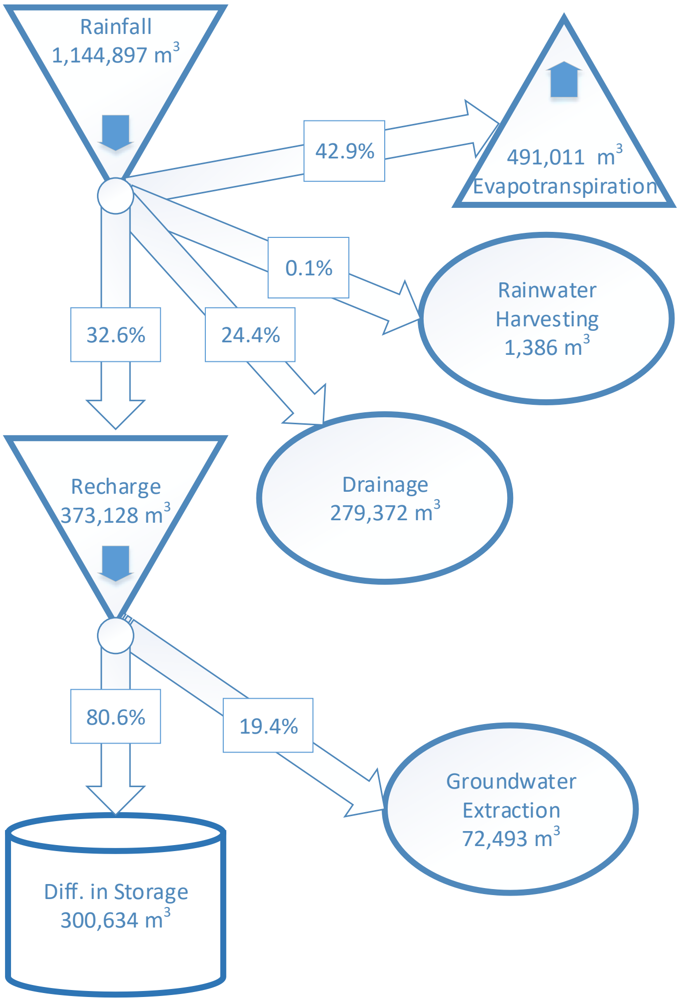


Figure 10.13: Schematic of water balance in Digurah Island

10.8.7 Sustainable yield of the lens

Sustainable yield of the water lens refers to the safe extraction potential of a given groundwater aquifer without significantly affecting its quality or quantity. This parameter is an important factor in the sustainable development of islands as it allows planning and design of water and sanitation intervention in islands.

The island has a sustainable yield of 824 m^3 per day which was calculated subtracting groundwater extraction from recharge volume derived from water balance (

Figure 8.13). According to Metai & Unit, n.d., based on geophysical investigations and drilling programme concluded that the safe sustainable yield was about 10% of mean annual rainfall. Such that the expected sustainable yield for the island should be 314 m^3 per day.

10.8.1 Permeability test

Permeability tests were carried out in the locations as outlined in Figure 10.14.

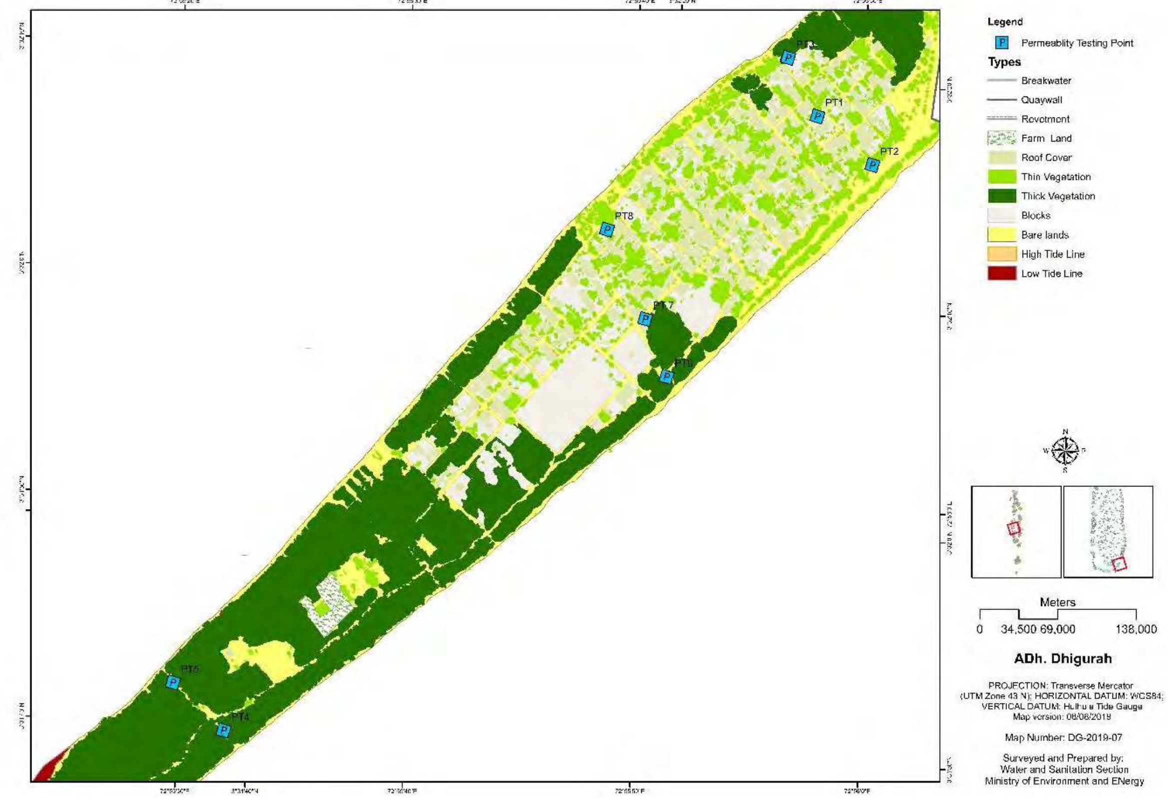


Figure 10.14: Locations of permeability tests in Dhigurah Island

The estimated permeability values for the above test locations are presented below.

Table 10.11: The estimated permeability Values

r_e		0.0260
r_l		0.0285

Point	H	Tu	Cs	H/r_e	Q	K (m/s)	K (m/day)	Q (l/min)	Q (m^3/s)
DhPT1	0.7	1.1	50	26.9	1.7E-04	2.14E-04	18.52	10.0	0.00017
DhPT2	0.8	0.8	50	30.8	8.3E-06	1.47E-05	1.27	0.5	0.00001
DhPT3	0.8	0.9	50	30.8	1.9E-04	3.01E-04	26.03	11.5	0.00019
DhPT4	0.7	1.1	50	26.9	2.9E-04	3.75E-04	32.40	17.5	0.00029
DhPT5	0.7	1.2	50	26.9	5.0E-04	5.89E-04	50.92	30.0	0.00050

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m^3/s), H = Height of water in well (m), l = length of perforated section (m), r_l = outside radius of casing (radius of hole in consolidated material) (m), r_e = effective radius of well = r_l (area of perforations) / (outside area of perforated section of casing) : $r_l = r_e$ in consolidated material that will stand open and is not cast, C_u and C_s =Conductivity Coefficients, and T_u = distance from water level in casing to water table (m).

10.8.2 Groundwater availability

1) The selected Dhigurah island has dimensions of width = 285 m and length = 3759 m, with a total land area of 52.11 ha, a population of 610 persons, and a land use of built-up area 3.95 ha (7.6%), thick vegetation 26.60 ha (51.3%), light vegetation 6.35 ha (12.2%), bare lands 14.93 ha (28.8%) and farmlands 0.283 ha (0.54%).

2) In order to recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of freshwater lens (FWL) and its associated recharge-discharge characteristics, 55 number of Electrical Resistivity (ER) location readings along 14 representatively selected transects were collected.

3) Soil overburden permeability tests (constant head) were carried out at 08 locations. In addition, groundwater level was also recorded at 09 locations where groundwater water quality samples were tested.

4) Permeability tests were carried out at representatively selected 05 number of locations. The measured permeability (K m/day) values ranged from a minimum of 1.27 m/day to a maximum of 50.92 m/day, with an average of 25.83 ± 18.23 m/day (Mean ± 1 Standard Deviation).

5) The ground elevation values ranged from a minimum of 0.76 m MSL to a maximum of 2.22 m MSL, with an average of 1.51 ± 0.28 m MSL (Mean ± 1 Standard Deviation).

6) The upper boundary of the freshwater lens (FWL) varied from a minimum of 0.10 m MSL to a maximum of 0.52 m MSL, with an average of 0.29 ± 0.10 m MSL (Mean ± 1 Standard Deviation).

7) The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -4.90 m MSL to a maximum of 0.22 m MSL, with an average of -2.21 ± 1.16 m MSL (Mean ± 1 Standard Deviation).

8) Accordingly, the freshwater lens (FWL) thickness values ranged from a minimum of 0.00 m to a maximum of 5.34 m, with an average of 2.50 ± 1.22 m (Mean ± 1 Standard Deviation).

9) The groundwater profile in the island is characterised by a relatively Low (0.12%) Rainwater Harvesting, relatively Low (24.40%) Drainage, relatively Low (32.59%) Recharge, while the water use shows relatively Low (19.43%) Groundwater extraction, leading to relatively High (80.57%) Difference in Balance Storage.

10) The freshwater lens (FWL) volume calculated based on ER transect test data is 145,149 m^3 with a maximum FWL thickness of 5.34 m. The potential maximum FWL volume and thickness estimated based on Falkland (1994) method are 99,085 m^3 and 5.57 m.

10.8.3 Conclusive Comments and Recommendations

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 824 m^3 per day, while it is 314 m^3 per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 209 m^3 per day and this is about 67% of the allowable Safe Yield in the island with minor up-coning and slight drawdown in freshwater lens cross-sections. At present, there exists an island-wide sewerage network (local) but no water supply network. The water samples tested were found to be Very Slightly Odorous with 15.0% or 3/20 samples tested producing odour. The Hydrological condition of the freshwater lens aquifer can be categorised as Moderate based on above measurements and findings while Water quality aspects can be regarded as Contaminated with an Average Electrical Conductivity (EC) of 2,725.81 ± 4,347.49 µS/cm with measured values ranging from a minimum of 502.40 µS/cm to a maximum of 20,684.80 µS/cm, and an Average Ammonia Concentration of 0.54 ± 1.48 mg/L with measured values ranging from a minimum of 0.02 mg/L to a maximum of 6.20 mg/L.

The Availability of space for incorporating recharge measures and related infrastructure is High while therefore the Potential for Recharging is considered to be Moderate. Overall recommendation for groundwater recharging would be to use recharging trenches and ponds in roads and recharging pits in individual households and land blocks.

11 M. RAIYMANDHOO ISLAND

11.1 General overview of the island

The island of Raiymandhoo is located on the North Easter periphery of Meemu Atoll at coordinates 2°10’5”N and 73°3’59”E. The island is about 763 m in length and 364 m in width, with an area of 26.57 ha. The island has a population of 112 people, via the 2014 Census. The island has a jetty on the Western side of the island. The following table outlines some basic information about the island and the following figure outlines the location of Raiymandhoo.

Table 11.1: Basic statistical information on Raiymandhoo island in Meemu Atoll.

Name of the island	M.Raiymandhoo
Longitude and Latitude	73°3’58.9”E, 2°10’4.7”N
Area	26.66 ha
Population (Census, 2014)	112
Distance from Atoll Capital (M.Muli)	19.82 km
Distance from Male’	120.81 km
Harbour	Absent
Island sewerage network	No
Water supply network	No
Other infrastructure	Lighthouse

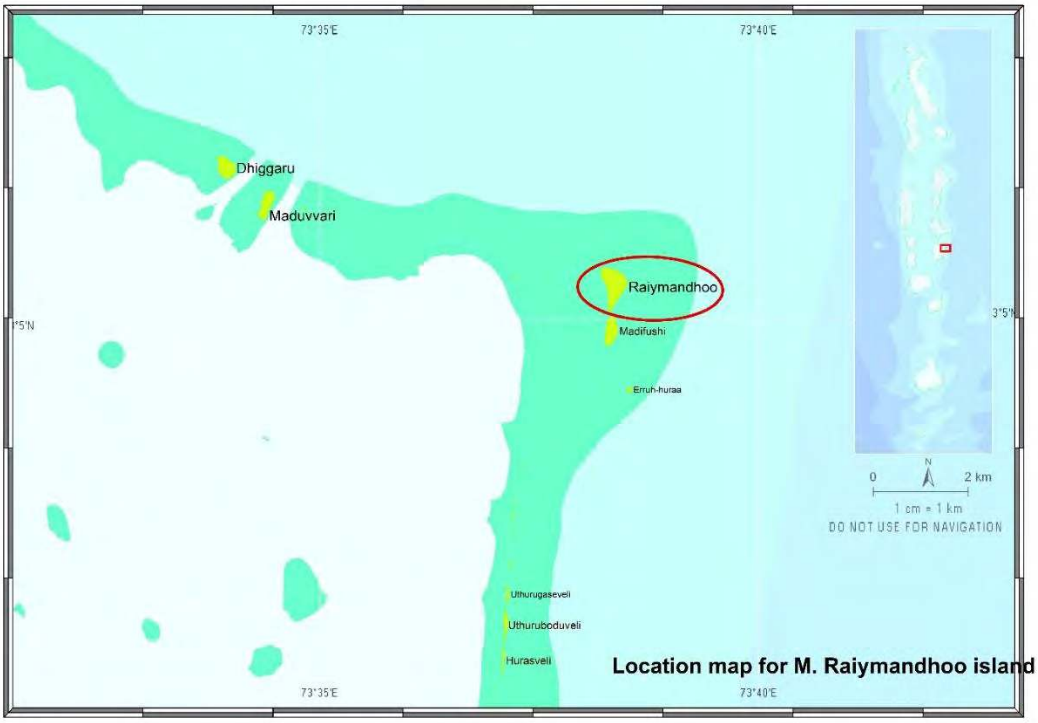


Figure 11.1: Location map for Raiymandhoo Island, Meemu Atoll.

11.2 Geology and vegetation

The island is about 763 m in length and 364 m in width, with an area of 53.14 ha. Of this about 73% of the land is covered in vegetation. With the exception of the Western side of the island where people live, most of the island is thick vegetation. The majority of vegetation in the forested area comprise of coconut trees. There are a number of other tropical native vegetation in this area, all of which are potential sources of organic matter input to the groundwater lens. In addition to home gardens, farming takes place along the eastern side of the island within the vegetation.

11.3 Topography

Raiymandhoo has a topography that ranges from an elevation of 0.35 meters to 1.55 meters above Mean Sea Level with an average elevation of 1.02 meters above Mean Sea Level. The Digital Surface Model is found in Figure 11.2.

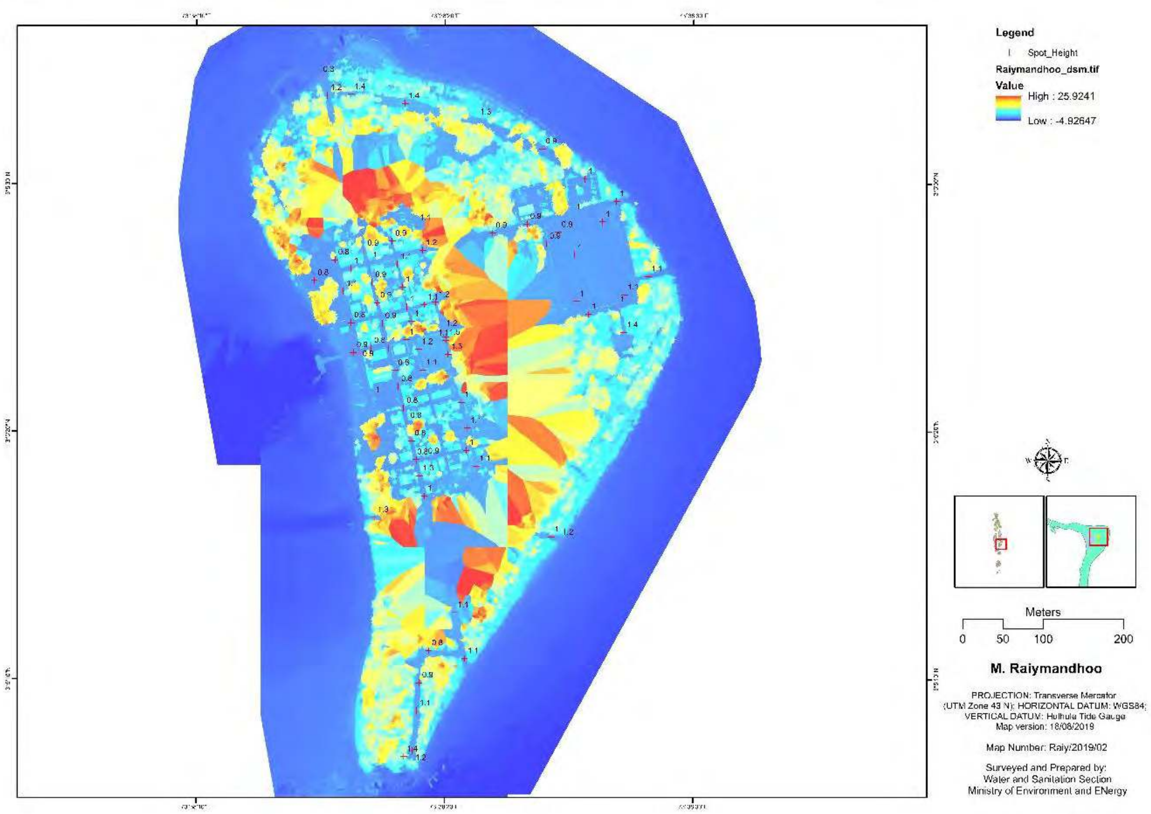


Figure 11.2: Digital Surface Model of Raiymandhoo showing spot heights

11.4 Climate

Raiymandhoo experiences the typical two monsoons namely, north east monsoon from November to April and South-west monsoons from April to November. There are no specific wind and rainfall data available for Raiymandhoo as there are no weather monitoring stations on the island.

11.5 Demography

As per the 2014 Census, Raiymandhoo has a registered population of 112 people. However, this figure is not accurate as the resident population has 231 people according to the Island Council. Within the population, there are slightly more females than males on the island. The only foreigner registered on the island is female.

Table 11.2: Demographic Breakdown of Raiymandhoo Island

Atoll	locality	Resident population (Census, 2014)								
		Total			Maldivians			Foreigners		
		Both sexes	Male	Female	Both sexes	Male	Female	Both sexes	Male	Female
M	Raiymandhoo	112	55	57	111	55	56	1	0	1

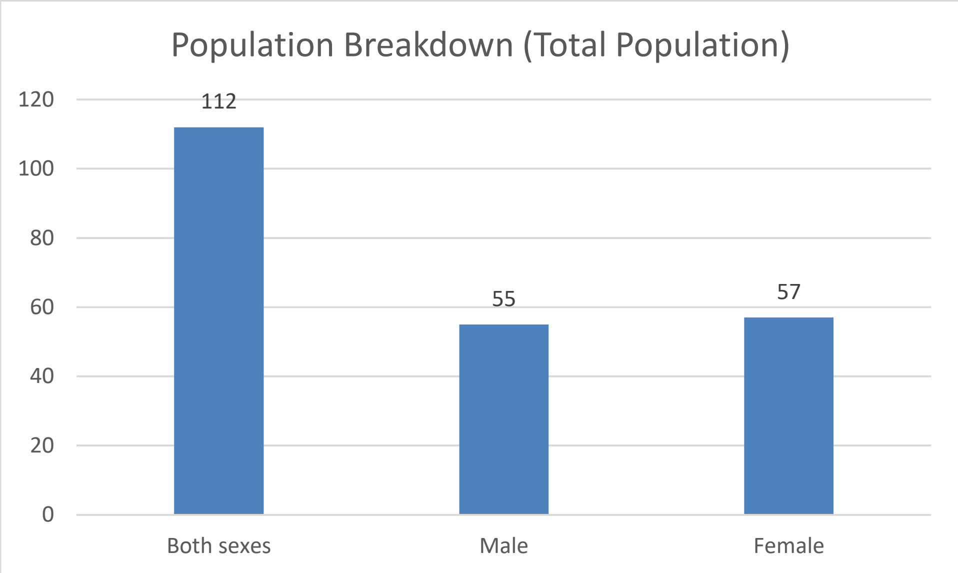


Figure 11.3: Population breakdown of Raiymandhoo (Maldivians & Foreigners)

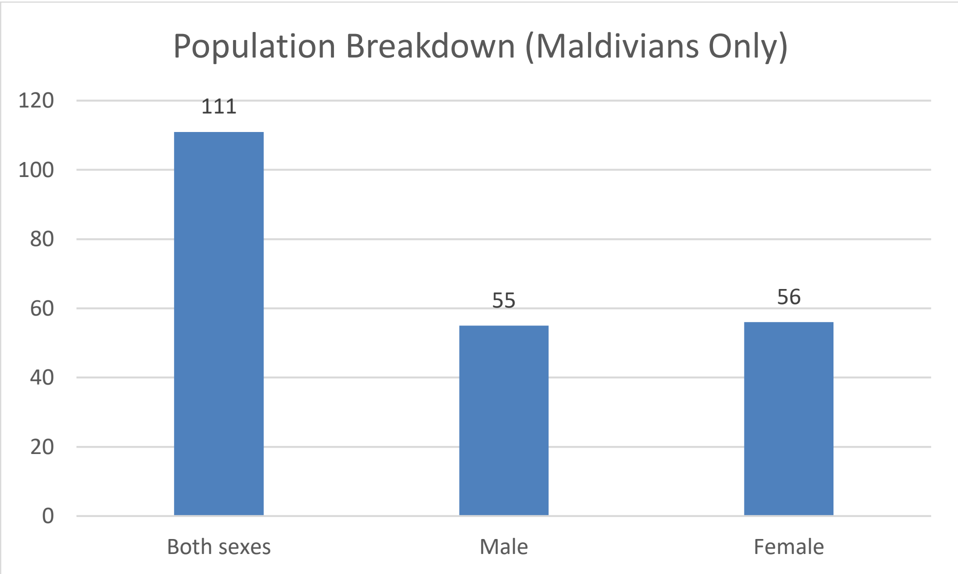


Figure 11.4: Population breakdown of Raiymandhoo (Maldivians)

11.6 Socio-economic condition

Raiymandhoo is a slow growing island, particularly due to the low population of the island. In fact, this island has the lowest population from the 13 islands surveyed for this project, with 112 residents. Raiymandhoo has a very low population density of 3.8 residents per hectar. The island contains 40 households as reported by the island council, with 35 households occupied through the year.

Raiymandhoo School has 15 registered students, and the school teaches up to primary education. Raiymandhoo has a total of 1 restaurant and 0 guesthouses.

11.7 Existing water and sanitation situation

The island does not currently have an island wide sewerage system nor a water supply system. The primary form of sanitation on the island is via the use of septic tanks. Each household has one or two septic tanks. 67% of the surveyed households clean their septic tanks by periodically disposing the septic waste to sea, while 33% of households bury septic waste in other parts of the island. On average, there is an approximate distance of 6.8 meters between septic tanks and nearest well. There are plans for an island wide sewerage system in the 2019 budget.

The primary source of drinking water is rainwater that is collected in either household or community tanks. The primary source of water used for cooking is also rainwater. As this tends to run out during the dry season for several households, they borrow rainwater from neighbouring houses or take water from the community tanks in the mosques.

11.8 Results

11.8.1 Water sources and water use

Based on domestic, commercial, institutional and industrial water usage, a total of 55,266 liters of groundwater are estimated to be used every day. 239 liters of groundwater are used per capita per day. The respective water use situations are detailed in the following sections.

11.8.1.1 Domestic water use situation

Based on the questionnaire to collect data on domestic water consumption, a summary of results are present in this section.

According to the survey, 100% of the households surveyed uses HDPE rainwater tanks as their main storage for water. A total of 100% households use rainwater for drinking and 100% use it for cooking. None of the surveyed houses use rainwater for bathing or washing.

None (0%) of the households use groundwater as drinking. Groundwater is mainly used for non-potable use in all the households surveyed.

The following table summarizes the groundwater and rainwater use data for Raiymandhoo Island.

Table 11.3: Groundwater and rainwater use data for Raiymandhoo

Rainwater	
Households with rainwater tanks	100%
Rainwater use for drinking	100%
Rainwater use for cooking	100%
Rainwater use for bathing and washing	0%
Groundwater	
Groundwater as drinking source	0%
Groundwater for cooking	0%
Groundwater for non-potable use	100%

Total number of households surveyed	(14.3%)
Percentage of wells surveyed fitted with pumps	100%

Based on the survey questionnaire, average daily water demand per capita for domestic purposes has been estimated based on the average amount of water used per person for showering, toilet flushing, laundry and gardening, this data is shown in table 11.3. The total domestic water use is estimated to be 230 liters per capita per day.

Table 11.4: Domestic Water Usage in Raiymandhoo

Shower/ Liters per capita per day	Toilet/ Liters per capita per day	Laundry/ Liters per capita per day	Gardening/ Liters per capita per day	**Total/ Liters per capita per day**
107	26	12	85	**230**

11.8.1.2 Commercial water use situation

Based on the questionnaire to collect data on commercial water consumption, a summary of results are present in this section. Raiymandhoo has a total of 1 restaurant and 0 guesthouses. 1 restaurant was surveyed.

For the restaurant, the main use of groundwater was for mopping, gardening, dishwashing and toilet use. From the survey data, the total groundwater consumption for this restaurant was estimated to be 738 liters per day, therefore the total commercial groundwater consumption for the island is also 738 liters per day.

11.8.1.3 Institutional water use situation

Based on the questionnaire to collect data on institutional water consumption, a summary of results are present in this section. Four institutions were surveyed for this study, namely the magistrate court, health center, council office and school. Groundwater in the institutions in Raiymandhoo Island are mainly used for gardening, mopping floors and flushing toilets. Additionally, the health center also uses groundwater for laundering and washing the ambulance. A total of approximately 749 liters of groundwater are estimated to be used per day by the institutions. Therefore, a total of approximately 3.24 liters of groundwater are estimated to be used per capita per day by the institutions of Raiymandhoo Island.

Table 11.5: Water Usage in Institutions in Raiymandhoo

	Water Flushed (Liters per day)	**Gardening (Liters per day)**	**Mopping (Liters per day)**	**Others (Liters per day)**	**Total Water Usage (Liters)**	**Institutional Groundwater Usage (Liters per day)**	**Institutional Groundwater Usage (Liters per capita per day)**
Magistrate Court	36	360	20	-	416	749	3.24
Health Center	48	-	20	16	69		
Council Office	55	90	10	-	175		
School	76	2	12	-	90		

11.8.2 Groundwater quality

Groundwater quality measurements were made at selected wells in Raiymandhoo for both physical and microbiological testing.

The following table summarizes the water quality results.

Table 11.6: Summary of groundwater quality tests from Raiymandhoo, July 2019

Sample No	Odour	Physical Appearance
gw1	yes	Pale yellow with particles
gw2	yes	Pale yellow with particles
gw3	no	Pale yellow with particles
gw4	yes	Pale yellow with particles
gw5	yes	Pale yellow with particles
gw6	yes	Pale yellow with particles
gw7	yes	Pale yellow with particles
gw8	no	Pale yellow with particles
gw9	yes	Pale yellow with particles

Sample No	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)
gw1	3420	2008	7.47	1.7	1.41	30.61	1.59	28.6	3.87	0.44	1
gw2	589	349	7.74	1.05	2.1	30.00	0.26	4.4	0.71	0.76	37
gw3	647	381	7.80	0	2.53	30.39	0.28	2.9	0.28	0.11	>2420
gw4	1236	732	7.67	0.53	1.59	30.17	0.55	10.2	0.97	0.08	
gw5	5486	3294	7.23	2.08	1.17	29.33	2.7	28.3	5.61	0.2	
gw6	27228	16780	7.92	0.87	5.46	27.83	15.7	108.9	30.82	0.15	>2420
gw7	1640	1003	8.49	2	4.66	28.28	0.77	15.2	1.01	0.11	>2420
gw8	1588	970	7.79	0.42	3.69	28.33	0.74	10.8	0.49	0.09	
gw9	3520	2130	7.10	0.51	0.65	28.89	1.7	20.6	2.48	0.19	

	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)
WHO Standards	Suggested maximum limit of freshwater for potable purposes = 1500 µS/cm Suggested maximum limit of freshwater for non-potable purposes = 2500 µS/cm	-	-	-	-	-

	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
WHO Values	-	Guideline Value = 50 mg/L-NO3	Natural Level of Ammonia < 0.2 mg/L Threshold odour concentration = 1.5 mg/L Taste threshold = 35 mg/L	-	-	-

Figure 11.5: Location of groundwater sampling points in Raiymandhoo Island

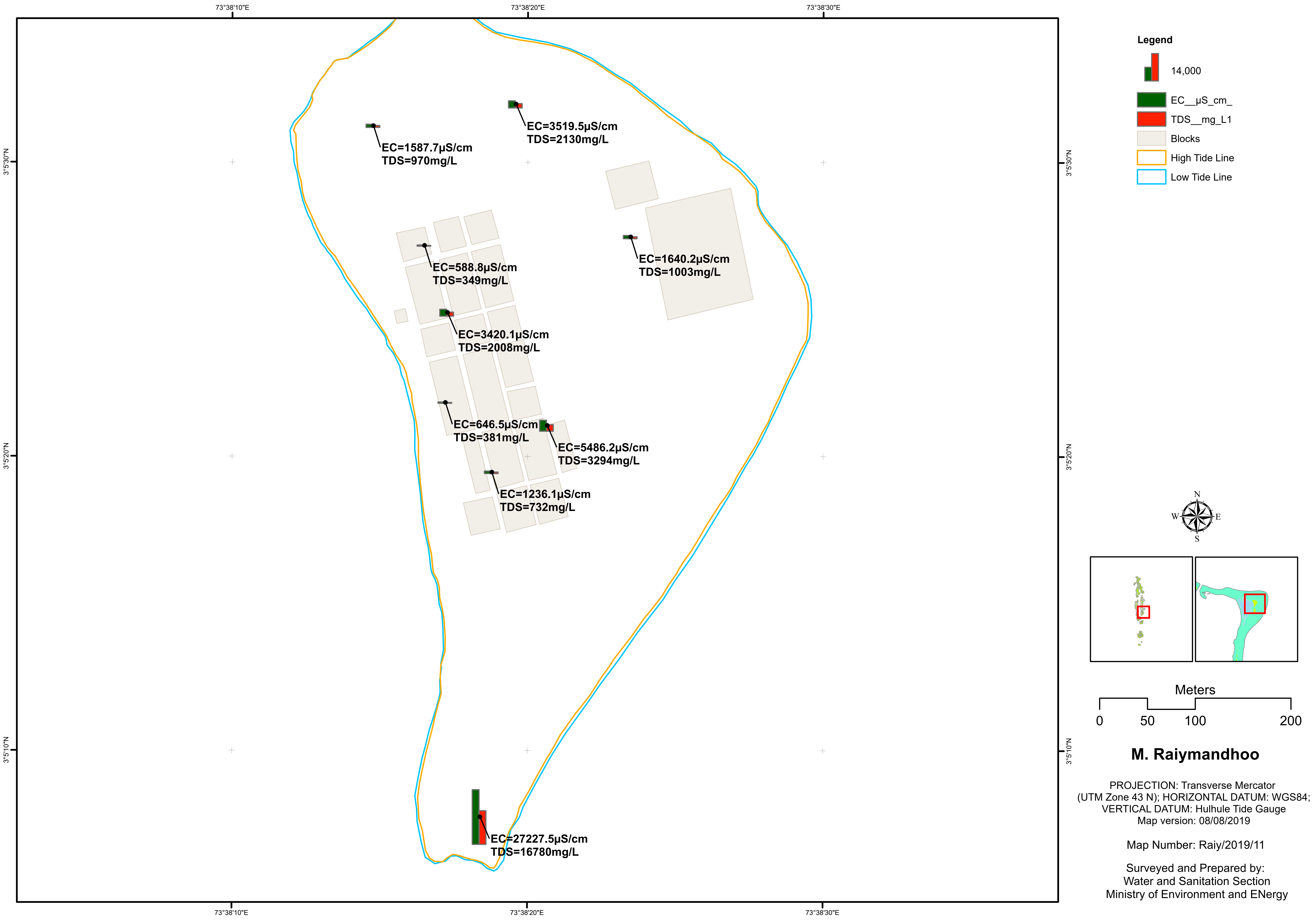
Based on the full results and the summary shown in Table 11.5, the following can be summarized for Raiymandhoo:

- Samples gw1, gw2, gw4 and gw5 were taken from residential areas. Sample gw3 was taken from school. Samples gw7 and gw9 were taken from farm wells within the vegetated area. Sample gw8 was taken from a well within deep vegetated area.
- Compared to other samples, sample gw6 has distinct parameters as it was taken from a well near the vegetated area and the shoreline. Gw6 has comparatively higher EC, TDS, pH, salinity, Nitrate and Ammonia concentration. Sample gw6 also has a lower temperature.
- The average Electrical Conductivity (EC) of the groundwater is 5039 µS/cm which is above the acceptable limit for potable water of 1,500 µS/cm and the acceptable limit for freshwater

for non-potable water of 2500 µS/cm (refer section 2.2). Sample gw6 shows the highest EC of 27228 µS/cm. The average EC of the groundwater not including gw6 is 2266 µS/cm, which is still above the acceptable limit for potable water but below the limit for non-potable water. The minimum EC of groundwater observed was 589 µS/cm (gw2.) 6 samples from 9 (66.7%) tested water samples had EC higher than the acceptable limit for potable water and 4 samples (44.4%) had EC higher than the acceptable limit for non-potable water (refer section 2.2).

- Total Dissolved Solids recorded ranged from 349 mg/L to 16780 mg/L with an average of 3071.89 mg/L. Sample gw6 has the highest TDS. The average TDS of the groundwater excluding gw6 is 1358 mg/L.
- The pH of groundwater ranged from 7.1 to 8.49 with an average pH of 7.69.
- Turbidity ranged from 0 NTU to 2.08 NTU with an average of 1.02 NTU. As a guide, "crystal-clear" water has a turbidity below 1 NTU, and water becomes visibly cloudy at 4 NTU and above.
- Dissolved oxygen levels ranged from 0.65 mg/L to 5.46 mg/L averaging 2.58 mg/L.
- The salinity of groundwater ranged from 0.26 PSU to 15.7 PSU with an average of 2.7 PSU. Salinity is expressed in Practical Salinity Units, PSU which is equivalent to PPT. The average salinity of groundwater excluding sample gw6 is 1.07 PSU.
- The average Nitrate concentration was 25.6 mg/L and therefore does not exceed the WHO guideline limit of 50 mg/L. The Nitrate concentrations ranged from 2.9 mg/L to 108.9 mg/L (gw6). Only 1 of the 9 tested water samples exceeded the limit of 50 mg/L. Sample gw6 which has the highest Nitrate concentration of 108.9 mg/L has a high concentration as this sample was taken near a thickly vegetated area where Nitrate was expected to reach groundwater as a consequence of natural vegetation.
- Ammonia concentrations were generally high. The average ammonia concentration was 5.12 mg/L and ranged from 0.28 mg/L to 30.82 mg/L. This exceeds the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. Five (5) tested water samples exceeded this limit. The average ammonia concentration excluding gw6 is 1.93 mg/L which while substantially lower than the average concentration including this sample, is still higher than the WHO aesthetic guideline value (1.5 mg/L). Natural concentration levels of ammonia are generally below 0.2 mg/L (WHO, 1993) and no tests showed concentrations below this level. There is no apparent correlation between increasing levels of ammonia and other nutrients.
- Phosphate concentrations were moderate and ranged from 0.08 mg/L to 0.76 mg/L with an average of 0.24 mg/L. There is no WHO drinking water guideline value for phosphate. However, it would normally be expected that phosphate concentrations in groundwater are less than 0.1 mg/L, where there are no impacts from human wastewater (e.g. effluent from septic tanks and 'greywater' from kitchens and bathrooms). Only 2 of 9 samples tested had concentration below 0.1 mg/L.
- Total coliform levels were also found to be significant and ranged from lowest count of 1 MPN/100 mL to the highest count of more than 2420 MPN/100 mL, with an average count of 1459.6 MPN/100 mL. As expected, the groundwater layer is contaminated with effluent from septic tanks. However it should be noted that the samples taken from the residential areas showed lower total coliform counts (1 MPN/100ml and 37 MPN/100ml for gw1 and gw2 respectively) compared to samples from school and farm within the vegetated areas (>2420 MPN/100ml for gw3, gw6 and gw7).

In conclusion, M. Raiymandhoo Island contains groundwater with generally high Electrical Conductivity and TDS and low turbidity. Nitrate concentration was lower than than WHO maximum guidance value, but Phosphate and Ammonia concentrations were higher than expected in natural, undisturbed groundwater. In terms of microbiological contamination, Raiymandhoo Island shows variable patterns where residential areas have high contamination while school and vegetated area have lower contamination. Additionally, the following pages contain maps which show the main physiochemical parameters displayed on map of the island.


73°38'10"E
73°38'20"E
73°38'30"E
3°5'30"N
3°5'20"N
3°5'10"N
EC=1587.7µS/cm
TDS=970mg/L
EC=3519.5µS/cm
TDS=2130mg/L
EC=588.8µS/cm
TDS=349mg/L
EC=1640.2µS/cm
TDS=1003mg/L
EC=3420.1µS/cm
TDS=2008mg/L
EC=646.5µS/cm
TDS=381mg/L
EC=5486.2µS/cm
TDS=3294mg/L
EC=1236.1µS/cm
TDS=732mg/L
EC=27227.5µS/cm
TDS=16780mg/L
Legend
14,000
EC__µS_cm_
TDS__mg_L1
Blocks
High Tide Line
Low Tide Line
N
W
E
S
Meters
0
50
100
200
M. Raiymandhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 08/08/2019
Map Number: Raiy/2019/11
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


73°38'10"E
73°38'20"E
73°38'30"E
3°5'30"N
3°5'20"N
3°5'10"N
DO=3.69mg/L
Ammonia=0.49mg/L
Phosphate=0.09mg/L
Nitrate=10.8mg/L
DO=0.65mg/L
Ammonia=2.48mg/L
Phosphate=0.19mg/L
Nitrate=20.6mg/L
DO=2.1mg/L
Ammonia=0.71mg/L
Phosphate=0.76mg/L
Nitrate=4.4mg/L
DO=4.66mg/L
Ammonia=1.01mg/L
Phosphate=0.11mg/L
Nitrate=15.2mg/L
DO=1.41mg/L
Ammonia=3.87mg/L
Phosphate=0.44mg/L
Nitrate=28.6mg/L
DO=2.53mg/L
Ammonia=0.28mg/L
Phosphate=0.11mg/L
Nitrate=2.9mg/L
DO=1.17mg/L
Ammonia=5.61mg/L
Phosphate=0.2mg/L
Nitrate=28.3mg/L
DO=1.59mg/L
Ammonia=0.97mg/L
Phosphate=0.08mg/L
Nitrate=10.2mg/L
DO=5.46mg/L
Ammonia=30.82mg/L
Phosphate=0.15mg/L
Nitrate=108.9mg/L
Legend
15
Turbidity__NTU_
DO__mg_L
Ammonia__mg_L_
Phosphates__mg_L_
Blocks
High Tide Line
Low Tide Line
N
W
E
S
Meters
0 45 90 180
M. Raiymandhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 23/09/2019
Map Number: Raiy/2019/12
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

11.8.3 Geophysical survey

The Resistivity tests were carried out in the locations as outlined in Figure below.

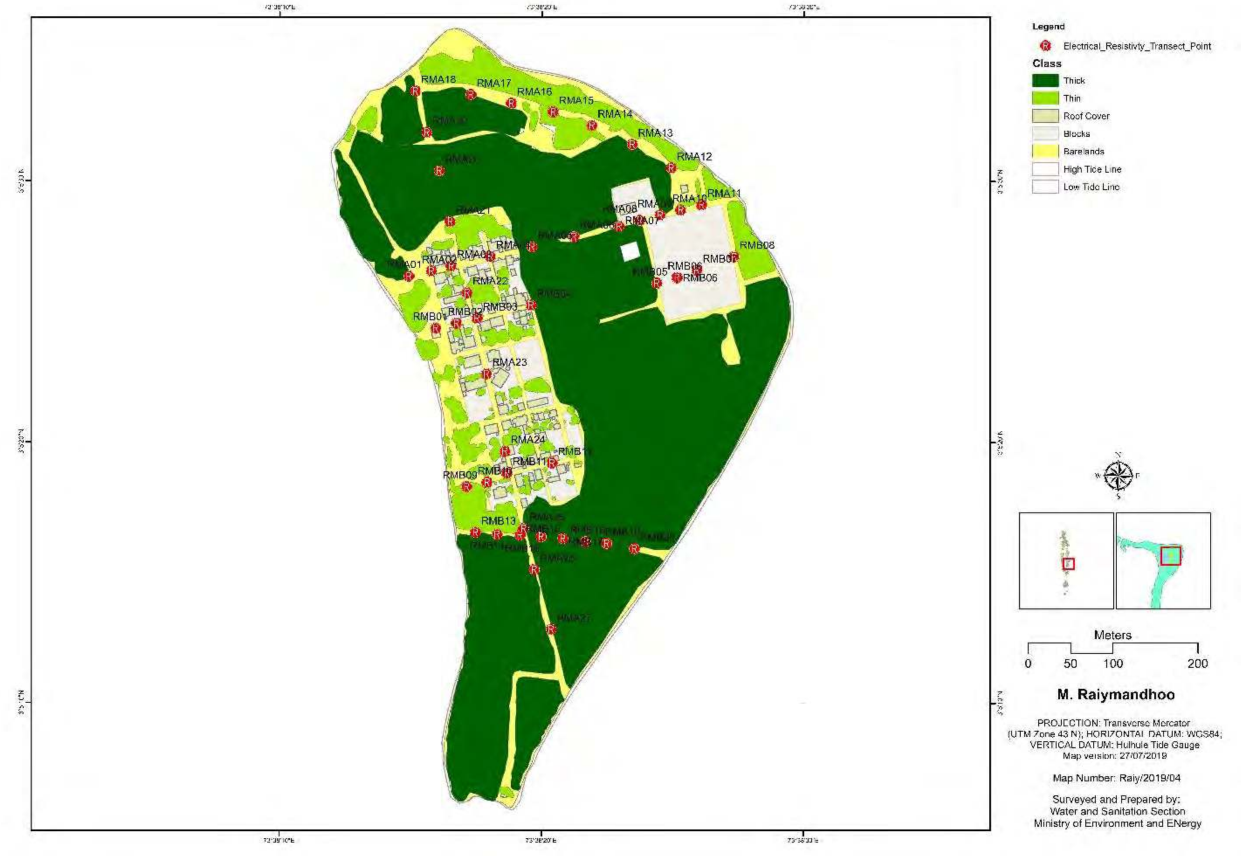


Figure 11.6: Location of ER points in Raiymandhoo Island

11.8.4 Aerial surveys

Based on the aerial survey, a multiple dataset consisting of roof cover, thick vegetation area, thin vegetation area, bare lands and shoreline were extracted. This data is shown in Figure 3.6 and the table shows the different area distribution.

Figure 11.7: Area Distribution in Raiymandhoo Island

Table 11.7 - Area Distribution in Raiymandhoo

	Area (Square Meters)	Percentage (%) of total area
Roof cover	8,643	3.3%
Vegetation (Thick)	161,659	60.8%
Vegetation (Light)	32,198	12.1%
Bare lands	61,809	23.4%
Farm Lands	1,409	0.5%
Wetlands (Inland)	-	

11.8.5 Water Demand

The only source of natural water is rainwater collected from the rooftops of households and institutions and groundwater extracted from shallow wells.

11.8.6 Freshwater lens

Based on the ER survey the depth to groundwater level and the freshwater-saline water interface was determined for a set of transverse transects as shown in Figure 11.8. Plots in the Figure 11.9 shows the cross sections of each transect line. The dotted lines in the plots indicating a simple interpolation of levels to mean sea level in the island boundaries. These cross sections were used to identify the spatial extent and volume of the freshwater lens while they were also useful in deriving implications on the stress level of the aquifer based on the observed, localized drawdown effect in the groundwater table and up-coning in the freshwater-saline interface, defining the upper and lower boundaries of the freshwater lens in an island.

The Table 11.8 illustrates the freshwater volume calculation for the island. The area covered by freshwater for each transect line has been calculated. To estimate the total volume of available freshwater lens, the cross-section area of freshwater extent under each transect was multiplied by the distance between two transects. The sum of these lengths represents the cumulative length of the island and thus, the above estimation could represent the total volume of the freshwater lens sandwiched between the groundwater table on top and freshwater-saline water interface in the bottom. Then the actual groundwater storage within this freshwater lens was calculated by multiplying the estimated total lens volume with the porosity of the topsoil in the island.

This estimation represents the total available freshwater volume within the freshwater lens at any given time (time of the measurement). The measurements were carried out towards the end of the dry period and the freshwater lens is presumed to be undergoing a 'stressed' condition due to continued groundwater abstractions despite reduced recharge in the dry period. Falkland (1994) method can be used to estimate the freshwater lend thickness under salient conditions using average annual rainfall, length and width of the island, and the comparison was used as a measure of stress level of the freshwater lens.

Table 11.8: Freshwater Volume Calculation for Raiymandhoo Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
1	Start		0	0	0	0			
			13	0.277	0	0			
	RMB14	ER	51	1.1	0.4	-1.28	32		
	RMB15	ER	78	1.025	0.3	-1.25	43		
	RMB16	ER	103	0.998	0.23	-1.31	39		
	RMB17	ER	129	1.16	0.24	0.24	20		
	RMB18	ER	156	1.2	0.3	0.3	0		
	RMB19	ER	181	1.464	0.29	-1.17	18		
	RMB20	ER	213	1.317	0.37	-1.54	55		
			246	0.915	0	0	31		
	End		259	0	0	0	0		
	Total						238	466	111026
2	Start		0	0	0	0			
			21	0.634	0	0	0		
	RMB01	ER	26	0.772	0.264	-1.408	4		
	RMB02	ER	51	0.954	0.261	-2	50		
	RMB03	ER	76	1.129	0.39	-3.02	70		
	RMB04	ER	141	1.162	0.32	-2.7	211		
	RMB05	ER	291	1.086	0.44	-0.01	260		
	RMB06	ER	316	1.006	0.36	-0.57	17		
	RMB08	ER	387	1.176	0.24	-1.38	90		
			405	1.060	0	0	15		

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
	End		427	0	0	0	0		
	Total						717	141	101123
3	Start		0		0	0			
			22		0	0	0		
	RMA01	ER	36	0.759	0.37	-1.75	15		
	RMA02	ER	63	0.95	0.34	-2.6	69		
	RMA03	ER	87	1.066	0.33	-1.57	58		
	RMA04	ER	134	1.058	0.4	-1.87	98		
	RMA05	ER	185	0.926	0.32	-1.39	100		
	RMA06	ER	236	1.47	0.4	0.4	44		
	RMA07	ER	290	0.91	0.34	0.34	0		
	RMA08	ER	315	0.86	0.39	0.39	0		
	RMA09	ER	340	0.903	0.29	0.29	0		
	RMA10	ER	365	1.051	0.23	0.23	0		
	RMA11	ER	391	0.955	0.27	0.27	0		
			414	0.774	0	0	0		
	End		436	0	0	0	0		
	Total						384	235	90305
									302,454

Volume of lens = 302454 m^3

Groundwater Storage = Porosity (15%) x Lens volume (m^3) = 45368 m^3

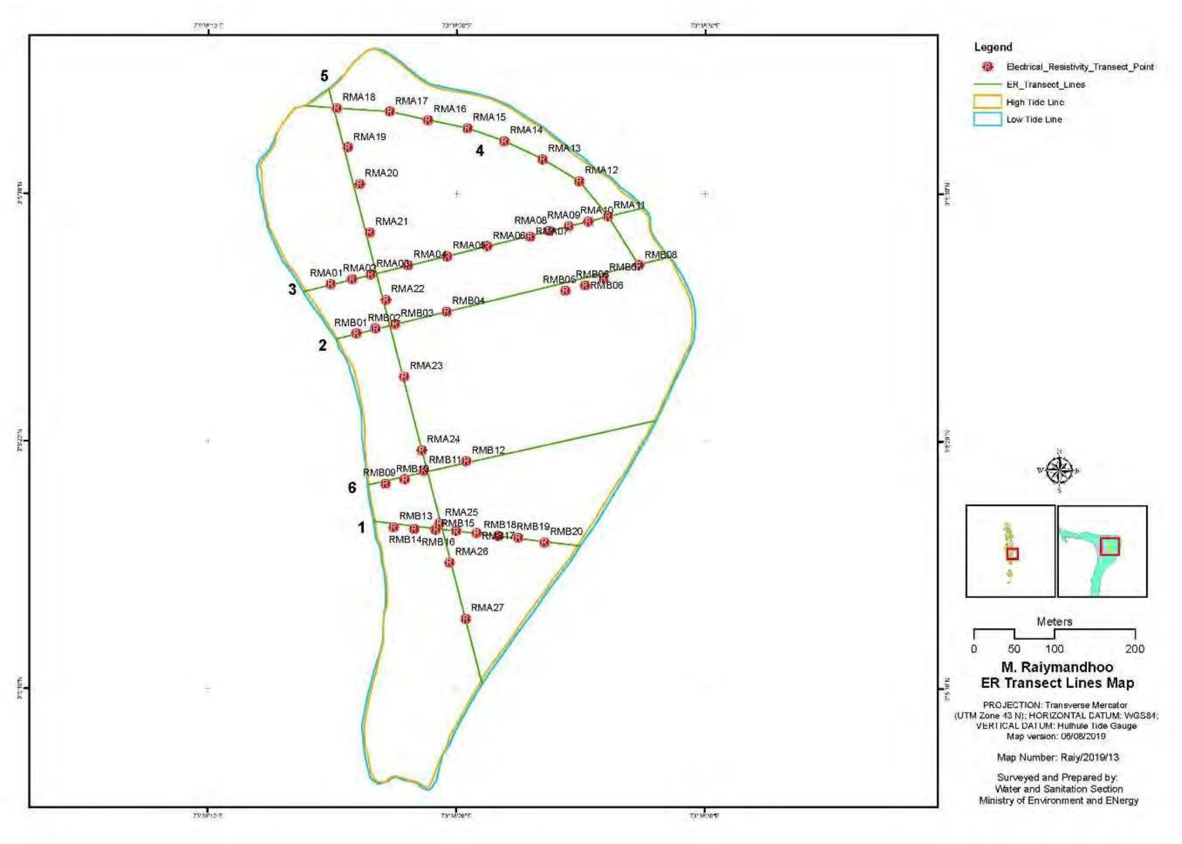
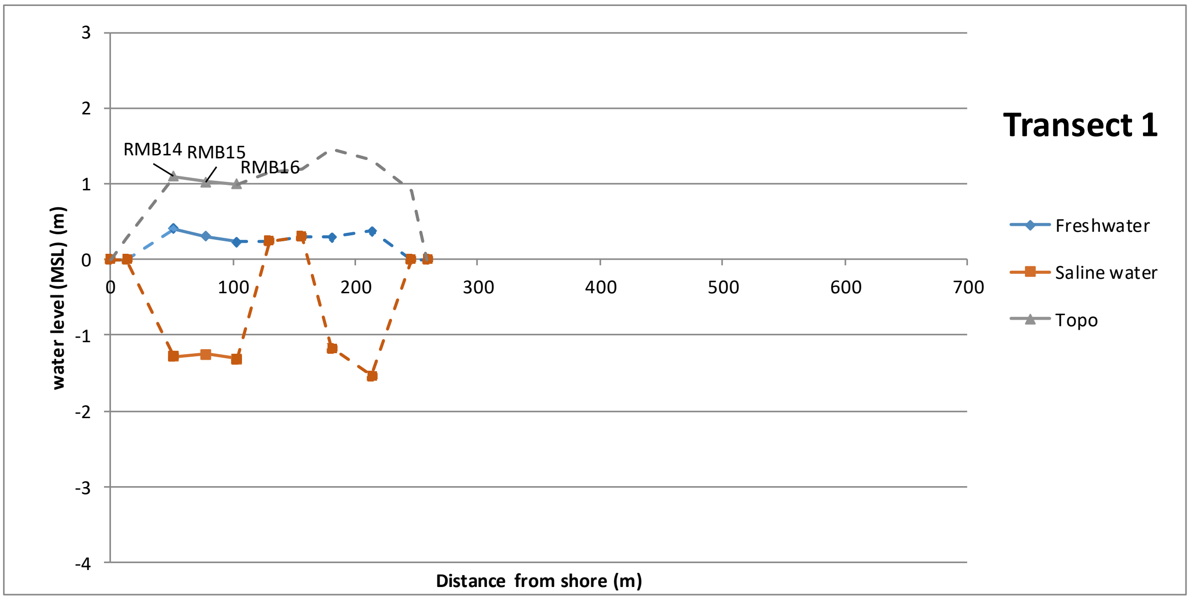


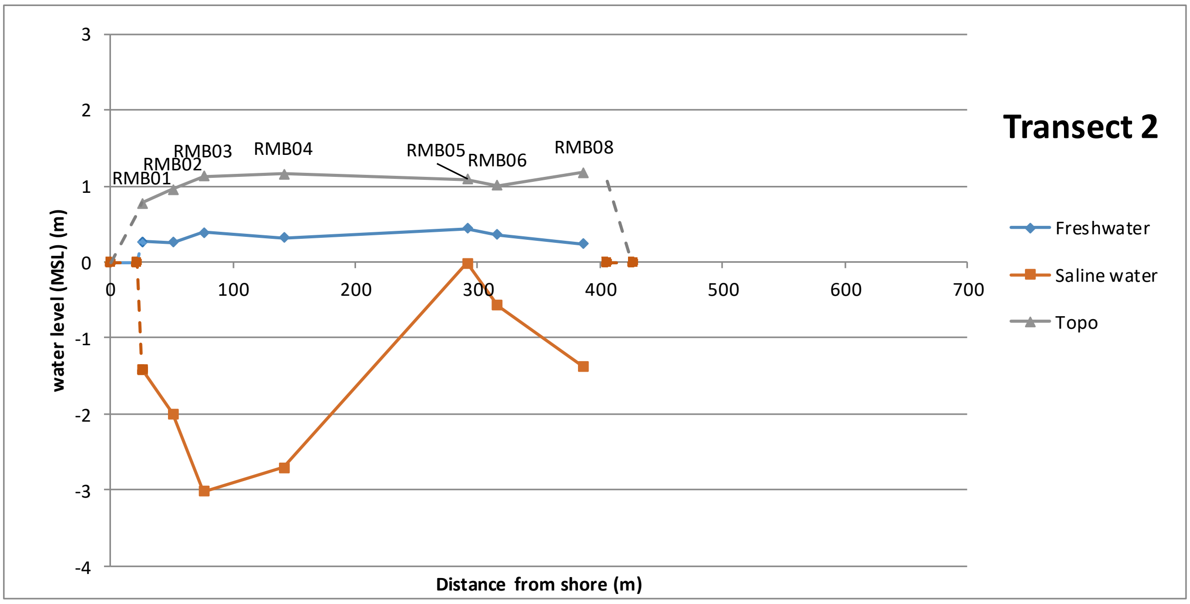
Figure 11.8: ER transect lines in Raiymandhoo Island

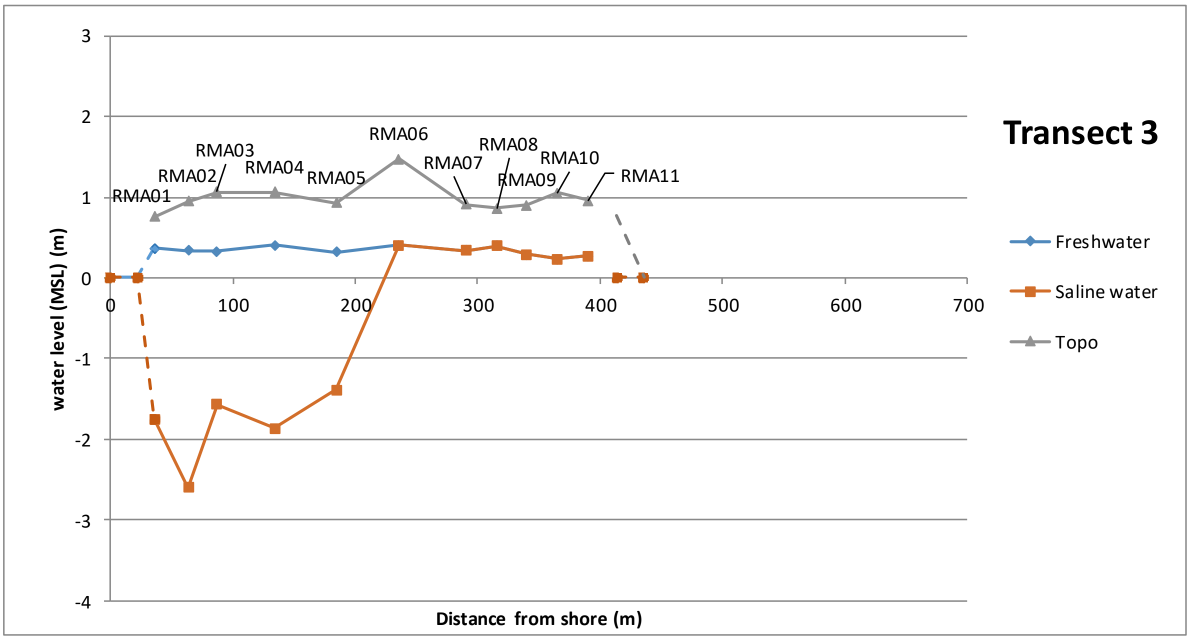
Table 11.9: ER Survey Results of Longitudinal Sections for Raiymandhoo Island

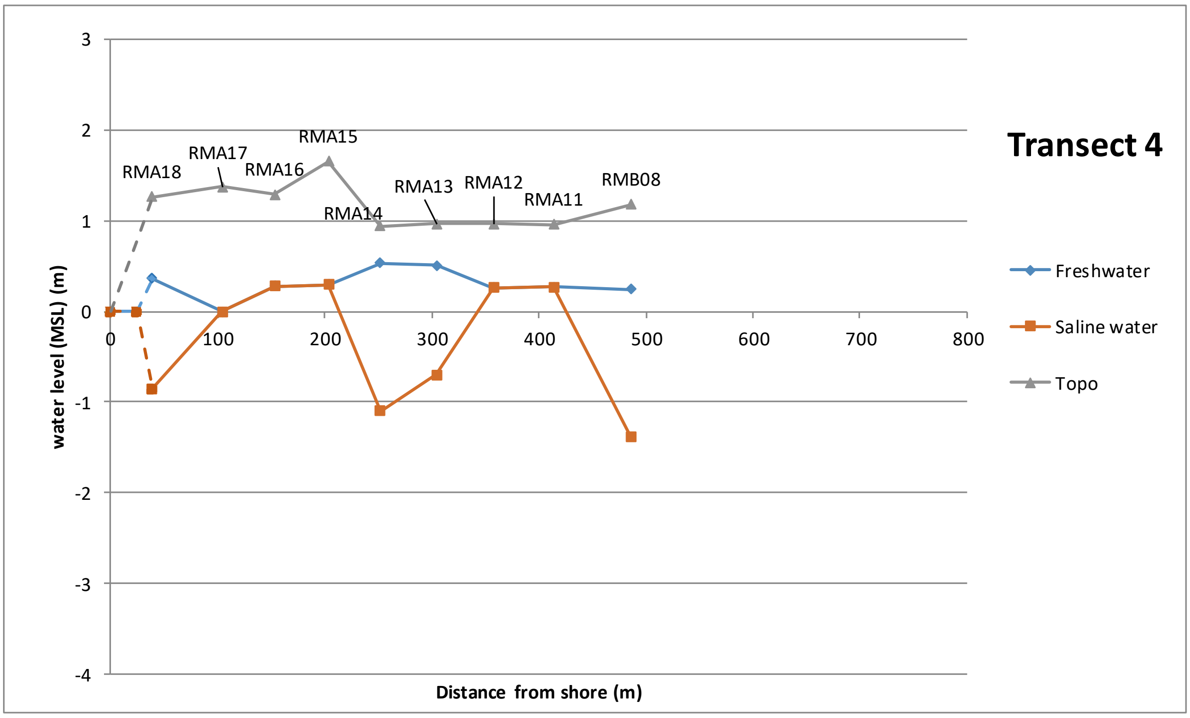
Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)
5	Start		0	0	0	0
			12	0.630	0	0
	RMA18	ER	25	1.259	0.36	-0.85
	RMA19	ER	76	1.051	0.24	-1.6
	RMA20	ER	125	1.21	0.29	-1.77
	RMA21	ER	184	1.05	0	0
	RMA03	ER	237	1.066	0.33	-1.57
	RMA22	ER	271	0.97	0.32	-1.42
	RMB03	ER	304	1.129	0.39	-3.02
	RMA23	ER	370	0.873	0.39	-1.32
	RMA24	ER	463	0.73	0.29	-1.45
	RMB11	ER	491	0.824	0.22	-1.47
	RMA25	ER	557	1.037	0.33	-1.09
	RMA26	ER	607	1.082	0.54	-1.1
	RMA27	ER	680	1.091	0.32	-1.91
			751	0.700	0	0

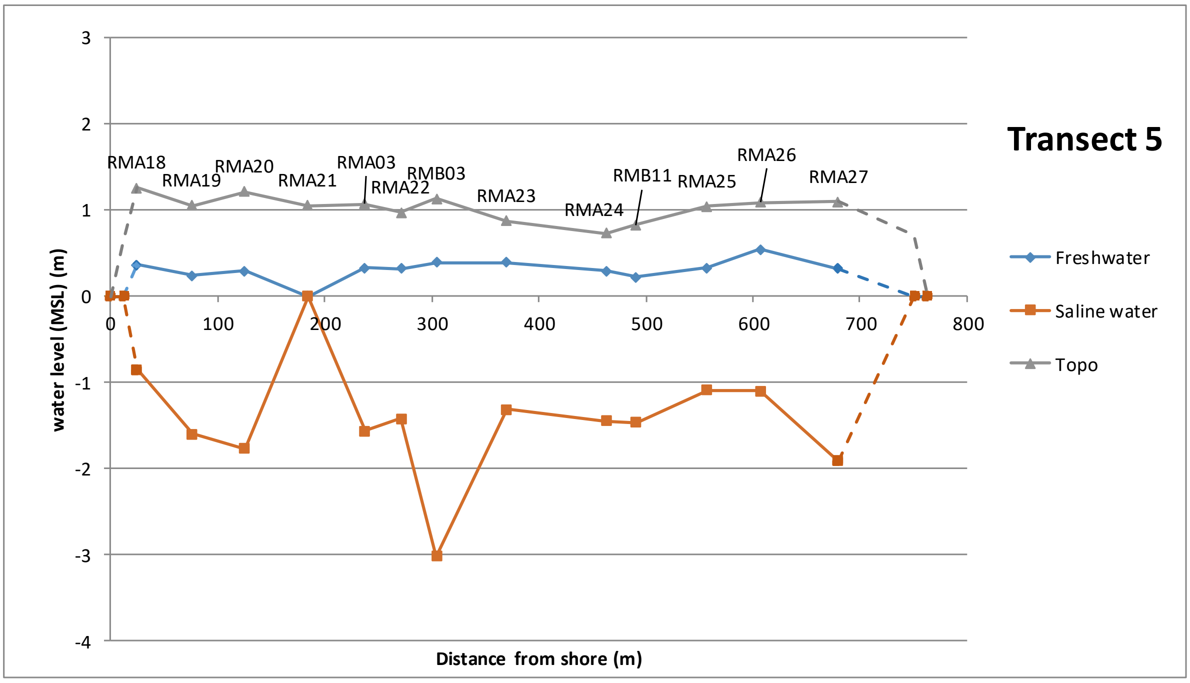
	End		763	0	0	0
Transect Line	**Location**	**Point ID**	**Distance from shore (m)**	**Topo Level (MSL) (m)**	**Freshwater level (MSL) (m)**	**Saltwater interface (MSL) (m)**
4	Start		0	0	0	0
			24	0.785	0	0
	RMA18	ER	39	1.259	0.36	-0.85
	RMA17	ER	105	1.377	0	0
	RMA16	ER	153	1.286	0.28	0.28
	RMA15	ER	203	1.65	0.29	0.29
	RMA14	ER	252	0.936	0.53	-1.1
	RMA13	ER	304	0.965	0.51	-0.7
	RMA12	ER	358	0.963	0.26	0.26
	RMA11	ER	414	0.955	0.27	0.27
	RMB08	ER	486	1.176	0.24	-1.38
6	Start		0	0	0	0
			18	0.803	0	0
	RMB09	ER	20	0.87	0.32	-1.61
	RMB10	ER	45	0.986	0.2	-1.58
	RMB11	ER	69	0.824	0.22	-1.47
	RMB12	ER	125	0.777	0.43	-0.56
			346	0.761	0	0
	End		364	0	0	0




Transect 2
water level (MSL) (m)
Distance from shore (m)
RMB01
RMB02
RMB03
RMB04
RMB05
RMB06
RMB08
Freshwater
Saline water
Topo


Transect 3
water level (MSL) (m)
Distance from shore (m)
RMA01
RMA02
RMA03
RMA04
RMA05
RMA06
RMA07
RMA08
RMA09
RMA10
RMA11
Freshwater
Saline water
Topo


Transcect 4
water level (MSL) (m)
Distance from shore (m)
RMA18
RMA17
RMA16
RMA15
RMA14
RMA13
RMA12
RMA11
RMB08
Freshwater
Saline water
Topo


Transect 5
water level (MSL) (m)
Distance from shore (m)
RMA18
RMA19
RMA20
RMA21
RMA03
RMA22
RMB03
RMA23
RMA24
RMB11
RMA25
RMA26
RMA27
Freshwater
Saline water
Topo

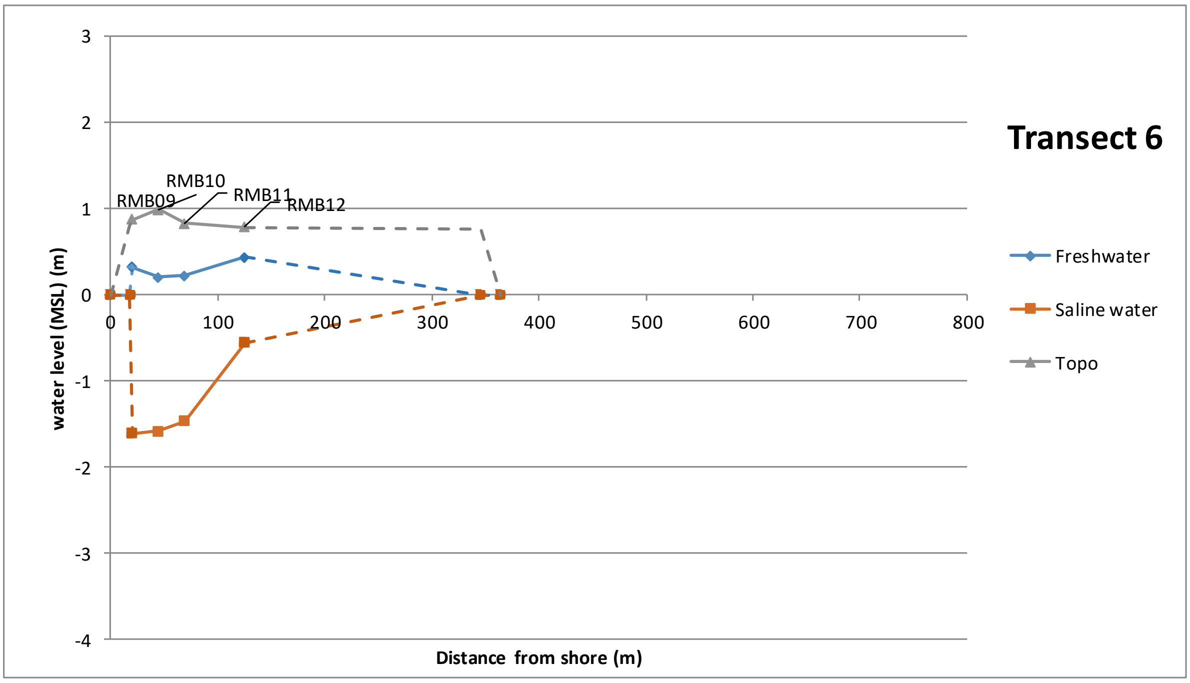


Figure 11.9: Cross-sections of transect lines in Raiymandhoo Island

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented below.

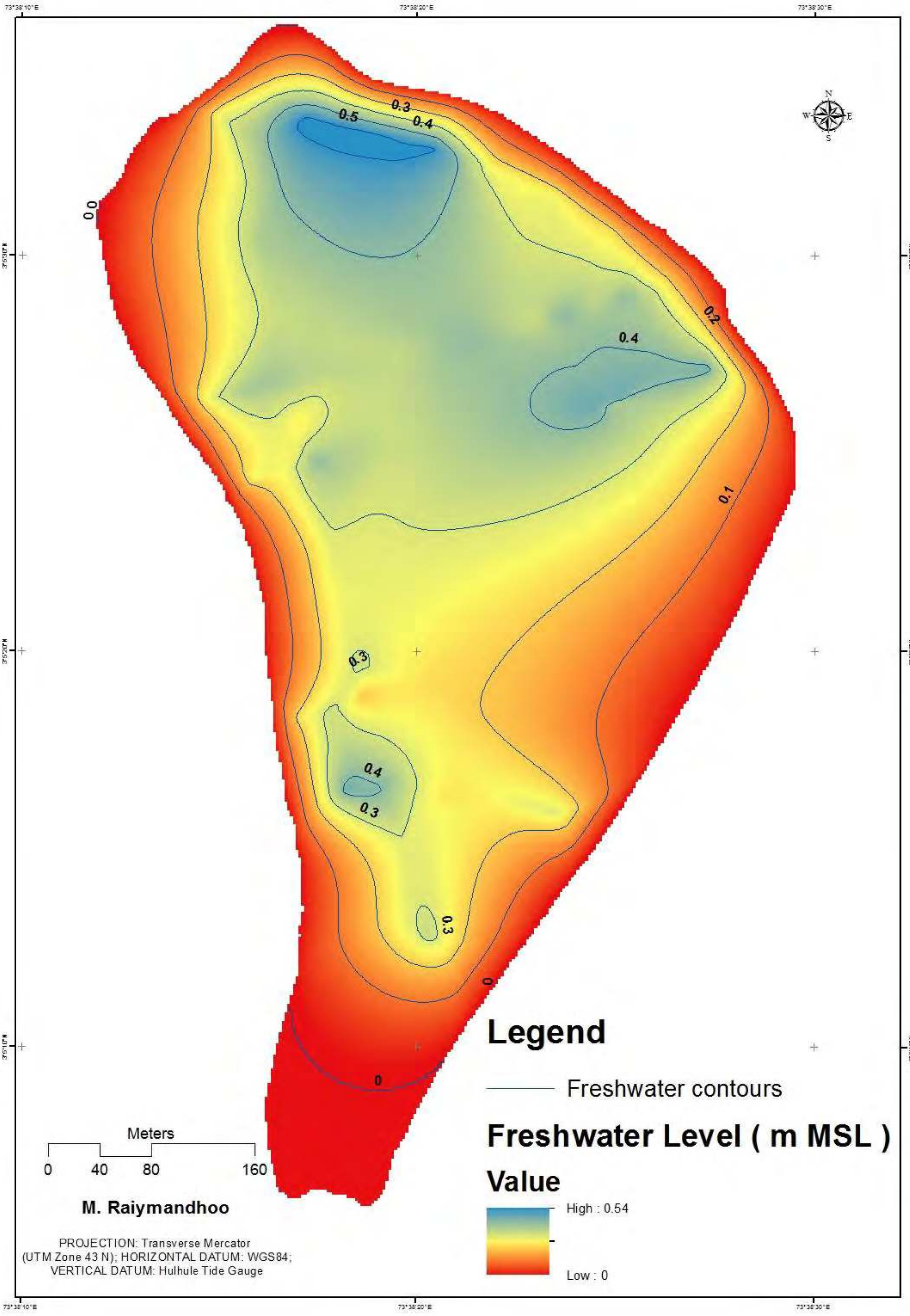

0.5
0.3
0.4
0.0
0.2
0.4
0.1
0.3
0.4
0.3
0.3
0
0
Legend
Freshwater contours
Freshwater Level (m MSL)
Value
High : 0.54
Low : 0
Meters
0 40 80 160
M. Raiymandhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge

Figure 11.10: Freshwater Level in Raiymandhoo Island

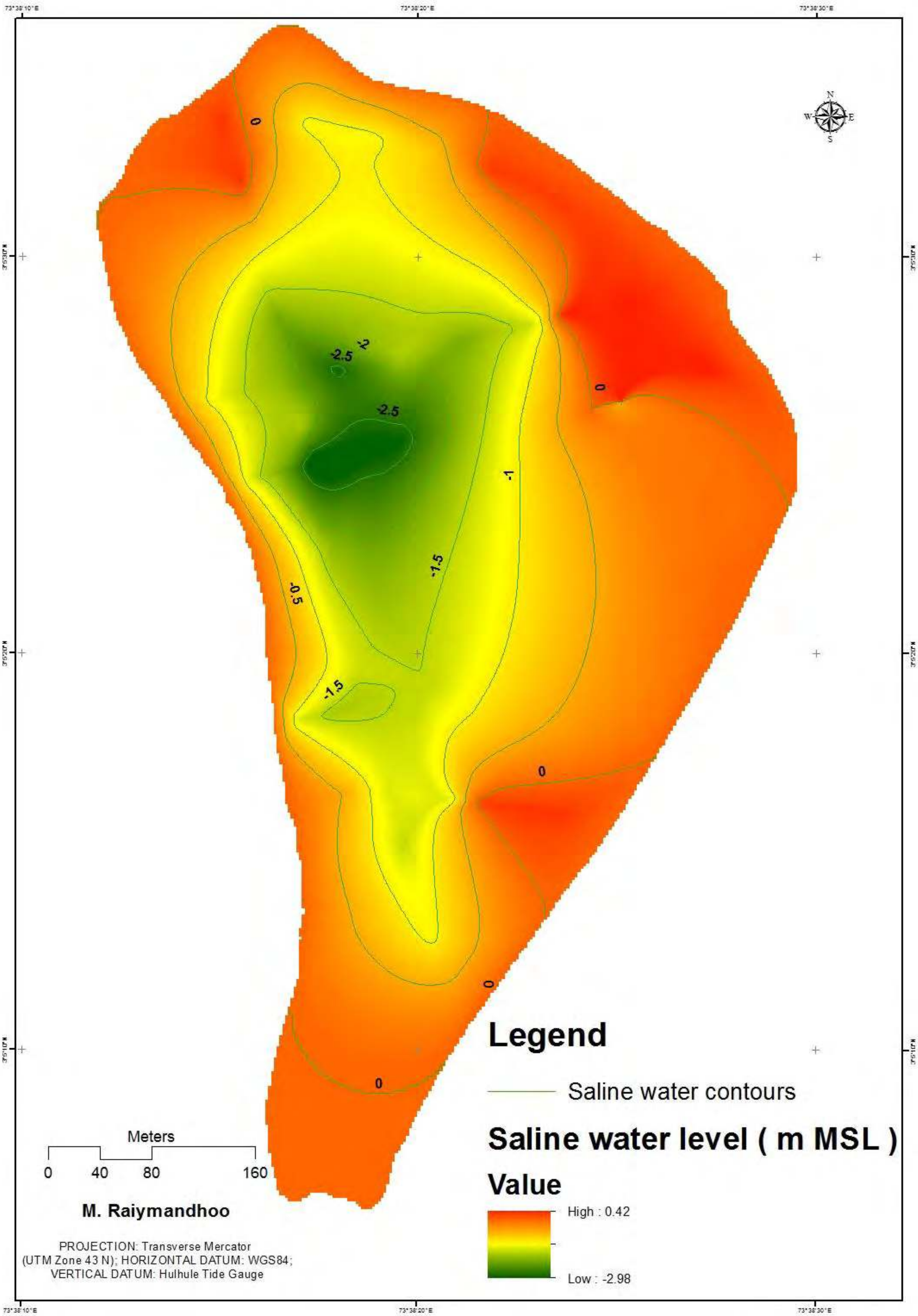


Figure 11.11: Saline water Level in Raiymandhoo Island

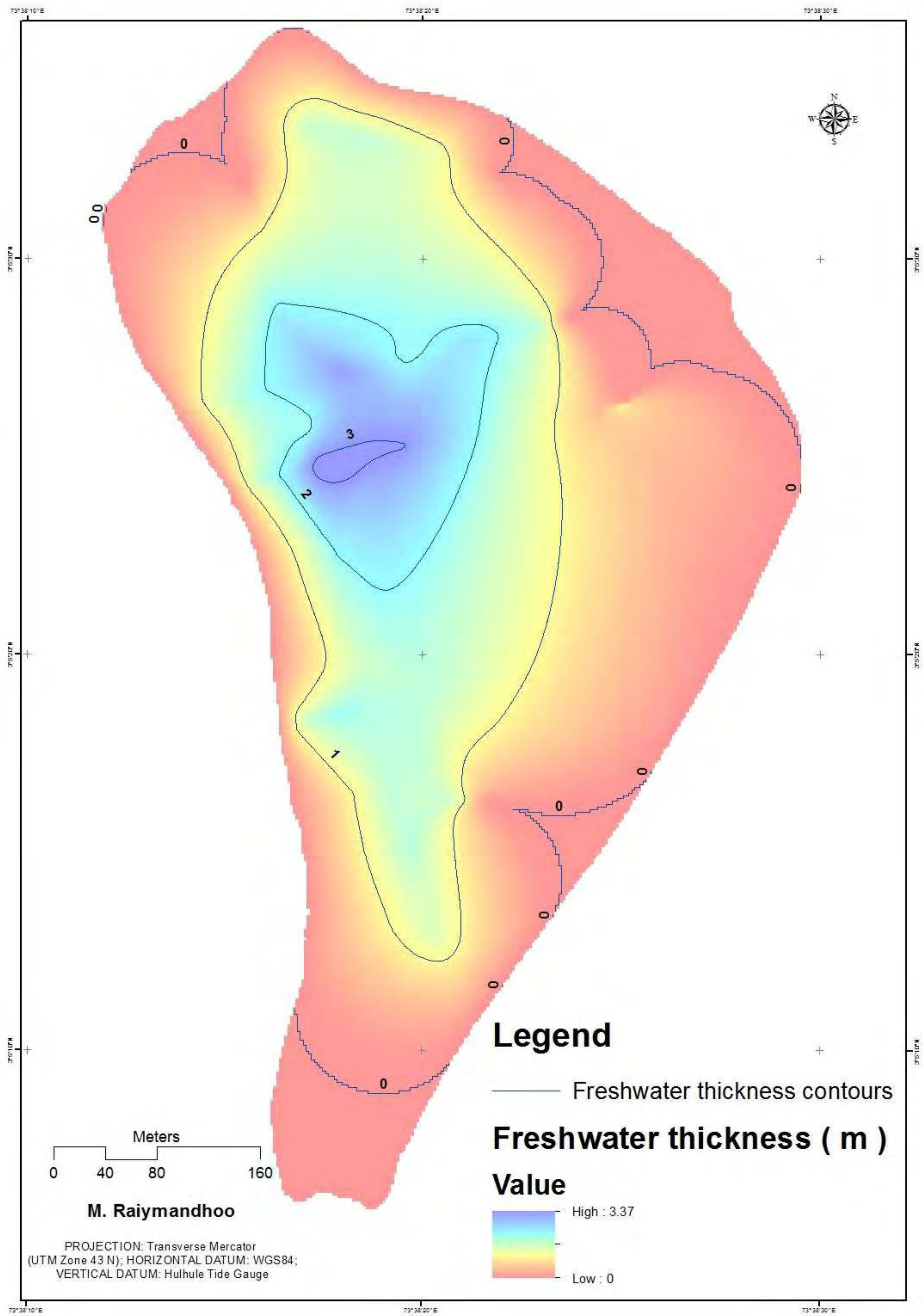


Figure 11.12: Freshwater thickness in Raiymandhoo Island

The maximum freshwater thickness of the island is 3.37 m. According to Falkland, 1994, the freshwater level thickness of the island is 7 m. The relevant calculations are as follows;

Average Annual Rainfall = 2150 mm/yr

Width of the island = 364 m

Length of the island = 763 m

Freshwater lens Thickness (m)

= (6.94*log(width of the island)-14.38)*Average Annual Rainfall = 7 m

11.8.7 Water balance and recharge

An annual estimation is carried out based on water balance method. Rainwater harvesting is calculated using number of rainwater harvesting units in the island. According to the spatial mean annual rainfall of Maldives, the island is reported as 2150 mm/year. Evapotranspiration was estimated using crop water requirement for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. The groundwater extractions were estimated from amount of water usage in different sectors (residential, resorts, restaurants, agriculture and farming).The difference between recharge and groundwater extraction is taken to estimate different in storage.

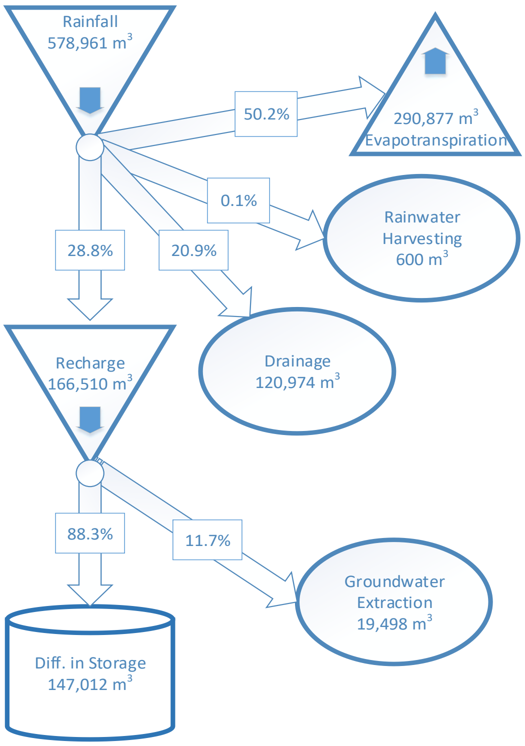


Figure 11.13: Schematic of water balance in Raiymandhoo Island

11.8.8 Sustainable yield of the lens

Sustainable yield of the water lens refers to the safe extraction potential of a given groundwater aquifer without significantly affecting its quality or quantity. This parameter is an important factor in the sustainable development of islands as it allows planning and design of water and sanitation intervention in islands.

The island has a sustainable yield of 403 m^3 per day which was calculated subtracting groundwater extraction from recharge volume derived from water balance (Figure 4.13). According to Metai & Unit, n.d., based on geophysical investigations and drilling programme concluded that the safe sustainable yield was about 10% of mean annual rainfall. Such that the expected sustainable yield for the island should be 159 m^3 per day.

11.8.9 Permeability test

Permeability tests were carried out in the locations as outlined in Figure 11.14.

Figure 11.14: Locations of permeability tests in Raiymandhoo Island

The estimated permeability values for the above test locations are presented below.

Table 11.10: The estimated permeability Values

r_e	0.026
r_1	0.0285

Point	H	Tu	Cs	H/re	Q	K (m/s)	K (m/day)	Q (l/min)	Q (m³/s)
PT1	0.6	1.55	43	23.1	1.2E-05	1.22E-05	1.06	0.7	1.17E-05
PT2	0.7	1.36	50	26.9	1.3E-05	1.39E-05	1.20	0.8	1.33E-05

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m^3/s), H = Height of water in well (m), l = length of perforated section (m), r_1 = outside radius of casing (radius of hole in consolidated material) (m), r_e = effective radius of well = r_1 (area of perforations) / (outside area of perforated section of casing) : $r_1 = r_e$ in consolidated material that will stand open and is not cast, C_u and C_s =Conductivity Coefficients, and T_u = distance from water level in casing to water table (m).

11.8.10 Pumping Test

Pumping tests were carried out in the locations as outlined in Figure 11.15

Figure 11.15: Pumping Test Locations

11.8.11 Groundwater availability

1) The selected Raiymandhoo island has dimensions of width = 364 m and length = 763 m, with a total land area of 26.57 ha, a population of 112 persons, and a land use of built-up area 0.86 ha (3.3%), thick vegetation 16.16 ha (60.8%), light vegetation 3.23 ha (12.1%), barelands 6.18 (23.4%) and farmlands 0.14 ha (0.5%).

2) In order to recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of freshwater lens (FWL) and its associated recharge-discharge characteristics, 48 number of Electrical Resistivity (ER) location readings along 06 representatively selected transects were collected.

3) Soil overburden permeability tests (constant head) were carried out at 06 locations while steady-state pumping tests were conducted at 01 locations. In addition, groundwater level was also recorded at 09 locations where groundwater water quality samples were tested.

4) Permeability tests were carried out at representatively selected 05 number of locations. The measured permeability (K m/day) values ranged from a minimum of 2.62 m/day to a maximum of 55.44 m/day, with an average of 27.53 ± 18.81 m/day (Mean ± 1 Standard Deviation). The steady state pumping test resulted an aquifer transmissivity value of 4.70 x 10-3 m2/s.

5) The ground elevation values ranged from a minimum of 0.35 m MSL to a maximum of 1.55 m MSL, with an average of 1.02 ± 0.18 m MSL (Mean ± 1 Standard Deviation).

6) The upper boundary of the freshwater lens (FWL) varied from a minimum of 0.20 m MSL to a maximum of 0.54 m MSL, with an average of 0.33 ± 0.08 m MSL (Mean ± 1 Standard Deviation).

7) The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -3.02 m MSL to a maximum of 0.44 m MSL, with an average of -0.91 ± 0.96 m MSL (Mean ± 1 Standard Deviation).

8) Accordingly, the freshwater lens (FWL) thickness values ranged from a minimum of 0.00 m to a maximum of 3.41 m, with an average of 1.24 ± 0.96 m (Mean ± 1 Standard Deviation).

9) The groundwater profile in the island is characterised by a relatively Low (0.10%) Rainwater Harvesting, relatively Very Low (20.90%) Drainage, relatively Very Low (28.76%) Recharge, while the water use shows relatively Very Low (11.71%) Groundwater extraction, leading to relatively Very High (88.29%) Difference in Balance Storage.

10) The freshwater lens (FWL) volume calculated based on ER transect test data is 45,368 m^3 with a maximum FWL thickness of 3.41 m. The potential maximum FWL volume and thickness estimated based on Falkland (1994) method are 22,164 m^3 and 7.30 m.

11.8.12 Conclusive Comments and Recommendations

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 403 m^3 per day, while it is 159 m^3 per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 55 m^3 per day and this is about 35% of the allowable Safe Yield in the island with severe up-coning and severe drawdown in freshwater lens cross-sections in populated area. At present, there exists no island-wide sewerage network or water supply network. The water samples tested were found to be Moderately Odorous with 77.8% or 7/9 samples tested producing odour. The Hydrological condition of the freshwater lens aquifer can be categorised as Moderate based on above measurements and findings while Water quality aspects can be regarded as Contaminated with an Average Electrical Conductivity (EC) of 5,039.33 ± 8,474.21 µS/cm with measured values ranging from a minimum of 589.00 µS/cm to a maximum of 27,228.00 µS/cm, and an Average Ammonia Concentration of 5.14 ± 9.80 mg/L with measured values ranging from a minimum of 0.28 mg/L to a maximum of 30.82 mg/L.

The Availability of space for incorporating recharge measures and related infrastructure is High while therefore the Potential for Recharging is considered to be High. Overall recommendation for groundwater recharging would be to use recharging trenches and ponds in roads and recharging pits in individual households and land blocks.

12 KINBIDHOO ISLAND

12.1 General overview of the island

The island of Kinbidhoo is located at 2°10'5"N and 73°3'59"E in the Thaa Administrative Atoll. The island is about 1029 m long and 388 km wide, giving it an area of 37.77 ha. The island has a population of 768 people, via the 2014 Census. The island has a harbor on the northern side of the island. The following table outlines some basic information about the island and the following figure outlines the location of Kinbidhoo.

Table 12.1: Basic statistical information on Kinbidhoo island in Thaa Atoll.

Name of the island	Th. Kinbidhoo
Longitude and Latitude	73°3'58.9"E, 2°10'4.7"N
Area	37.77 ha
Population (Census, 2014)	768
Distance from Atoll Capital (Th.Veymandhoo)	3.9 km
Distance from Male'	227.4km
Harbour	Present
Island sewerage network	No
Water supply network	No
Other infrastructure	None

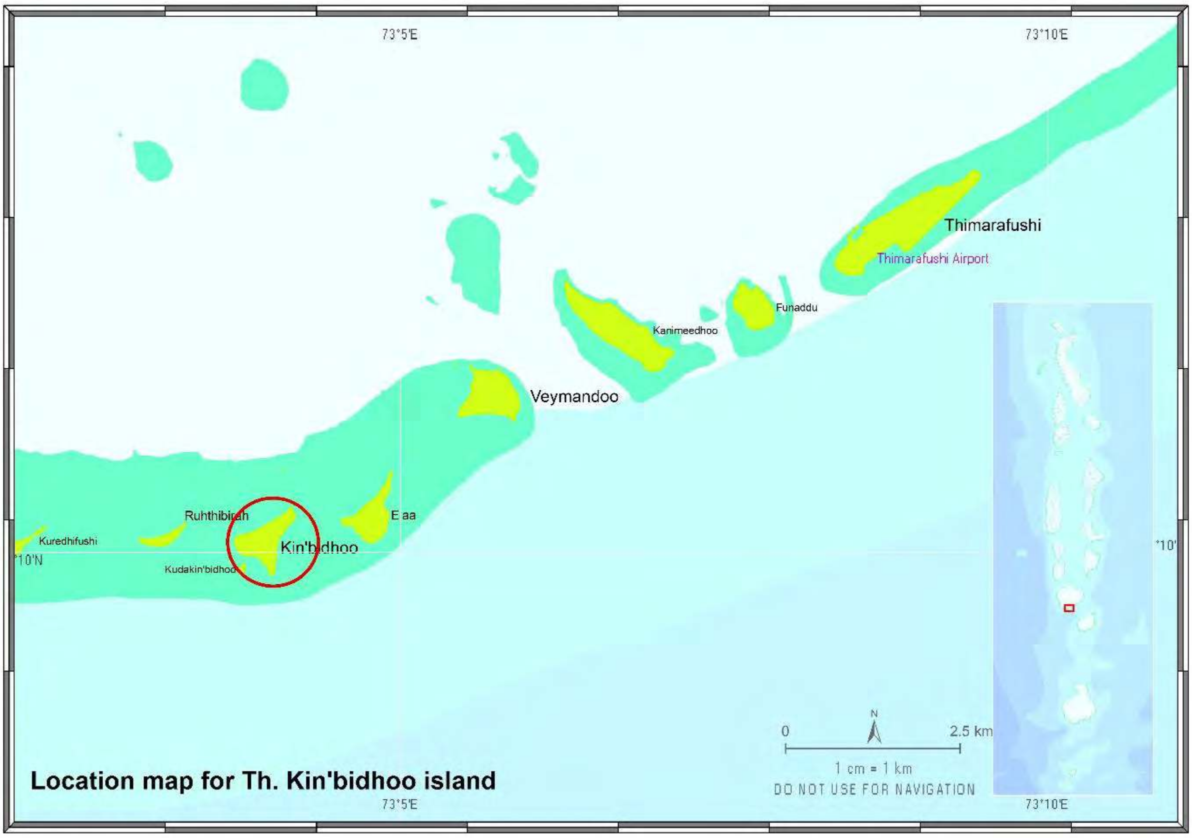


Figure 12.1: Location map for Kinbidhoo Island, Thaa Atoll.

12.2 Geology and vegetation

The island is about 990 m long and 860 m wide, with an area of 37.77 Ha. Of this about 61% of the land is covered in vegetation. The vegetation is mostly concentrated on the Western sides of the island, with thick vegetation on the Southwest tip of the island and Northeast of the island. The majority of vegetation in the forested area comprise of coconut trees. There are a number of other tropical native vegetation in this area, all of which are potential sources of organic matter input to the groundwater lens. There are no designated farmlands on Kinbidhoo island.

12.3 Topography

Kinbidhoo has a topography that ranges from an elevation of 0.16 meters to 1.34 meters above Mean Sea Level, with an average elevation of 0.86 meters above MSL. The digital terrain model with elevation contours and spot heights is shown in Figure 12.2.

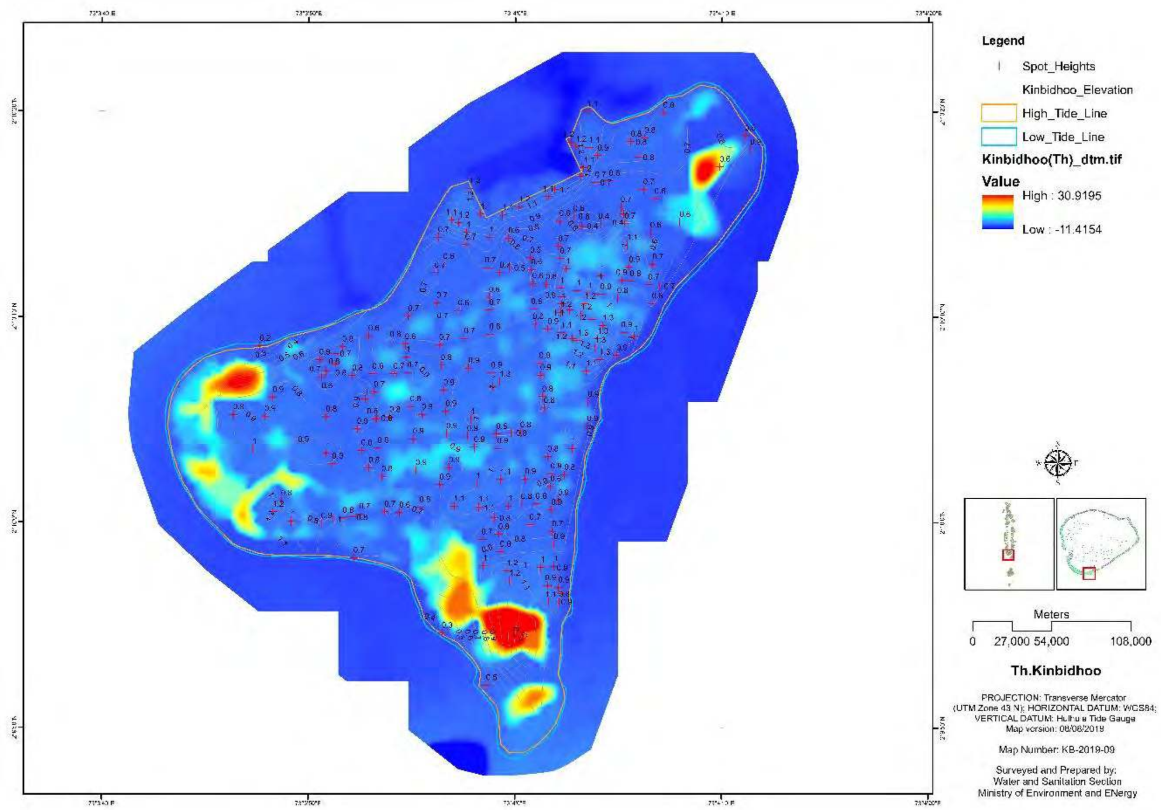


Figure 12.2: Digital Terrain Model of Kinbidhoo Island

12.4 Climate

Kinbidhoo experiences the typical two monsoons namely, north east monsoon from November to April and South-west monsoons from April to November. There are no specific wind and rainfall data available for Kinbidhoo as there are no weather monitoring stations on the island.

12.5 Demography

As per the 2014 Census, Kinbidhoo has a registered population of 768 people. However this figure may be inaccurate as the island council reports a different number of 1469 people in 2019. The island has more females than males for both the total and local population, with females comprising 51.6% of the total population. However for the foreign population there are significantly more males than females, with 90% of the foreigners being male. The following table and graphs illustrate the demographic breakdown of Kinbidhoo.

Table 12.2: Demographic Breakdown of Kinbidhoo Island

Atoll	locality	Resident population (Census, 2014)								
		Total			Maldivians			Foreigners		
		Both sexes	Male	Female	Both sexes	Male	Female	Both sexes	Male	Female
Th	Kinbidhoo	768	371	397	747	352	395	21	19	2

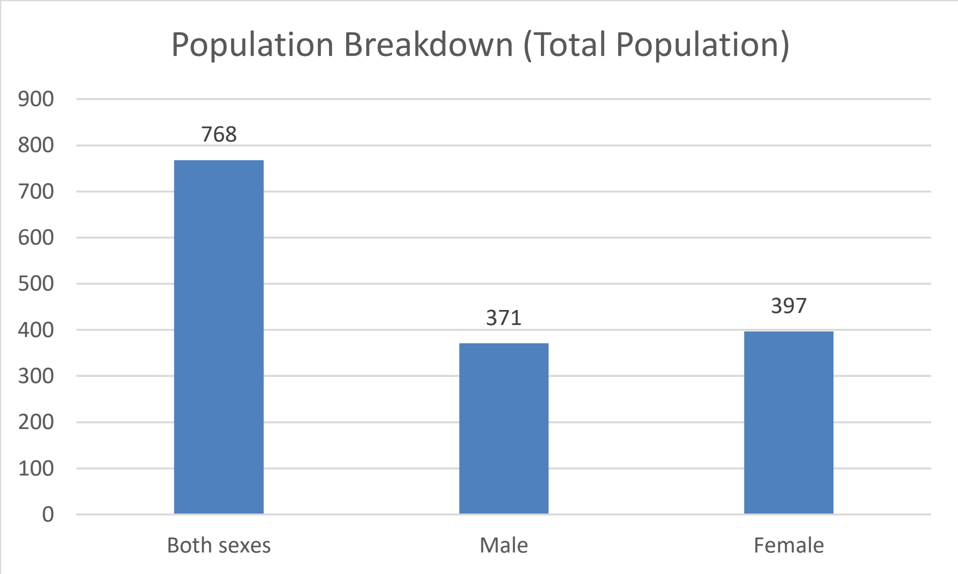


Figure 12.3: Population breakdown of Kinbidhoo (Maldivians & Foreigners)

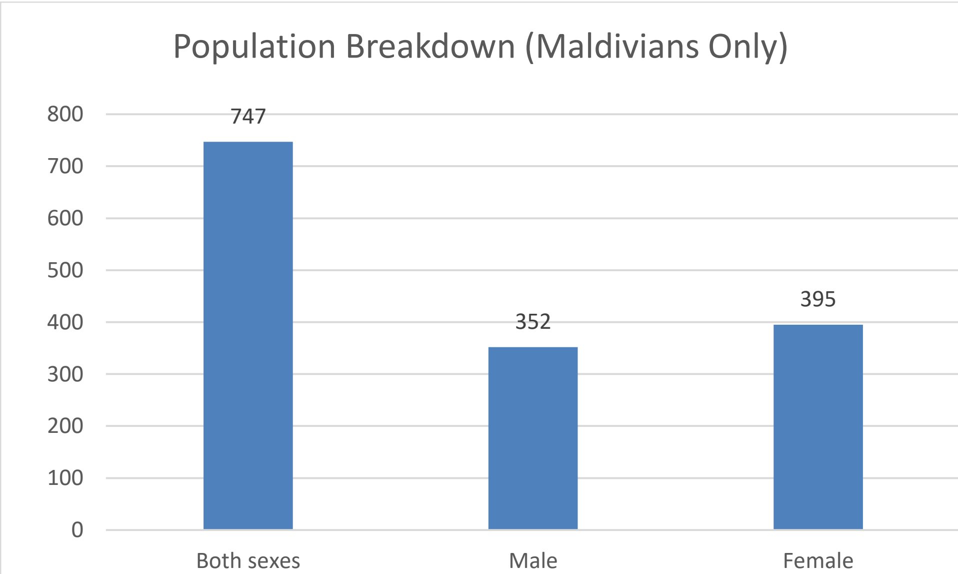


Figure 12.4: Population breakdown of Kinbidhoo (Maldivians)

12.6 Socio-economic condition

Kinbidhoo is a fast growing island in Thaa atoll, particularly due to its proximity to the atoll capital Veymandoo and Thimarafushi airport. This island has a population density of 20.33 residents per hectare, in accordance to the most recent population data provided by the island council and aerial survey. The island contains 300 households as reported by the island council, with 165 households occupied through the year. Raiymandhoo School has 217 registered students and has a total of 1 restaurant and 0 guesthouses.

12.7 Existing water and sanitation situation

The island does not currently have an island wide sewerage system nor a water supply system. The primary form of sanitation on the island is via the use of septic tanks. Each household has one or two septic tanks. 72.7% of the surveyed households clean their septic tanks by periodically disposing the septic waste to sea, while 18.2% of households bury septic waste in other parts of the island and the remaining claim not to have cleaned their septic tanks. On average, there is an approximate distance of 6.32 meters between septic tanks and nearest well. There are plans for both a water supply system and an island wide sewerage system in the 2019 budget.

The primary source of drinking water is rainwater that is collected in either household or community tanks. The primary source of water used for cooking is also rainwater. As this tends to run out during the dry season for several households, they borrow rainwater from neighbouring houses or take water from the community tanks in the mosques.

12.8 Results

12.8.1 Water sources and water use

Based on domestic, commercial, institutional and industrial water usage, a total of 321,346 liters of groundwater are estimated to be used every day. Otherwise stated, 218.75 liters of groundwater are used per capita per day. For the purpose of computing groundwater use, the population of the island is assumed to be 1469, which is the most recent number reported by the island council. The respective water use situations are detailed in the following sections.

12.8.1.1 Domestic water use situation

Based on the questionnaire to collect data on domestic water consumption, a summary of results are present in this section.

According to the survey, 100% of the households surveyed uses HDPE rainwater tanks as their main storage for water. A total of 100% households use rainwater for drinking and 100% use it for cooking. None of the surveyed houses use rainwater for bathing or washing.

None (0%) of the households use groundwater as drinking. Groundwater is mainly used for non-potable use in all the households surveyed.

Table 12.3 summarizes the groundwater and rainwater use data for Kinbidhoo Island.

Table 12.3: Groundwater and rainwater use data for Kinbidhoo

Rainwater	
Households with rainwater tanks	100%
Rainwater use for drinking	100%
Rainwater use for cooking	100%
Rainwater use for bathing and washing	0%

Groundwater	
Groundwater as drinking source	0%
Groundwater for cooking	0%
Groundwater for non-potable use	100%
Total number of households surveyed	10%
Percentage of wells surveyed fitted with pumps	100%

Based on the survey questionnaire, average daily water demand per capita for domestic purposes has been estimated based on the average amount of water used per person for showering, toilet flushing, laundry and gardening, this data is shown in table 12.4. The total domestic water use is estimated to be 215 liters per capita per day.

Table 12.4: Domestic Water Usage in Kinbidhoo

Shower/ Liters per capita per day	Toilet/ Liters per capita per day	Laundry/ Liters per capita per day	Gardening/ Liters per capita per day	**Total/ Liters per capita per day**
123	34	12	47	**215**

12.8.1.2 Commercial water use situation

Based on the questionnaire to collect data on commercial water consumption, a summary of results are present in this section. Kinbidhoo has a total of 1 restaurant and 0 guesthouses. 1 restaurant was surveyed.

For the restaurant, the main use of groundwater was for mopping, gardening, dishwashing and toilet use. From the survey data, the total groundwater consumption for this restaurant was estimated to be 2003 liters per day, therefore the total commercial groundwater consumption for the island is also 2003 liters per day. Otherwise stated, 1.36 liters of groundwater are used per capita per day for commercial purposes.

12.8.1.3 Institutional water use situation

Based on the questionnaire to collect data on institutional water consumption, a summary of results are present in this section. Four institutions were surveyed for this study namely the council office, health center, school and Fenaka – the island powerhouse. Groundwater in the institutions in Kinbidhoo Island are mainly used for flushing toilets, gardening and mopping floors. A total of approximately 2796 liters of groundwater are estimated to be used per day by the institutions. Therefore, a total of approximately 1.90 liters of groundwater are estimated to be used per capita per day by the institutions of Kinbidhoo Island.

Table 12.5: Water Usage in Institutions in Kinbidhoo

	Water Flushed (Liters per day)	**Gardening (Liters per day)**	**Mopping (Liters per day)**	**Total Water Usage (Liters per day)**	**Total Water Usage (Liters per day)**	**Institutional Groundwater Usage (Liters per capita per day)**
Council Office	109	405	43	557	2796	1.90

Health Center	133	540	60	733		
School	660	540	32	1232		
Fenaka	79	180	14	273		

12.8.2 Groundwater quality

Groundwater quality measurements were made at selected wells in Kinbidhoo for both physical and microbiological testing.

The following table summarizes the water quality results.

Table 12.6: Summary of groundwater quality tests from Kinbidhoo, April 2019

Sample No	Odour	Physical Appearance
gw1	yes	Clear with particles
gw2	yes	Clear with particles
gw3	yes	Clear with particles
gw4	no	Clear with particles
gw5	yes	Clear with particles
gw6	yes	Clear with particles
gw7	yes	Clear with particles
gw8	no	Clear with particles
gw9	yes	Brown with particles
gw10	yes	Brown with particles

Sample No	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100 ml)	Faecal Coliform (MPN/100 ml)
gw1	874	468	7.48	1.19	4.92	36.22	0.34	25.5	1.28	1.94	1733	>2420
gw2	748	453	7.35	4.36	4.71	28.89	0.34	4.1	0.7	0.21	517	517
gw3	685	414	7.69	0.1	3.78	28.89	0.31	17.1	0.7	0.14		
gw4	844	516	7.53	1.17	2.6	28.33	0.39	6.1	0.43	0.15	387	387
gw5	764	451	7.59	0.21	2.35	30.28	0.33	11.0	1.27	0.24		
gw6	1048	631	7.40	3.28	1.96	29.17	0.47	6.0	1.15	0.15		
gw7	998	606	7.20	0.59	4.59	28.72	0.45	12.5	4.33	1.1		
gw8	755	444	7.41	0.00	4.45	30.56	0.33	5.4	0.35	0.06		
gw9	1065	640	7.53	690.5	1.64	29.28	0.48	7.9	0.67	0.08		
gw10	1611	967	7.28	4541	3.2	29.33	0.74	11.0	0.87	<0.05	>2420	>2420

	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)
WHO Standards	Suggested maximum limit of freshwater for potable purposes = 1500 µS/cm Suggested maximum limit of freshwater for non-potable purposes = 2500 µS/cm	-	-	-	-	-

	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
WHO Values	-	Guideline Value = 50 mg/L-NO3	Natural Level of Ammonia < 0.2 mg/L Threshold odour concentration = 1.5 mg/L Taste threshold = 35 mg/L	-	-	-

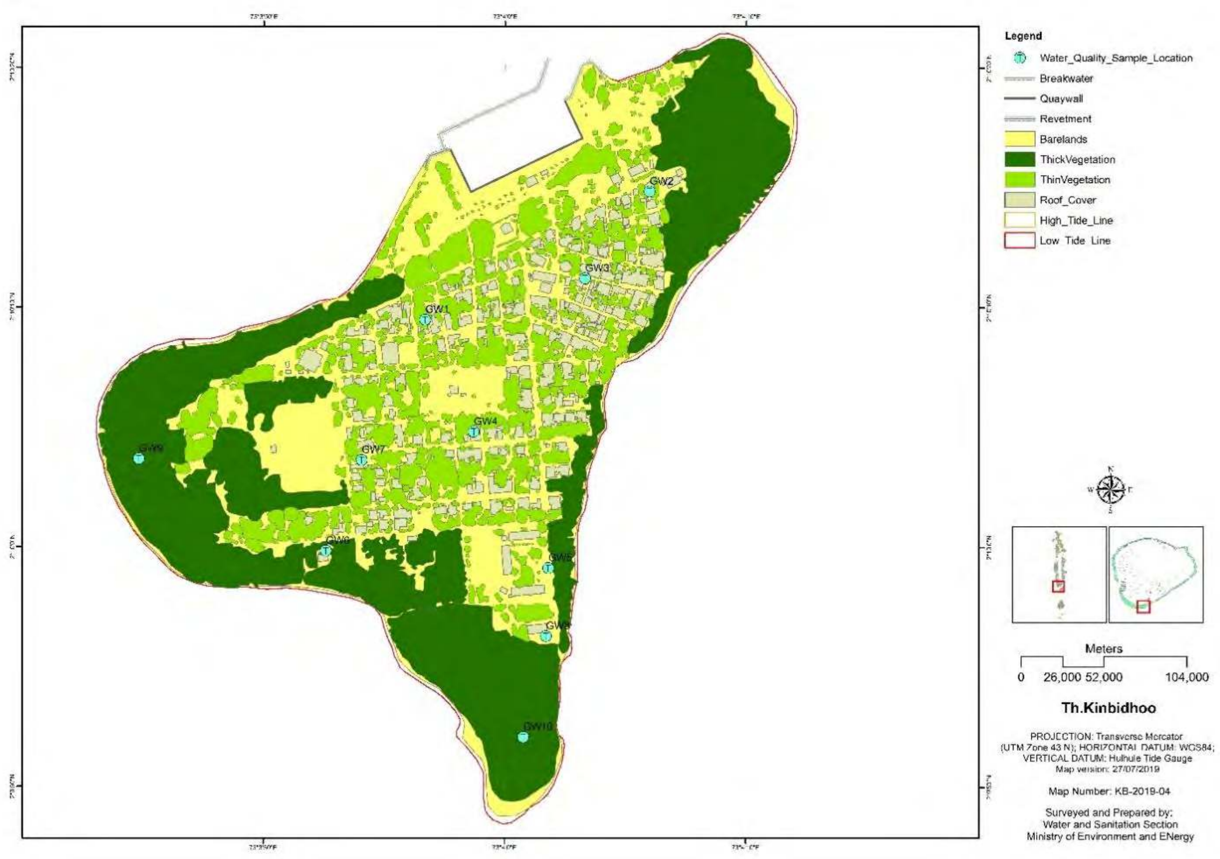
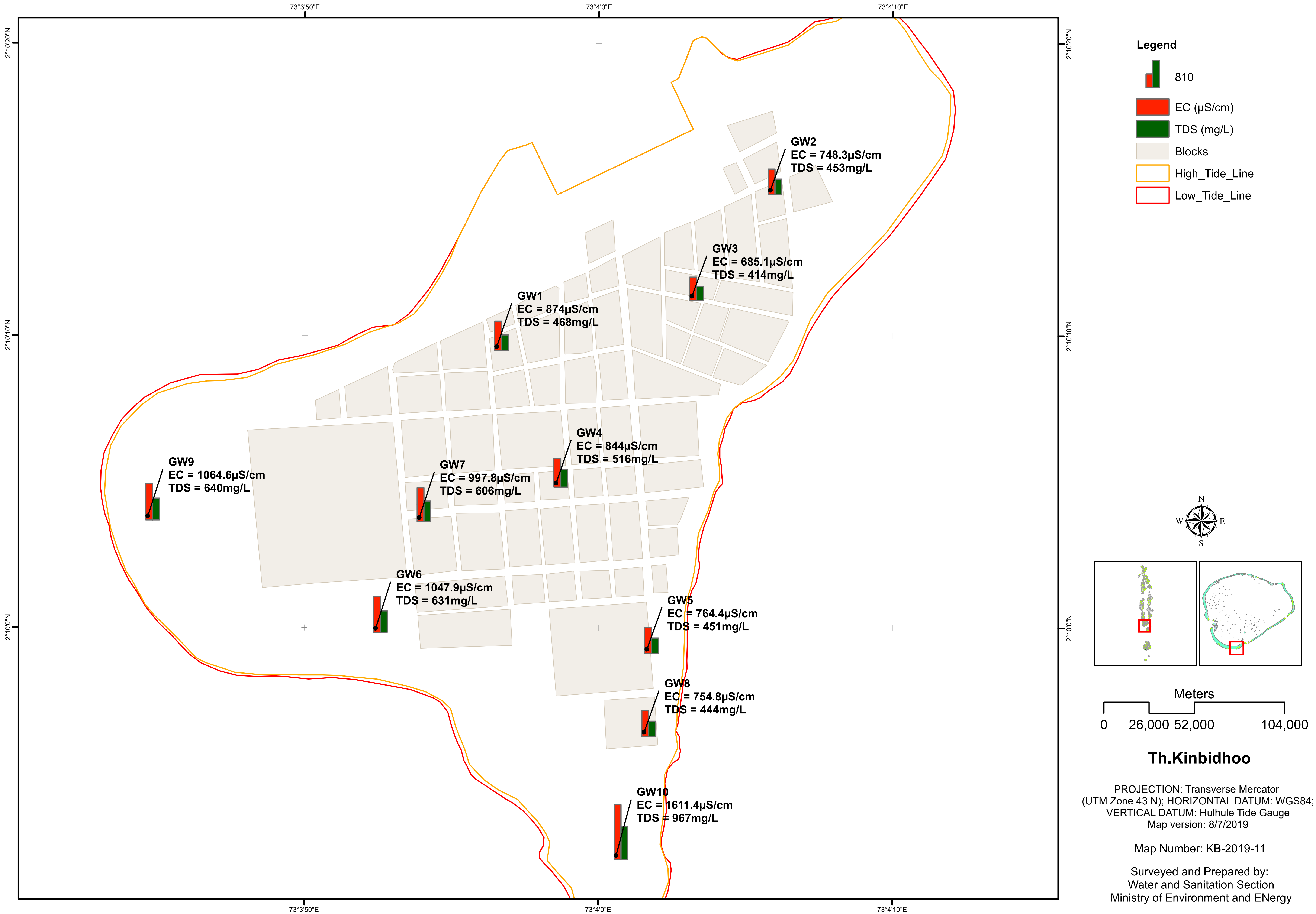


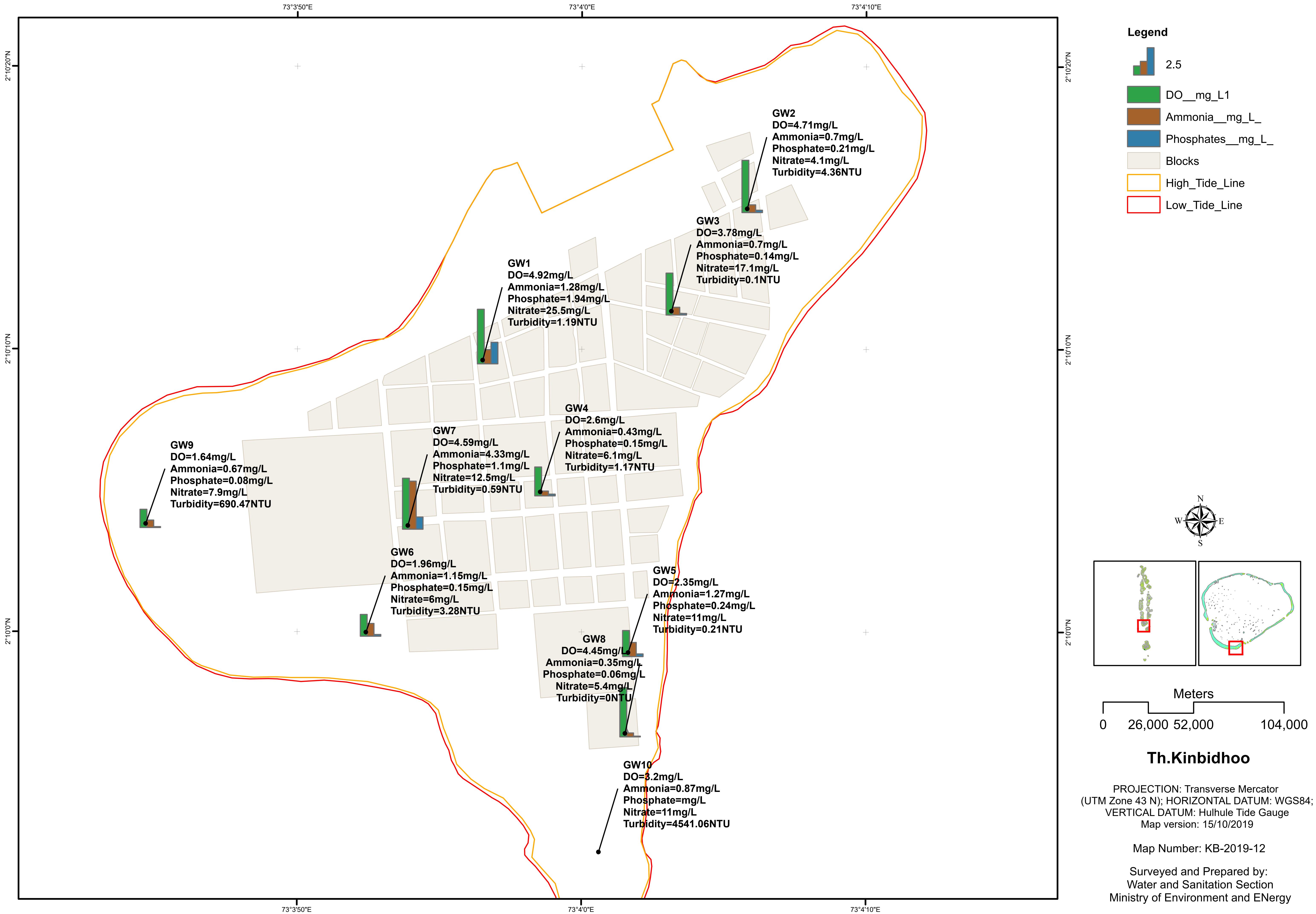
Figure 12.5: Location of groundwater sampling points in Kinbidhoo Island

Based on the full results and the summary shown in Table 5, the following can be summarized for Kinbidhoo:

- Samples gw1-gw4 and gw6-gw7 were taken from residential areas. gw5 was taken from the school and gw8 was taken from Fenaka. Samples gw9 and gw10 were drilled and taken from the vegetated areas.
- The average Electrical Conductivity (EC) of the groundwater is 939 μS/cm which is below the acceptable limit for potable water of 1,500 μS/cm (refer section 2.2). Only Sample gw10 has a higher EC (1611μS/cm) than the acceptable limit for potable water. The EC of the samples range from 685μS/cm to 1611 μS/cm. Other than samples gw9 and gw10 which were drilled samples, all the samples had EC in a small range from 685 μS/cm to 1048 μS/cm.
- Total Dissolved Solids recorded ranged from 414 mg/L to 967 mg/L with an average of 559 mg/L.
- The pH of groundwater ranged from 7.2 to 7.67 with an average pH of 7.45.
- Turbidity ranged from the lowest of 0 NTU to 4541 NTU with an average of 524 NTU. Thesamples gw9 and gw10 have significantly higher turbidity than other samples as they were drilled and taken from highly vegetated areas. The average turbidity excluding samples gw9 and gw10 is 1.36 NTU which is significantly lower. As a guide, "crystal-clear" water has a turbidity below 1 NTU, and water becomes visibly cloudy at 4 NTU and above.
- Dissolved oxygen levels were low to moderate, with values varying from 1.64 to 4.92 mg/L. The average value was 3.42 mg/L.
- The salinity of groundwater ranged from 0.31 PSU to 0.74 PSU with an average of 0.42 PSU. Salinity is expressed in Practical Salinity Units, PSU which is equivalent to PPT.
- The average Nitrate concentration was 10.7 mg/L and therefore does not exceed the WHO guideline limit of 50 mg/L. None of the tested water samples exceeded this guidance limit. The Nitrate concentrations ranged from 4.11 mg/L to 25.5 mg/L.
- Ammonia concentrations were generally low. The average ammonia concentration was 1.18 mg/L and ranged from 0.35 mg/L to 4.33 mg/L. The average does not exceed the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. Only 1 sample (gw7) exceeded this limit at 4.33 mg/L/. There is no apparent correlation between increasing levels of ammonia and other nutrients.
- Phosphate concentrations were moderately high and ranged from 0.06 mg/L to 1.94 mg/L with an average of 0.45 mg/L. There is no WHO drinking water guideline value for phosphate. However, it would normally be expected that phosphate concentrations in groundwater are less than 0.1 mg/L, where there are no impacts from human wastewater (e.g. effluent from septic tanks and 'greywater' from kitchens and bathrooms). Only 3 (gw8, gw9 and gw10) of 10 samples tested were below 0.1 mg/L. None of these three samples were taken from residential areas, with gw8 being taken from Fenaka and gw9 and gw10 being drilled samples from vegetated areas. Therefore phosphate concentration of groundwater is high in residential areas in Kinbidhoo Island.
- Total coliform levels were found to be significant and ranged from lowest count of 387 MPN/100mL to the highest count of more than 2420 MPN/100mL, with an average count of 1436 MPN/100 mL. Faecal coliform levels ranged from lowest count of 387 MPN/100 mL to the highest count of more than 2420 MPN/100mL, with an average count of 1264 MPN/100mL. As expected, the groundwater layer is contaminated with effluent from septic tanks.

In conclusion, Kinbidhoo has groundwater with low EC especially in residential areas, Nitrate concentration lower than WHO maximum guidance value but ammonia and phosphate concentration higher than expected in natural, undisturbed groundwater. Regarding microbiological contamination, an island wide contamination is observed. Additionally, the following pages contain maps which show the main physiochemical parameters displayed on map of the island.


73°3'50"E
73°4'0"E
73°4'10"E
2°10'20"N
2°10'10"N
2°10'0"N
GW1
EC = 874µS/cm
TDS = 468mg/L
GW2
EC = 748.3µS/cm
TDS = 453mg/L
GW3
EC = 685.1µS/cm
TDS = 414mg/L
GW4
EC = 844µS/cm
TDS = 516mg/L
GW5
EC = 764.4µS/cm
TDS = 451mg/L
GW6
EC = 1047.9µS/cm
TDS = 631mg/L
GW7
EC = 997.8µS/cm
TDS = 606mg/L
GW8
EC = 754.8µS/cm
TDS = 444mg/L
GW9
EC = 1064.6µS/cm
TDS = 640mg/L
GW10
EC = 1611.4µS/cm
TDS = 967mg/L
Legend
810
EC (µS/cm)
TDS (mg/L)
Blocks
High_Tide_Line
Low_Tide_Line
N
E
S
W
Meters
0
26,000 52,000
104,000
Th.Kinbidhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/7/2019
Map Number: KB-2019-11
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


73°3'50"E
73°4'0"E
73°4'10"E
2°10'20"N
2°10'10"N
2°10'0"N
GW1
DO=4.92mg/L
Ammonia=1.28mg/L
Phosphate=1.94mg/L
Nitrate=25.5mg/L
Turbidity=1.19NTU
GW2
DO=4.71mg/L
Ammonia=0.7mg/L
Phosphate=0.21mg/L
Nitrate=4.1mg/L
Turbidity=4.36NTU
GW3
DO=3.78mg/L
Ammonia=0.7mg/L
Phosphate=0.14mg/L
Nitrate=17.1mg/L
Turbidity=0.1NTU
GW4
DO=2.6mg/L
Ammonia=0.43mg/L
Phosphate=0.15mg/L
Nitrate=6.1mg/L
Turbidity=1.17NTU
GW5
DO=2.35mg/L
Ammonia=1.27mg/L
Phosphate=0.24mg/L
Nitrate=11mg/L
Turbidity=0.21NTU
GW6
DO=1.96mg/L
Ammonia=1.15mg/L
Phosphate=0.15mg/L
Nitrate=6mg/L
Turbidity=3.28NTU
GW7
DO=4.59mg/L
Ammonia=4.33mg/L
Phosphate=1.1mg/L
Nitrate=12.5mg/L
Turbidity=0.59NTU
GW8
DO=4.45mg/L
Ammonia=0.35mg/L
Phosphate=0.06mg/L
Nitrate=5.4mg/L
Turbidity=0NTU
GW9
DO=1.64mg/L
Ammonia=0.67mg/L
Phosphate=0.08mg/L
Nitrate=7.9mg/L
Turbidity=690.47NTU
GW10
DO=3.2mg/L
Ammonia=0.87mg/L
Phosphate=mg/L
Nitrate=11mg/L
Turbidity=4541.06NTU
Legend
2.5
DO__mg_L1
Ammonia__mg_L_
Phosphates__mg_L_
Blocks
High_Tide_Line
Low_Tide_Line
N
W
E
S
Meters
0 26,000 52,000 104,000
Th.Kinbidhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 15/10/2019
Map Number: KB-2019-12
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

12.8.3 Geophysical survey

The Resistivity tests were carried out in the locations as outlined in Figure below.

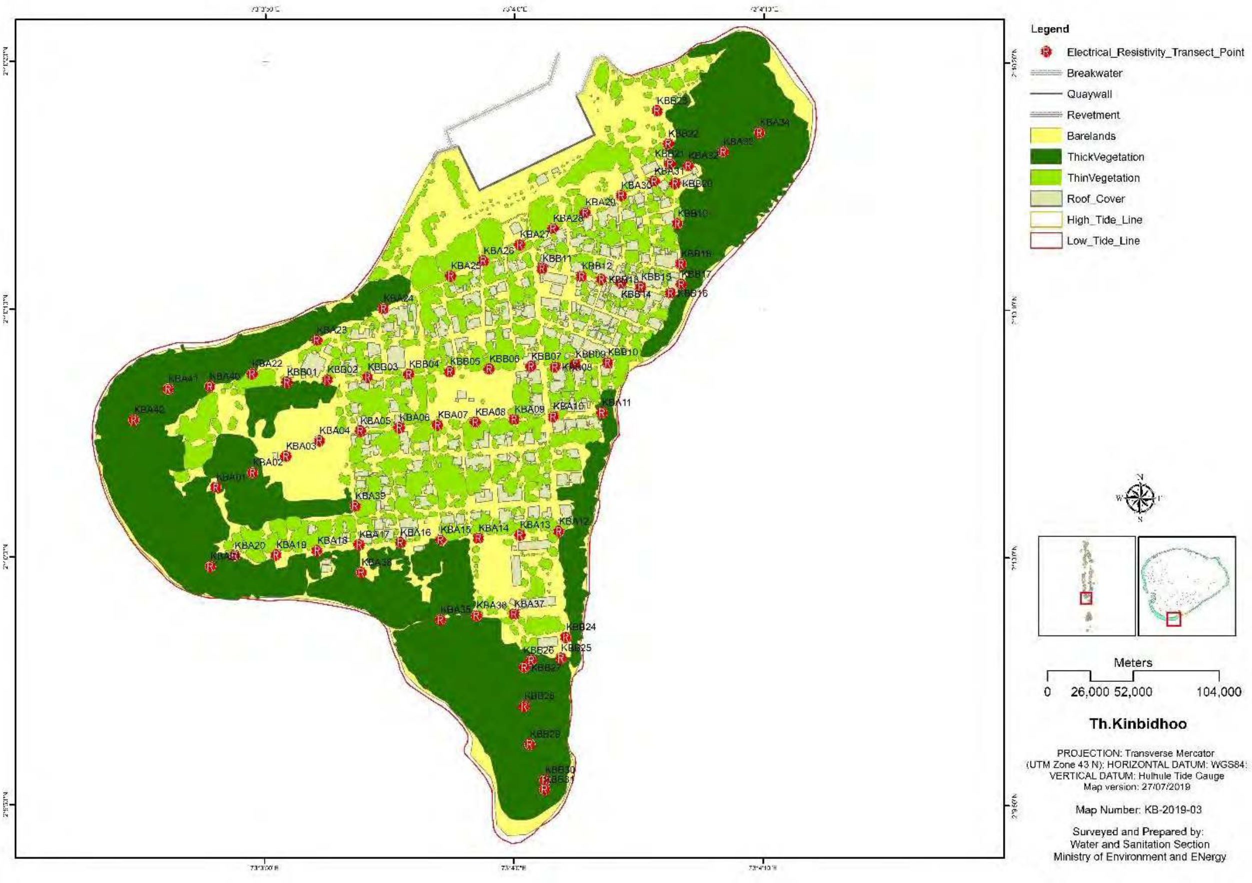


Figure 12.6: Location of ER points in Kinbidhoo Island

12.8.4 Aerial surveys

Based on the aerial survey, a multiple dataset consisting of roof cover, thick vegetation area, thin vegetation area, bare lands and shoreline were extracted. This data is shown in Figure 12.7 and the Table 12.7 shows the different area distribution.

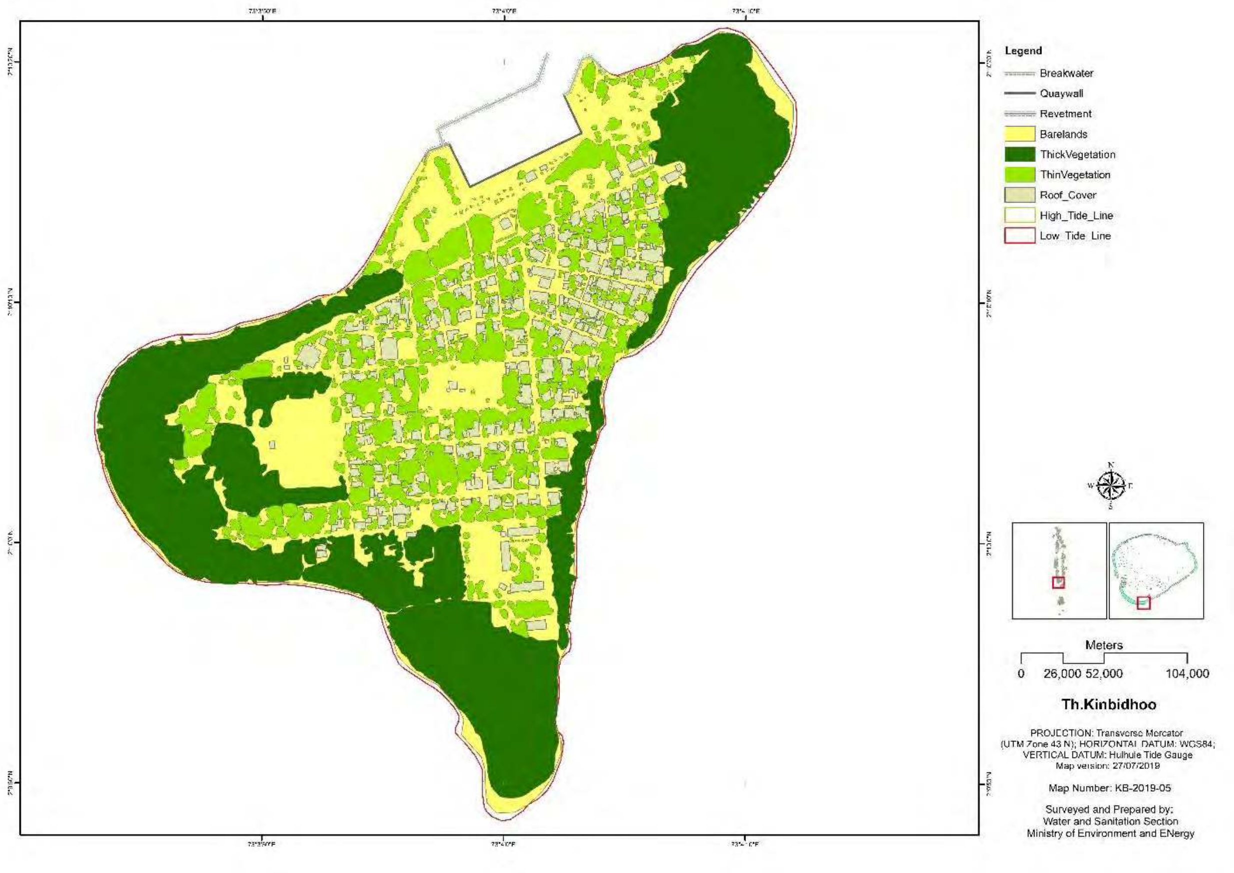


Figure 12.7: Area Distribution in Kinbidhoo Island

Table 12.7 Area Distribution in Kinbidhoo

	Area (Square Meters)	Percentage (%) of total area
Roof cover	37,685	10.0%
Vegetation (Thick)	147,937	39.2%
Vegetation (Light)	80,968	21.4%
Bare lands	111,163	29.4%
Farm Lands	-	
Wetlands (Inland)	-	

12.8.5 Water Demand

The only source of natural water is rainwater collected from the rooftops of households and institutions and groundwater extracted from shallow wells.

12.8.6 Freshwater lens

Based on the ER survey the depth to groundwater level and the freshwater-saline water interface was determined for a set of transverse transects as shown in Figure 12.8. Plots in the Figure 8.9 shows the cross sections of each transect line. The dotted lines in the plots indicating a simple interpolation of levels to mean sea level in the island boundaries. These cross sections were used to identify the spatial extent and volume of the freshwater lens while they were also useful in deriving implications on the stress level of the aquifer based on the observed, localized drawdown effect in the groundwater table and up-coning in the freshwater-saline interface, defining the upper and lower boundaries of the freshwater lens in an island.

The Table 12.8 illustrate the freshwater volume calculation for the island. The area covered by freshwater for each transect line has been calculated. To estimate the total volume of available freshwater lens, the cross-section area of freshwater extent under each transect was multiplied by the distance between two transects. The sum of these lengths represents the cumulative length of the island and thus, the above estimation could represent the total volume of the freshwater lens sandwiched between the groundwater table on top and freshwater-saline water interface in the bottom. Then the actual groundwater storage within this freshwater lens was calculated by multiplying the estimated total lens volume with the porosity of the topsoil in the island.

This estimation represents the total available freshwater volume within the freshwater lens at any given time (time of the measurement). The measurements were carried out towards the end of the dry period and the freshwater lens is presumed to be undergoing a 'stressed' condition due to continued groundwater abstractions despite reduced recharge in the dry period. Falkland (1994) method can be used to estimate the freshwater lend thickness under salient conditions using average annual rainfall, length and width of the island, and the comparison was used as a measure of stress level of the freshwater lens.

Table 12.8: Freshwater Volume Calculation for Kinbidhoo Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
1	Start		0	0	0	0			
			13	0.154	0	0			
	KBA37	ER	88	1.0657	0.43	-2.07	94		
	KBA36	ER	134	0.9009	0.43	-2.07	116		
	KBA35	ER	179	0.8233	0.37	-2.13	112		
			241	0.684	0	0	78		
	End		254	0	0	0	0		
	Total						399	224	89534
2	Start		0	0	0	0			
			27	0.539	0	0			
	KBA12	ER	40	0.784	0.384	-1.97	15		
	KBA13	ER	89	0.9107	0.471	-2.029	120		
	KBA14	ER	141	1.0828	0.46	-2.04	129		
	KBA15	ER	188	1.0699	0.46	-2.04	118		
	KBA16	ER	237	0.6663	0.216	-2.284	124		
	KBA17	ER	291	0.9057	0.39	-2.11	134		
	KBA18	ER	341	0.7759	0.37	-2.13	126		
	KBA19	ER	392	0.726	0.35	-2.15	128		
	KBA20	ER	441	1.1271	0.45	-1.76	115		
	KBA21	ER	478	1.1793	0.49	-1.88	207		
			519	0.708	0	0	85		
	End		546	0	0	0	0		
	Total						1301	128	166167
	Start		0		0	0			

3			9		0	0			
	KBA11	ER	19	0.8877	0.509	-1.17	8		
	KBA10	ER	79	0.9799	0.472	-2.028	126		
	KBA09	ER	127	0.9372	0.47	-2.03	119		
	KBA08	ER	176	0.9665	0.46	-2.04	123		
	KBA07	ER	222	0.8887	0.36	-2.14	116		
	KBA06	ER	271	0.7733	0.309	-2.191	121		
	KBA05	ER	320	0.8872	0.37	-2.13	123		
	KBA04	ER	371	0.8325	0.399	-2.101	127		
	KBA03	ER	416	0.9265	0.468	-2.032	114		
	KBA02	ER	464	0.9309	0.423	-2.077	119		
	KBA01	ER	512	0.7996	0.39	-2.11	839		
			627		0	0	145		
	End		637		0	0	0		
	Total						2080	95	197641
4	Start		0		0	0			
			34		0	0			
	KBB10	ER	53	1.1676	0.52	-1.48	20		
	KBB09	ER	94	1.1029	0.58	-1.92	92		
	KBB08	ER	119	1.0211	0.51	-1.99	63		
	KBB07	ER	149	0.9759	0.57	-1.93	74		
	KBB06	ER	201	0.9992	0.58	-1.92	130		
	KBB05	ER	250	0.8912	0.46	-2.04	123		
	KBB04	ER	302	0.9316	0.43	-2.07	129		
	KBB03	ER	354	0.703	0.31	-2.19	132		
	KBB02	ER	402	0.6474	0.34	-2.16	120		
	KBB01	ER	453	0.6244	0.26	-2.24	126		
	KBA22	ER	495	0.766	0.28	-2.22	104		
	KBA41	ER	598	0.6503	0.27	-2.23	259		
			637		0	0	294		
	End		671		0	0	0		
	Total						1666	108	179754
5	Start		0		0	0			
			19		0	0			
	KBB10	ER	34	1.1676	0.52	-1.48	15		
	KBB15	ER	71	1.0127	0.55	-1.95	83		
	KBB13	ER	96	1.1732	0.55	-1.95	63		
	KBB14	ER	121	1.1166	0.53	-1.97	63		
	KBB12	ER	146	1.1301	0.47	-2.03	62		
	KBB11	ER	196	0.8049	0.44	-2.06	125		
	KBA26	ER	268	0.6829	0.3	-2.2	180		
			369		0	0	126		
	End		388		0	0	0		
	Total						716	444	318075
									753529

Volume of lens = 753,529 m^3

Groundwater Storage = Porosity (15%) x Lens volume (m^3) = 113,029 m^3

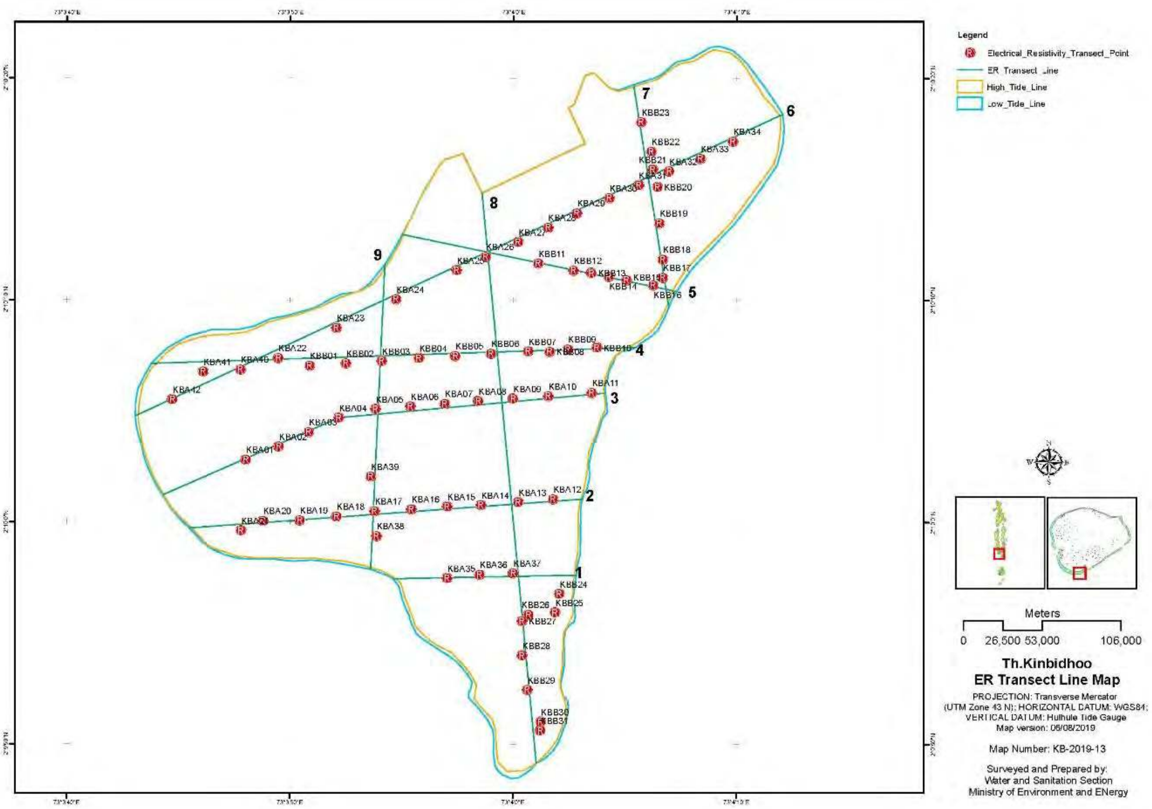
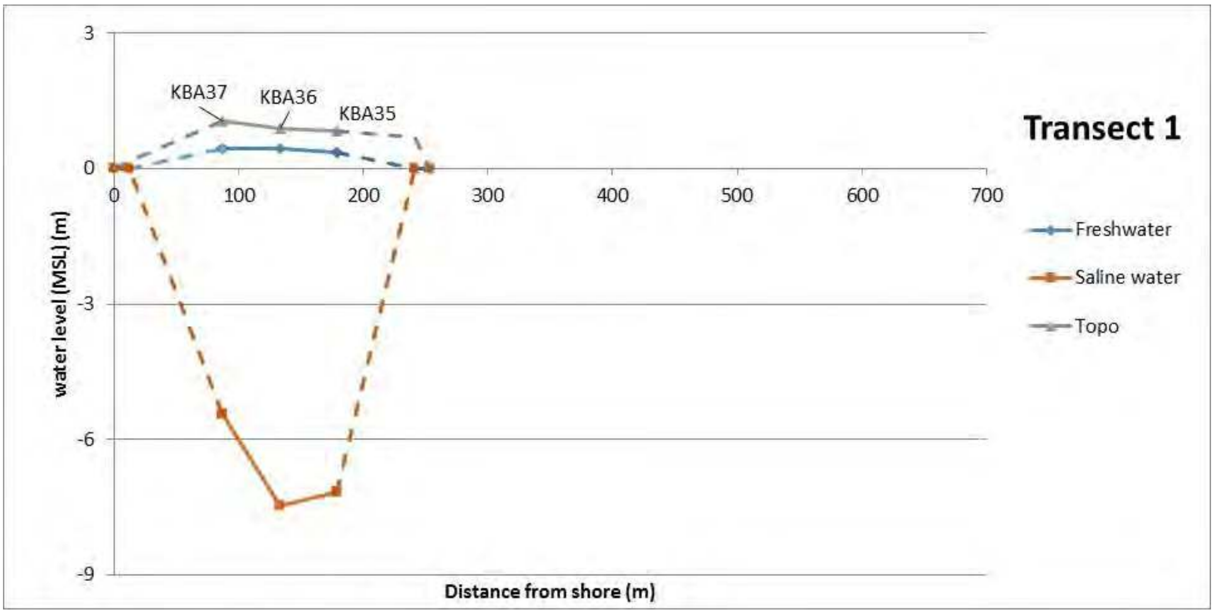
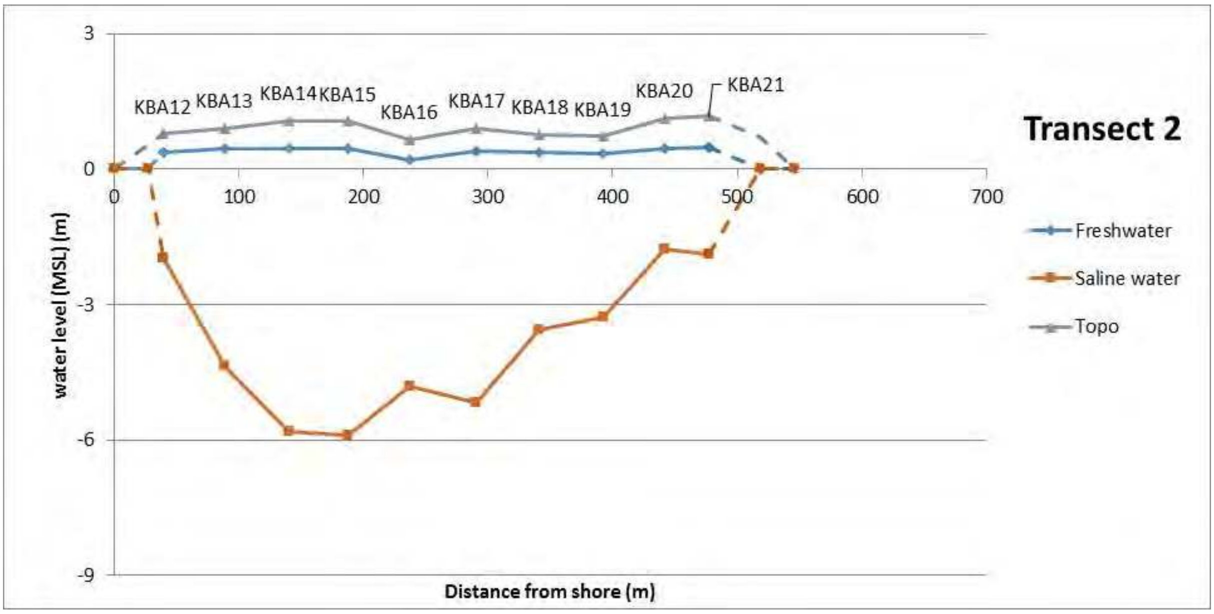
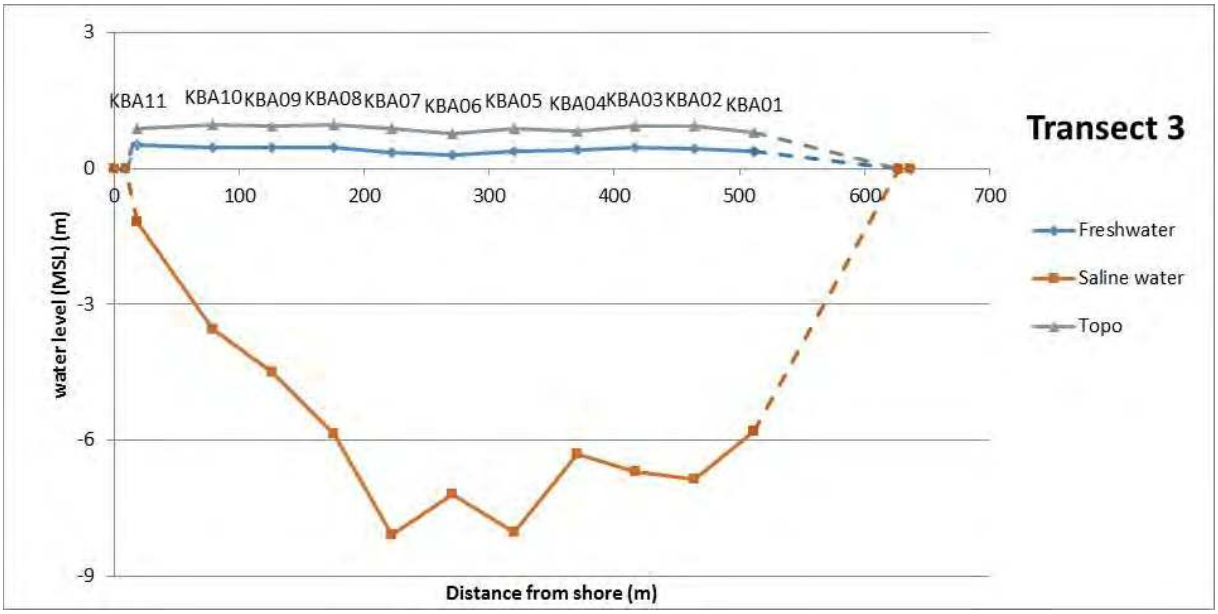
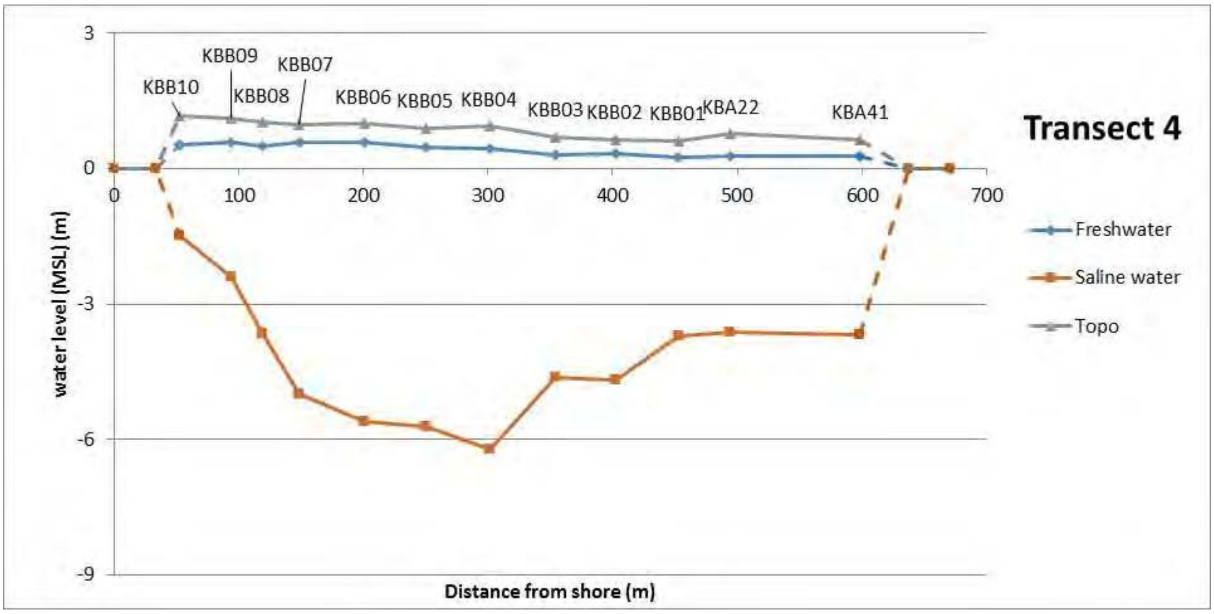


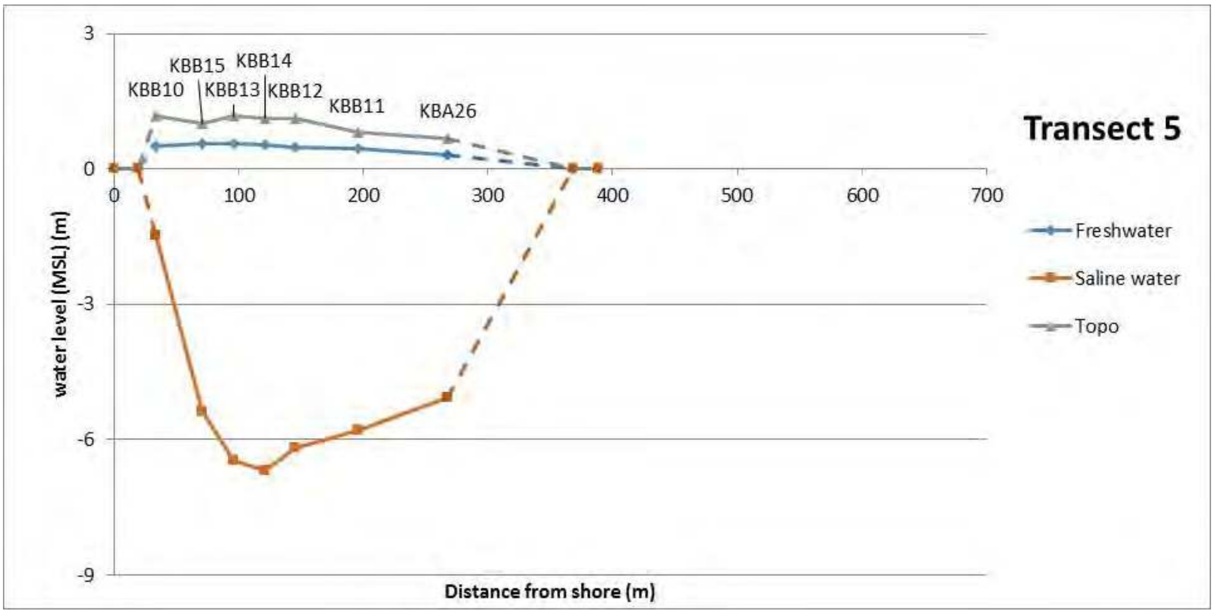
Figure 12.8: ER transect lines in Kinbidhoo Island

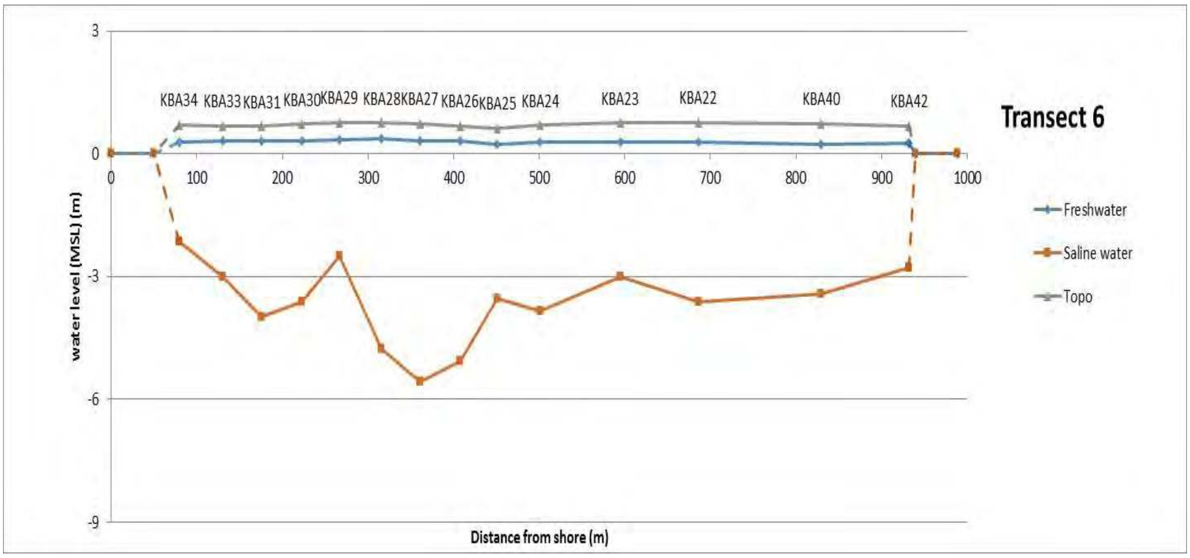


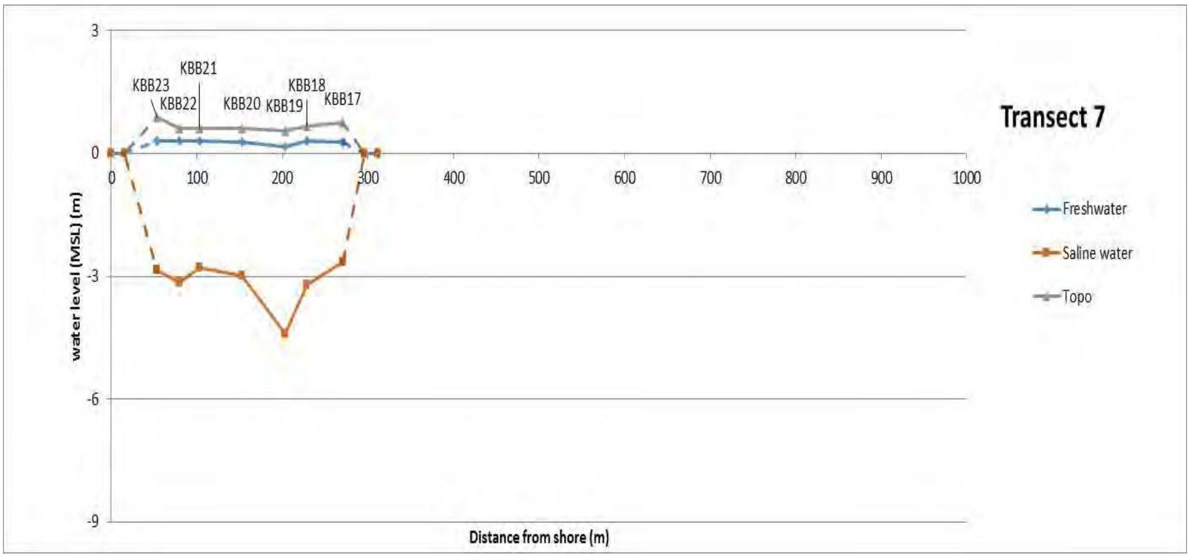

Transect 2
KBA12
KBA13
KBA14
KBA15
KBA16
KBA17
KBA18
KBA19
KBA20
KBA21
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo

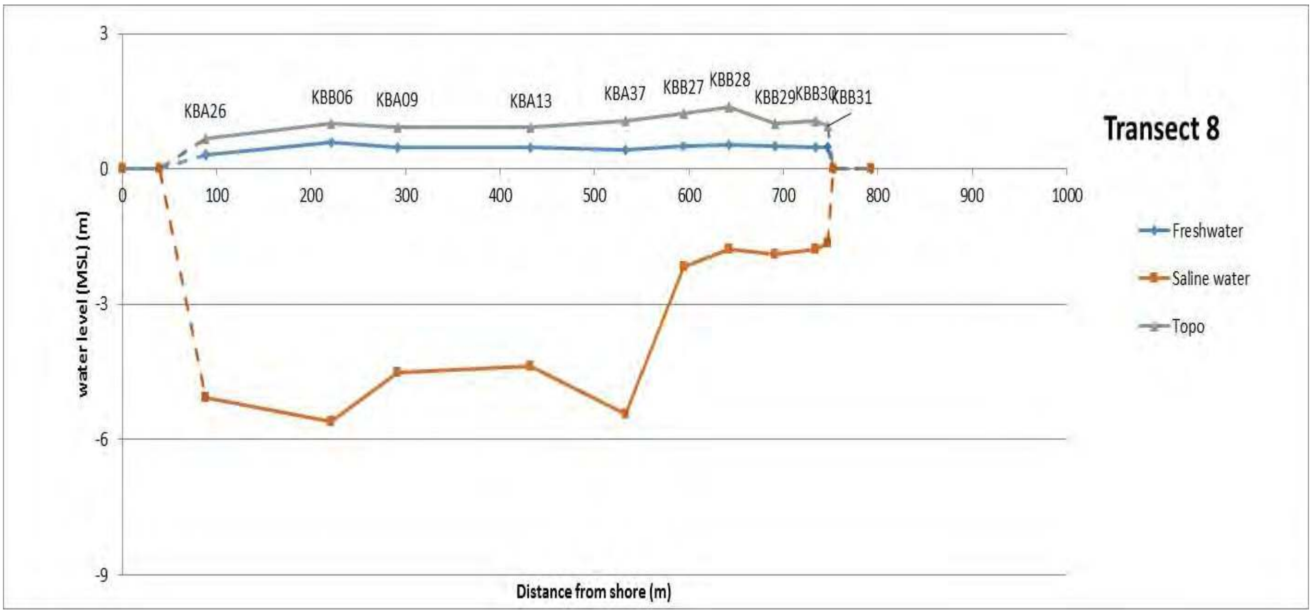

Transect 3
KBA11
KBA10
KBA09
KBA08
KBA07
KBA06
KBA05
KBA04
KBA03
KBA02
KBA01
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo


Transect 4
KBB10
KBB09
KBB08
KBB07
KBB06
KBB05
KBB04
KBB03
KBB02
KBB01
KBA22
KBA41
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo


Transect 5
KBB10
KBB15
KBB13
KBB14
KBB12
KBB11
KBA26
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo


Transect 6
KBA34 KBA33 KBA31 KBA30 KBA29 KBA28 KBA27 KBA26 KBA25 KBA24 KBA23 KBA22 KBA40 KBA42
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo


Transect 7
KBB23 KBB22 KBB21 KBB20 KBB19 KBB18 KBB17
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saline water
Topo



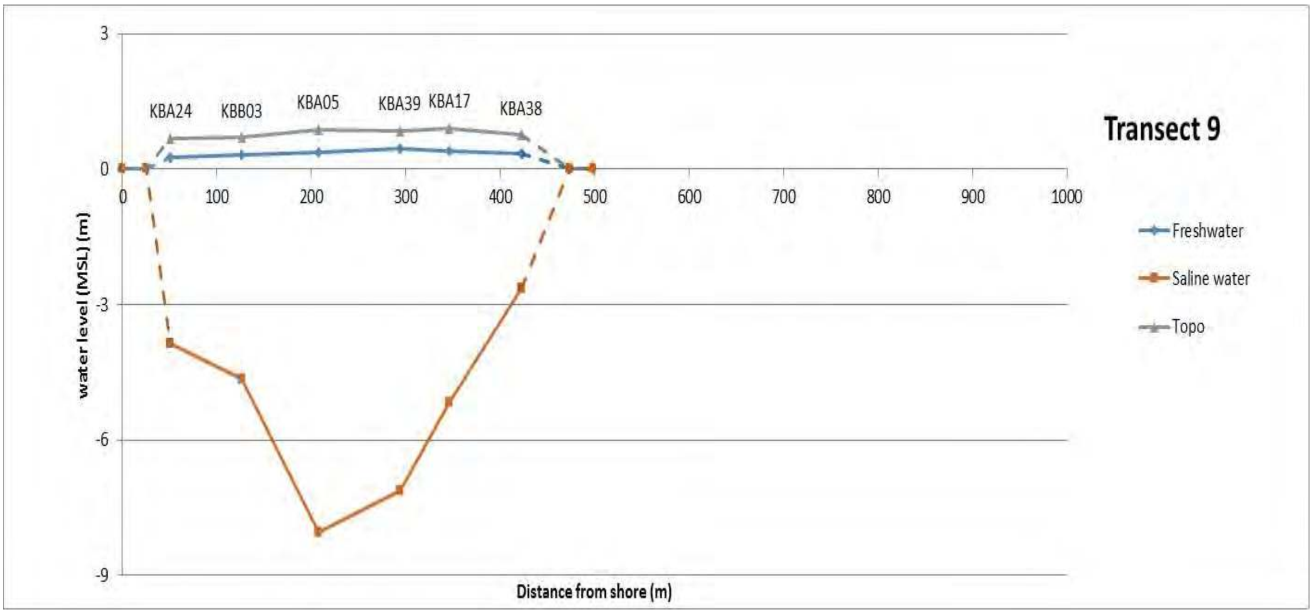


Figure 12.9: Cross-sections of transect lines in Kinbidhoo Island

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented below.

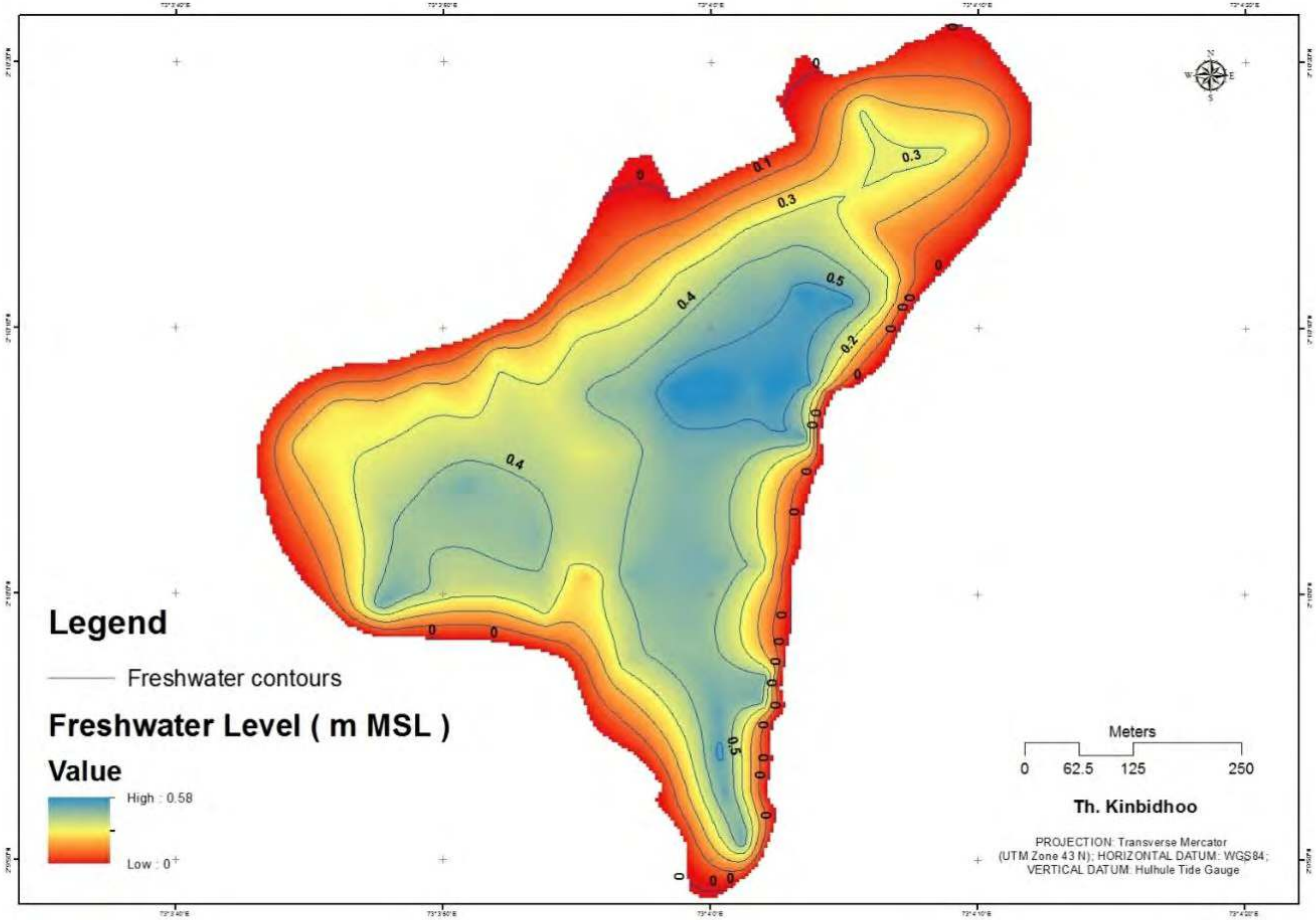


Figure 12.10: Freshwater Level in Kinbidhoo Island

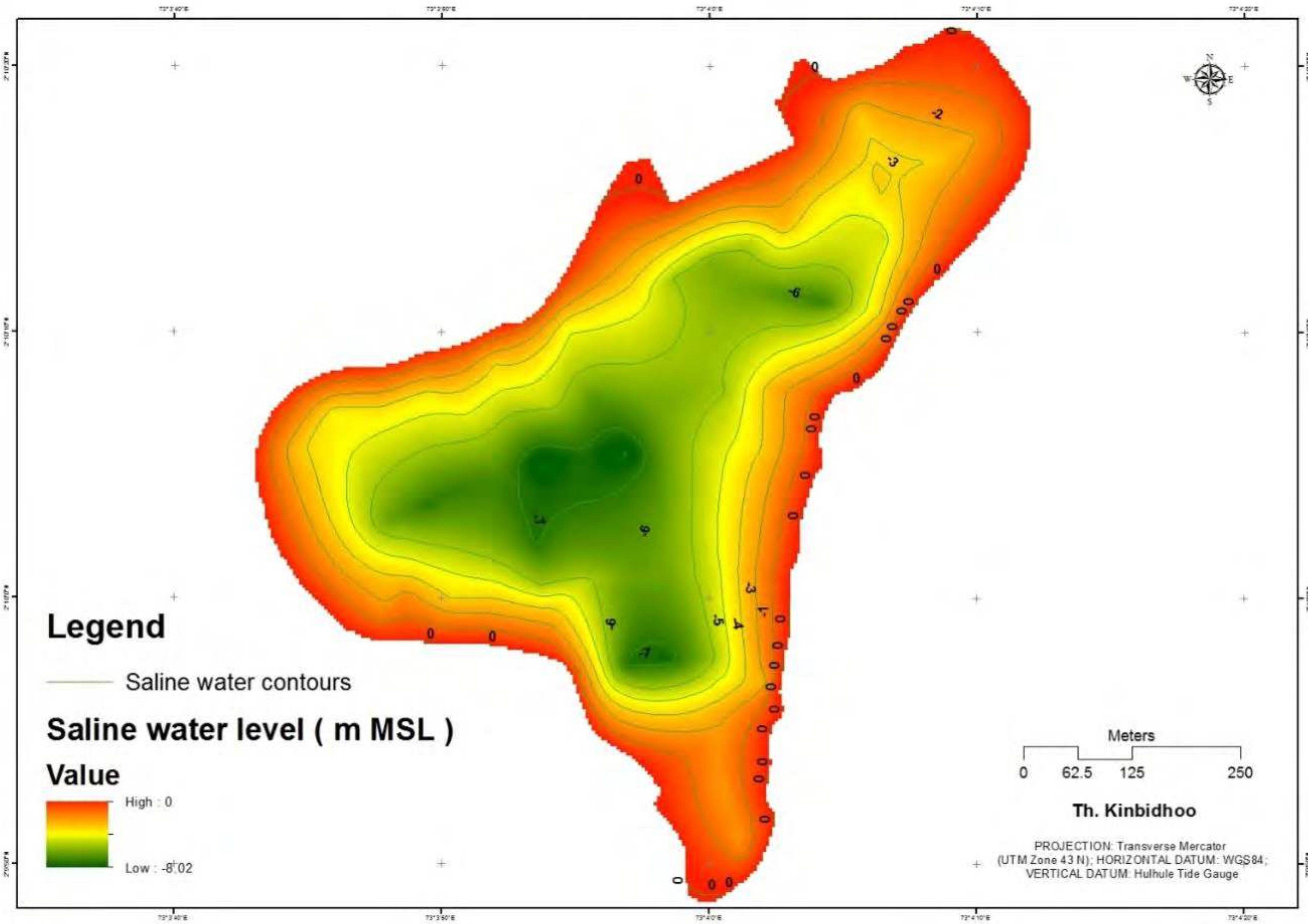


Figure 12.11: Saline water Level in Kinbidhoo Island

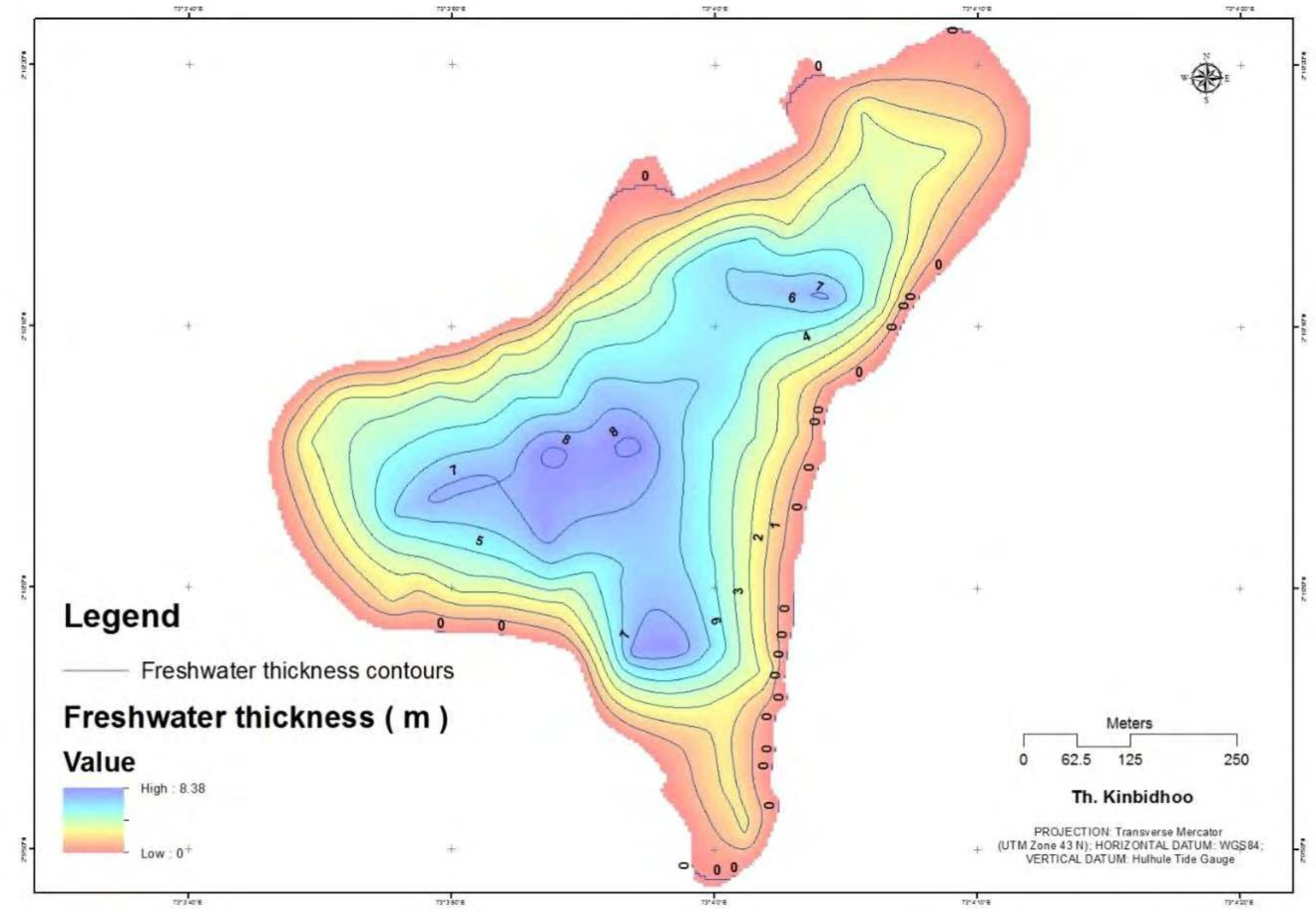


Figure 12.12: Freshwater thickness in Kinbidhoo Island

The maximum freshwater thickness of the island is 8.38 m. According to Falkland, 1994, the freshwater level thickness of the island is 8 m. The relevant calculations are as follows;

Average Annual Rainfall = 2300 mm/yr

Width of the island = 388 m

Length of the island = 1029 m

Freshwater lens Thickness (m)

= (6.94*log(width of the island)-14.38)*Average Annual Rainfall = 8 m

12.8.7 Water balance and recharge

An annual estimation is carried out based on water balance method. Rainwater harvesting is calculated using number of rainwater harvesting units in the island. According to the spatial mean annual rainfall of Maldives, the island is reported as 2300 mm/year. Evapotranspiration was estimated using crop water requirement for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. The groundwater extractions were estimated from amount of water usage in different sectors (residential, resorts, restaurants, agriculture and farming).The difference between recharge and groundwater extraction is taken to estimate different in storage.

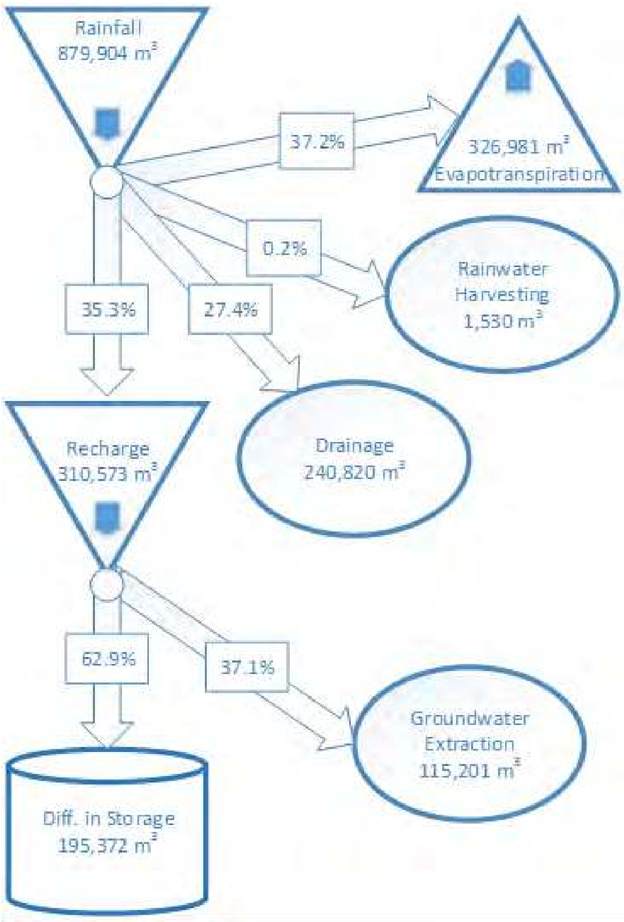


Figure 12.13: Schematic of water balance in Kinbidhoo Island

12.8.8 Sustainable yield of the lens

Sustainable yield of the water lens refers to the safe extraction potential of a given groundwater aquifer without significantly affecting its quality or quantity. This parameter is an important factor in the

sustainable development of islands as it allows planning and design of water and sanitation intervention in islands.

The island has a sustainable yield of 535 m^3 per day which was calculated subtracting groundwater extraction from recharge volume derived from water balance (Figure 12.13). According to Metai & Unit, n.d., based on geophysical investigations and drilling programme concluded that the safe sustainable yield was about 10% of mean annual rainfall. Such that the expected sustainable yield for the island should be 241 m^3 per day.

12.8.9 Permeability test

Permeability tests were carried out in the locations as outlined in Figure 12.14.

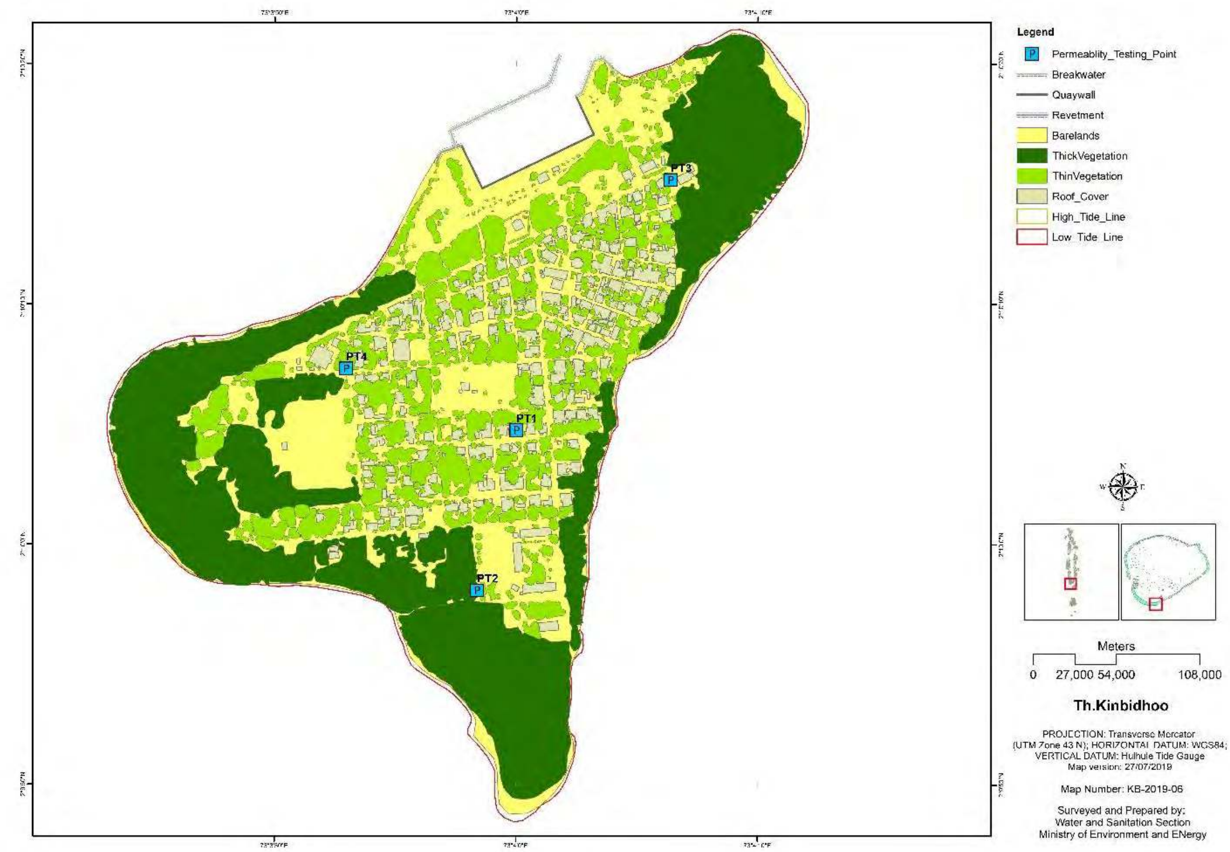


Figure 12.14: Locations of permeability tests in Kinbidhoo Island

The estimated permeability values for the above test locations are presented below.

Table 12.9: The estimated permeability Values

re	0.026
r1	0.0285

Point	H	Tu	Cs	H/re	Q	K (m/s)	K (m/day)		Q (l/min)	Q (m^3/s)
PT1	0.4	1	32	15.4	8.3E-06	1.76E-05	1.52		0.5	8.33E-06
PT2	0.5	0.6	40	19.2	6.3E-06	1.81E-05	1.56		0.375	6.25E-06
PT3	0.4	0.9	32	15.4	3.1E-06	7.32E-06	0.63		0.187	3.12E-06

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m^3/s), H = Height of water in well (m), l = length of perforated section (m), r_1 = outside radius of casing (radius of hole in consolidated material) (m), r_e = effective radius of well = r_1 (area of perforations) / (outside area of perforated section of casing) : $r_1 = r_e$ in consolidated material that will stand open and is not cast, C_u and C_s =Conductivity Coefficients, and T_u = distance from water level in casing to water table (m).

12.8.10 Pumping Test

Pumping tests were carried out in the locations as outlined in Figure 12.15.

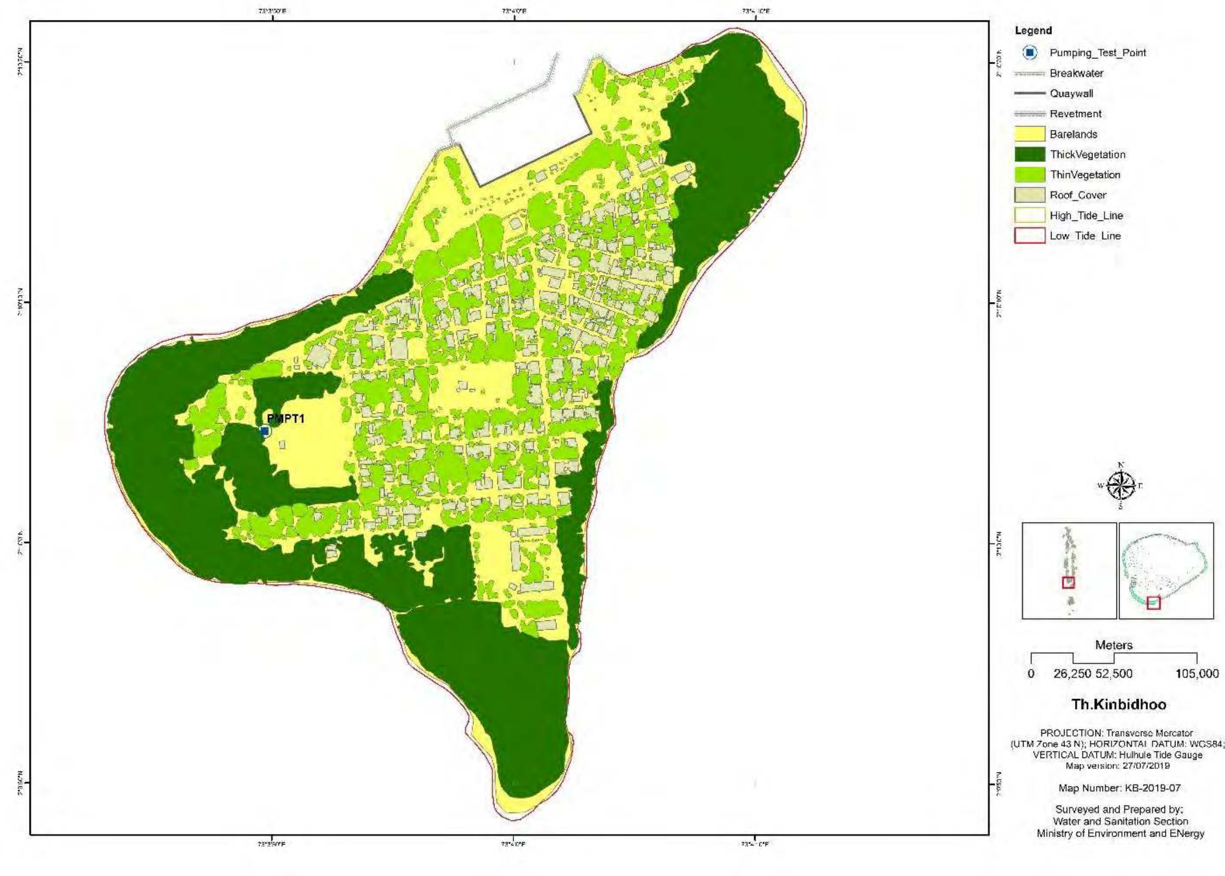


Figure 12.15: Location of Pumping Tests in Kinbidhoo Island

12.8.1 Groundwater availability

1) The selected Kinbidhoo island has dimensions of width = 388 m and length = 1029 m, with a total land area of 37.77 ha, a population of 768 persons, and a land use of built-up area 3.77 ha (10.0%), thick vegetation 14.79 ha (39.2%), light vegetation 8.09 ha (21.4%), and bare lands 11.11 ha (29.4%).

2) In order to recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of freshwater lens (FWL) and its associated recharge-discharge characteristics, 73 number of Electrical Resistivity (ER) location readings along 09 representatively selected transects were collected.

3) Soil overburden permeability tests (constant head) were carried out at 04 locations while steady-state pumping tests were conducted at 01 locations. In addition, groundwater level was also recorded at 07 locations where groundwater water quality samples were tested.

4) Permeability tests were carried out at representatively selected 03 number of locations. The measured permeability (K m/day) values ranged from a minimum of 0.63 m/day to a maximum of 1.56 m/day, with an average of 1.24 ± 0.52 m/day (Mean ± 1 Standard Deviation). The steady state pumping test resulted an aquifer transmissivity value of 9.80 x 10-3 m^2/s.

5) The ground elevation values ranged from a minimum of 0.16 m MSL to a maximum of 1.34 m MSL, with an average of 0.86 ± 0.18 m MSL (Mean ± 1 Standard Deviation).

6) The upper boundary of the freshwater lens (FWL) varied from a minimum of 0.16 m MSL to a maximum of 0.58 m MSL, with an average of 0.39 ± 0.10 m MSL (Mean ± 1 Standard Deviation).

7) The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -8.10 m MSL to a maximum of -1.17 m MSL, with an average of -4.17 ± 1.82 m MSL (Mean ± 1 Standard Deviation).

8) Accordingly, the freshwater lens (FWL) thickness values ranged from a minimum of 1.68 m to a maximum of 8.46 m, with an average of 4.56 ± 1.83 m (Mean ± 1 Standard Deviation).

9) The groundwater profile in the island is characterised by a relatively Low (0.17%) Rainwater Harvesting, relatively Low (27.37%) Drainage, relatively High (35.30%) Recharge, while the water use shows relatively Very High (37.09%) Groundwater extraction, leading to relatively Low (62.91%) Difference in Balance Storage.

10) The freshwater lens (FWL) volume calculated based on ER transect test data is 113,029 m^3 with a maximum FWL thickness of 8.46 m. The potential maximum FWL volume and thickness estimated based on Falkland (1994) method are 36,013 m^3 and 8.25 m.

12.8.2 Conclusive Comments and Recommendations

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 535 m^3 per day, while it is 241 m^3 per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 321 m^3 per day and this exceeds the allowable Safe Yield in the island by 133% (Slightly stressed) with moderate up-coning and moderate drawdown in freshwater lens cross-sections. At present, there exists no island wide sewerage network or water supply network. The water samples tested were found to be Highly Odorous with 80.0% or 8/10 samples tested producing odour. The Hydrological condition of the freshwater lens aquifer can be categorised as Moderate based on above measurements and findings while Water quality aspects can be regarded as Contaminated with an Average Electrical Conductivity (EC) of 939.23 ± 271.15 µS/cm with measured values ranging from a minimum of 685.10 µS/cm to a maximum of 1,611.40 µS/cm, and an Average Ammonia Concentration of 1.18 ± 1.16 mg/L with measured values ranging from a minimum of 0.35 mg/L to a maximum of 4.33 mg/L.

The Availability of space for incorporating recharge measures and related infrastructure is High while therefore the Potential for Recharging is considered to be High. Overall recommendation for groundwater recharging would be to use recharging trenches and ponds in roads and recharging pits in individual households and land blocks.

13 MEEDHOO ISLAND

13.1 General overview of the island

The island of Meedhoo is located at 73°0’24.9”E and 2°59’54”N in the Dhaalu Administrative Atoll. Meedhoo lies on the northern tip of the atoll chain that forms Dhaalu atoll. Its closest neighbours are two tourist resorts, namely Sun Aqua Vilu Reef and Angsana Velaavaru. The island is 885 m long and 593 m wide, with an area of 31.88 ha. The island has a registered population of 929 people via the 2014 Census. The island has a harbor on its Eastern side. The following table outlines some basic information of the island and the following map illustrates the location of Meedhoo.

Table 13.1: Basic statistical information on Meedhoo island in Dhaalu Atoll.

Name of the island	Dh.Meedhoo
Longitude and Latitude	73°0’24.9”E, 2°59’54”N
Area	32.56 ha
Population (Census, 2014)	929
Distance from Atoll Capital (Dh.Kudahuvadhoo)	38.82 km
Distance from Male’	141.64 km
Harbour	Present
Island sewerage network	Yes
Water supply network	No
Other infrastructure	None

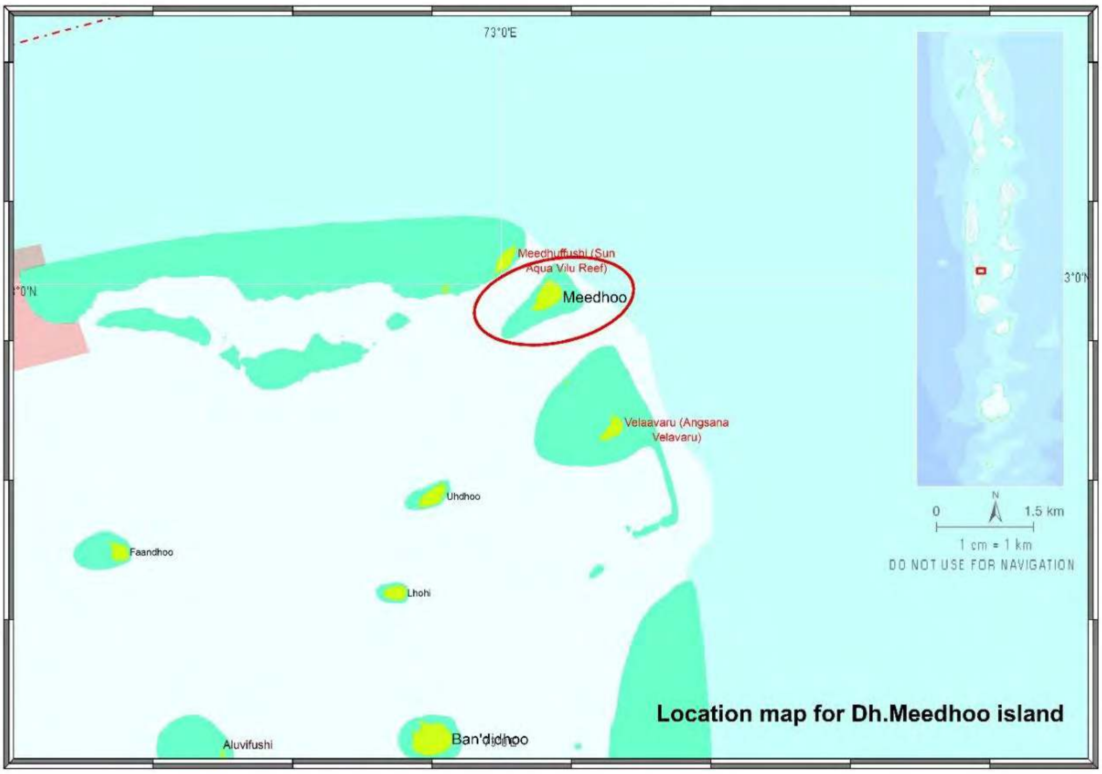


Figure 13.1: Location map for Meedhoo Island, Dhaalu Atoll.

13.2 Geology and vegetation

The island is about 885 m long and 593 m wide, with an area of 31.92 Ha. Of this land, 7% is covered in thin vegetation. This vegetation is scattered throughout the island and not concentrated in one specific area. Of the island's 31.92 ha, around 55% comprises of reclaimed land alongside the Eastern and South-Eastern side of the island. Outside of home gardens, no farming activities take place on the island.

There are no areas of the island with thick tree cover. The islands flora can be described as having two types. The first is the thinly spread mature vegetation clusters found around different parts of the island periphery, while the second is the trees and plants found inside the island, mainly within the individual house plots.

13.3 Topography

Meedhoo has a topography that ranges from an elevation of 0.608 meters to 2.263 meters above MSL with an average of 1.44 meters above MSL. The map of Meedhoo Island with random spot heights is found in Figure 13.2.

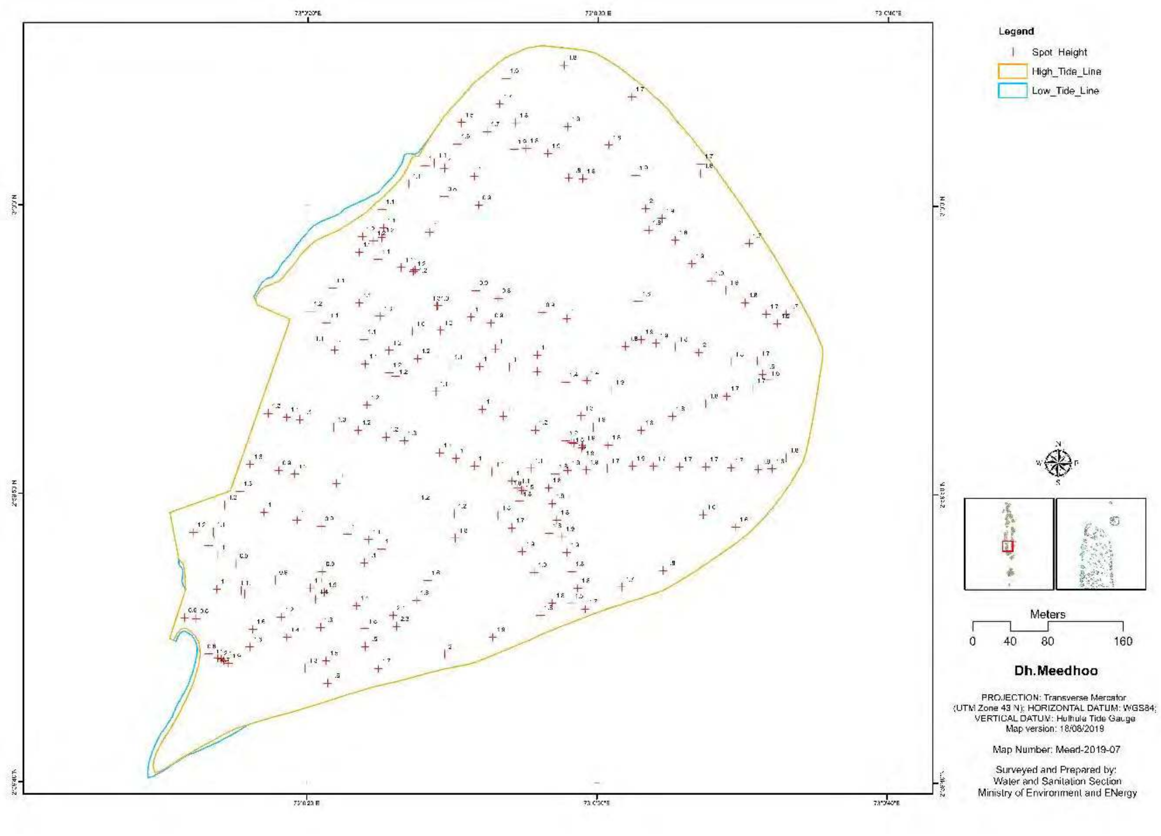


Figure 13.2: Meedhoo Island Spot Heights

13.4 Climate

Meedhoo experiences the typical two monsoons namely, north east monsoon from November to April and South-west monsoons from April to November. There are no specific wind and rainfall data available for Meedhoo as there are no weather monitoring stations on the island.

13.5 Demography

As per the 2014 Census, Meedhoo has a registered population of 929 people. However this figure may be inaccurate as the island council reports a population of 950 people in 2019. The island has more males than females for both the total (56% being male) and foreign (82% being male) populations. This gap is less significant amongst the local population, with 54% of them being male. The following table and graphs illustrates the demographic breakdown on Meedhoo.

Table 13.2: Demographic Breakdown of Meedhoo Island

Atoll	locality	Resident population (Census, 2014)								
		Total			Maldivians			Foreigners		
		Both sexes	Male	Female	Both sexes	Male	Female	Both sexes	Male	Female
Dh	Meedhoo	929	526	403	856	466	390	73	60	13

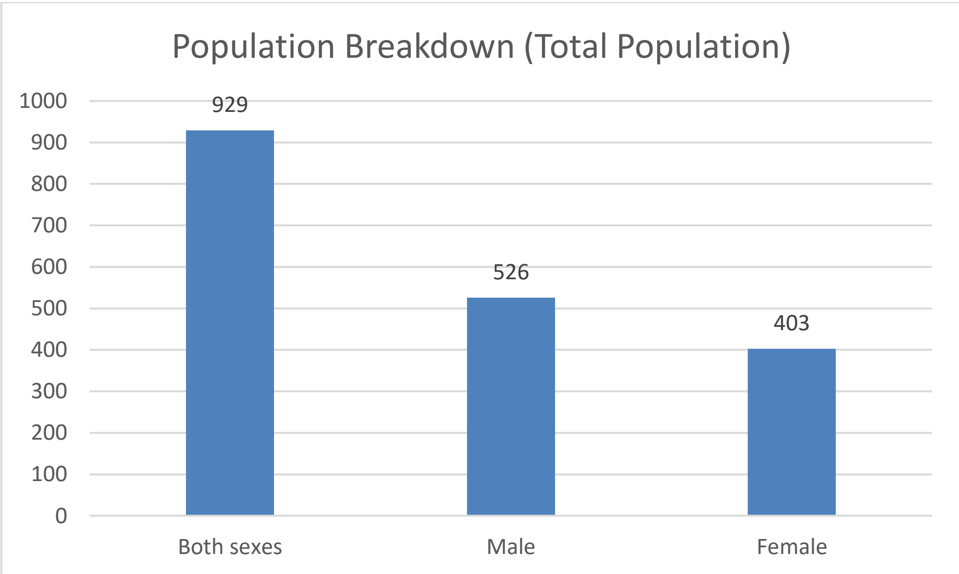


Figure 13.3: Population breakdown of Meedhoo (Maldivians & Foreigners)

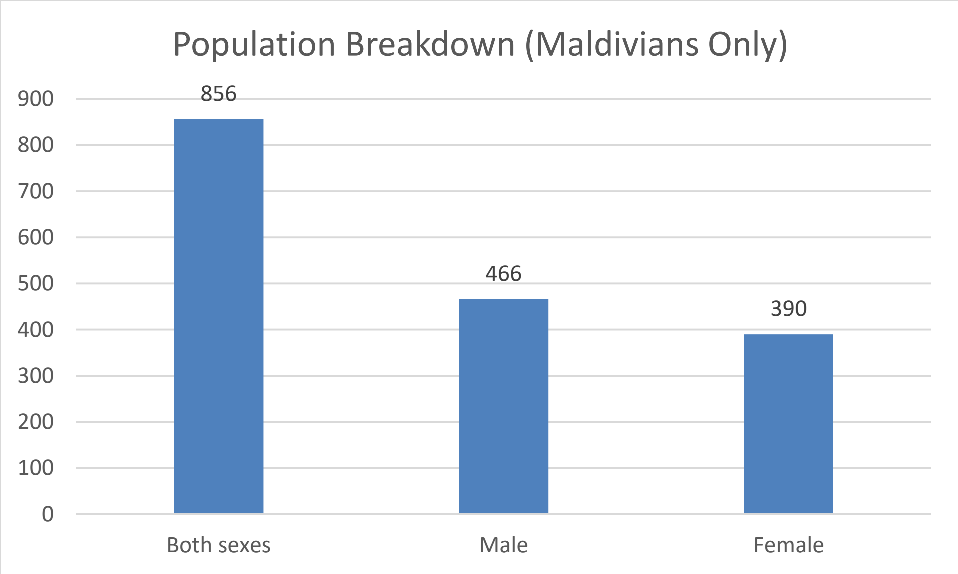


Figure 13.4: Population breakdown of Meedhoo (Maldivians)

13.6 Socio-economic condition

Meedhoo is a highly developed and densely packed island. This island was reclaimed in 2013 along the Eastern and South-Eastern side of the island, thereby increasing the area of the island by more than 100%. This island has a population density of 29.1 residents per hectar, in accordance to the most recent population data provided by the island council and aerial survey performed in 2019. The island contains 186 households, of which a significant number are multi-storey buildings. Dhaalu Atoll Madharusaa, (Meedhoo School) has 219 registered students. The island has a total of 2 restaurants and 1 guesthouse that is currently non-operational. The main occupation of the inhabitants of Meedhoo is fishing and it forms the major source of income to the islanders. Construction is also a major part of the economy of Meedhoo, with several construction projects being implemented in Meedhoo. Tourism plays a significant role in the economy of the island as residents of the island find employment in the neighbouring resorts.

13.7 Existing water and sanitation situation

Meedhoo does not currently have a water supply network but does have a vacuum sewerage system. The primary source of drinking water on the island is rainwater collected in either household or community tanks, with some houses using bottled mineral water. The main source of water for cooking is also rainwater. As rainwater tends to run out during the dry season, many households take rainwater from neighboring households or community tanks.

13.8 Results

13.8.1 Water sources and water use

Based on domestic, commercial, institutional and industrial water usage, a total of 329,105 liters of groundwater are estimated to be used every day. Therefore, 235 liters of groundwater are used per capita per day. The respective water use situations are detailed in the following sections.

13.8.1.1 Domestic water use situation

Based on the questionnaire to collect data on domestic water consumption, a summary of results are present in this section.

According to the survey, 100% of the households surveyed uses HDPE rainwater tanks as their main storage for water. A total of 70% households use rainwater for drinking and 94.7% use it for cooking. 25% of houses use bottled water for cooking, and 5% (1 house) use filtered groundwater for drinking and cooking. None of the surveyed houses use rainwater for bathing or washing.

None (0%) of the households use groundwater as drinking. Groundwater is mainly used for non-potable use in all the households surveyed.

The following table summarizes the groundwater and rainwater use data for Meedhoo Island.

Table 13.3: Groundwater and rainwater use data for Meedhoo

Rainwater	
Households with rainwater tanks	100%
Rainwater use for drinking	70%
Rainwater use for cooking	94.7%
Rainwater use for bathing and washing	0%
Groundwater	
Groundwater as drinking source	0%
Groundwater for cooking	0%
Groundwater for non-potable use	100%
Total number of households surveyed	(10.75%)
Percentage of wells surveyed fitted with pumps	100%

Based on the survey questionnaire, average daily water demand per capita for domestic purposes has been estimated based on the average amount of water used per person for showering, toilet flushing, laundry and gardening, this data is shown in table 3.4. The total domestic water use is estimated to be 229 liters per capita per day.

Table 13.4: Domestic Water Usage in Meedhoo

Shower/ Liters per capita per day	Toilet/ Liters per capita per day	Laundry/ Liters per capita per day	Gardening/ Liters per capita per day	**Total/ Liters per capita per day**
117	43	17	53	**229**

13.8.1.2 Commercial water use situation

Based on the questionnaire to collect data on commercial water consumption, a summary of results are present in this section. Based on information from the island council, Meedhoo has a total of 2 restaurants and 1 guesthouse that was non-operational. 1 restaurant was surveyed.

For the restaurant, the main use of groundwater was for mopping, gardening, dishwashing and toilet use. From the survey data, the total groundwater consumption for this restaurant was estimated to be 2460 liters per day, therefore the total commercial groundwater consumption for the island considering 2 restaurants is 4920 liters per day.

13.8.1.3 Institutional water use situation

Based on the questionnaire to collect data on institutional water consumption, a summary of results are present in this section. Four institutions were surveyed for this study namely the school, police office, council office and health center. Groundwater in the institutions in Meedhoo Island are mainly used for gardening, mopping floors and flushing toilets. Additionally, the health center also uses groundwater for laundering. A total of approximately 2412 liters of groundwater are estimated to be used per day by the institutions. Therefore, a total of approximately 1.72 liters of groundwater are estimated to be used per capita per day by the institutions of Meedhoo Island.

Table 13.5: Water Usage in Institutions in Meedhoo

	Water Flushed (Liters per day)	Gardening (Liters per day)	Mopping (Liters per day)	Laundry (L)	Total Water Usage (Liters per day)	Institutional Groundwater Usage (Liters per day)	Institutional Groundwater Usage (Liters per capita per day)
School	671	540	42	-	1253	2412	1.72
Police Office	30	225	-	-	255		
Council Office	67	-	-	-	67		
Health Center	212	405	90	130-	837		

13.8.2 Groundwater quality

Groundwater quality measurements were made at selected wells in Meedhoo for both physical and microbiological testing.

The following table summarizes the water quality results.

Table 13.6: Summary of groundwater quality tests from Meedhoo, July 2019

Sample No	Odour	Physical Appearance
gw1	yes	Clear with particles
gw2	yes	Clear with particles
gw3	yes	Clear with particles
gw4	yes	Clear with particles
gw5	yes	Clear with particles
gw6	no	Clear with particles
gw7	yes	Clear with particles
gw8	no	Clear with particles
gw9	yes	Clear with particles
gw10	yes	Clear with particles
gw11	no	Clear with particles
gw12	yes	Clear with particles
gw13	no	Clear with particles
gw14	yes	Clear with particles
gw15	yes	Clear with particles
gw16	yes	Clear with particles
gw17	no	Clear with particles
gw18	yes	Clear with particles
gw19	yes	Clear with particles
gw20	yes	Clear with particles
ws1	yes	Opaque with particles
ws2	yes	Opaque with particles
ws3	yes	Opaque with particles

Sample No	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100 ml)	Faecal Coliform (MPN/100 ml)
gw1	1262	772	7.48	1.04	3.37	28.2	0.59	13.3	1.18	0.14		
gw2	1220	734	7.39	1.04	1.97	29.2	0.56	25.3	1.16	0.24		
gw3	845	514	7.78	1.85	5.51	28.5	0.38	6.0	0.66	0.08		
gw4	857	513	7.90	3.78	2.63	29.4	0.38	8.1	1.30	0.22		
gw5	672	367	8.74	1.03	2.37	34.8	0.27	5.1	1.01	0.08	>2420	2420
gw6	658	393	7.41	1.17	1.71	29.6	0.29	10.3	0.46	1.06		
gw7	841	518	7.55	4.77	1.42	27.9	0.39	6.4	0.83	0.11		
gw8	458	269	7.79	2.01	1.72	30.6	0.20	2.0	0.26	0.17		
gw9	737	424	7.56	3.15	2.27	31.8	0.31	3.7	0.61	0.16		
gw10	721	431	7.49	0.14	1.13	29.6	0.32	4.3	0.97	0.41		
gw11	876	533	7.70	0.28	5.61	28.6	0.40	4.9	0.54	0.28	687	461
gw12	1116	661	7.43	1.05	1.92	30.1	0.50	6.8	0.71	0.34		
gw13	272	167	7.91	0.17	3.74	28.2	0.12	2.7	0.16	0.15	43	6
gw14	1433	874	7.65	1.03	7.31	28.4	0.67	11.4	1.06	0.22		
gw15	818	494	7.54	1.25	1.88	29.0	0.37	3.8	7.17	0.41		
gw16	959	561	7.59	1.20	1.97	30.8	0.42	6.5	1.19	0.19		
gw17	56	32	8.20	0.00	3.67	31.7	0.02	0.8	0.11	0.08		
gw18	1740	1043	7.69	1.28	5.12	29.4	0.80	10.2	1.74	0.19	43	20
gw19	1240	734	7.22	0.25	1.29	30.2	0.55	7.1	0.73	0.82		
gw20	2279	1341	7.68	0.10	4.39	30.4	1.04	24.6	2.08	0.86		
ws1	453.7	278	8.37	187.32	7.11	28.1	0.2	10.0	0.24	-		
ws2	416	253	8.37	232.55	7.19	28.6	0.18	18.8	0.22	-		
ws3	483.7	294	7.97	190.88	7.42	28.6	0.22	4.1	0.18	-		

	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)
WHO Standards	Suggested maximum limit of freshwater for potable purposes = 1500 µS/cm Suggested maximum limit of freshwater for non-potable purposes = 2500 µS/cm	-	-	-	-	-

	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
WHO Values	-	Guideline Value = 50 mg/L-NO3	Natural Level of Ammonia < 0.2 mg/L Threshold odour concentration = 1.5 mg/L Taste threshold = 35 mg/L	-	-	-

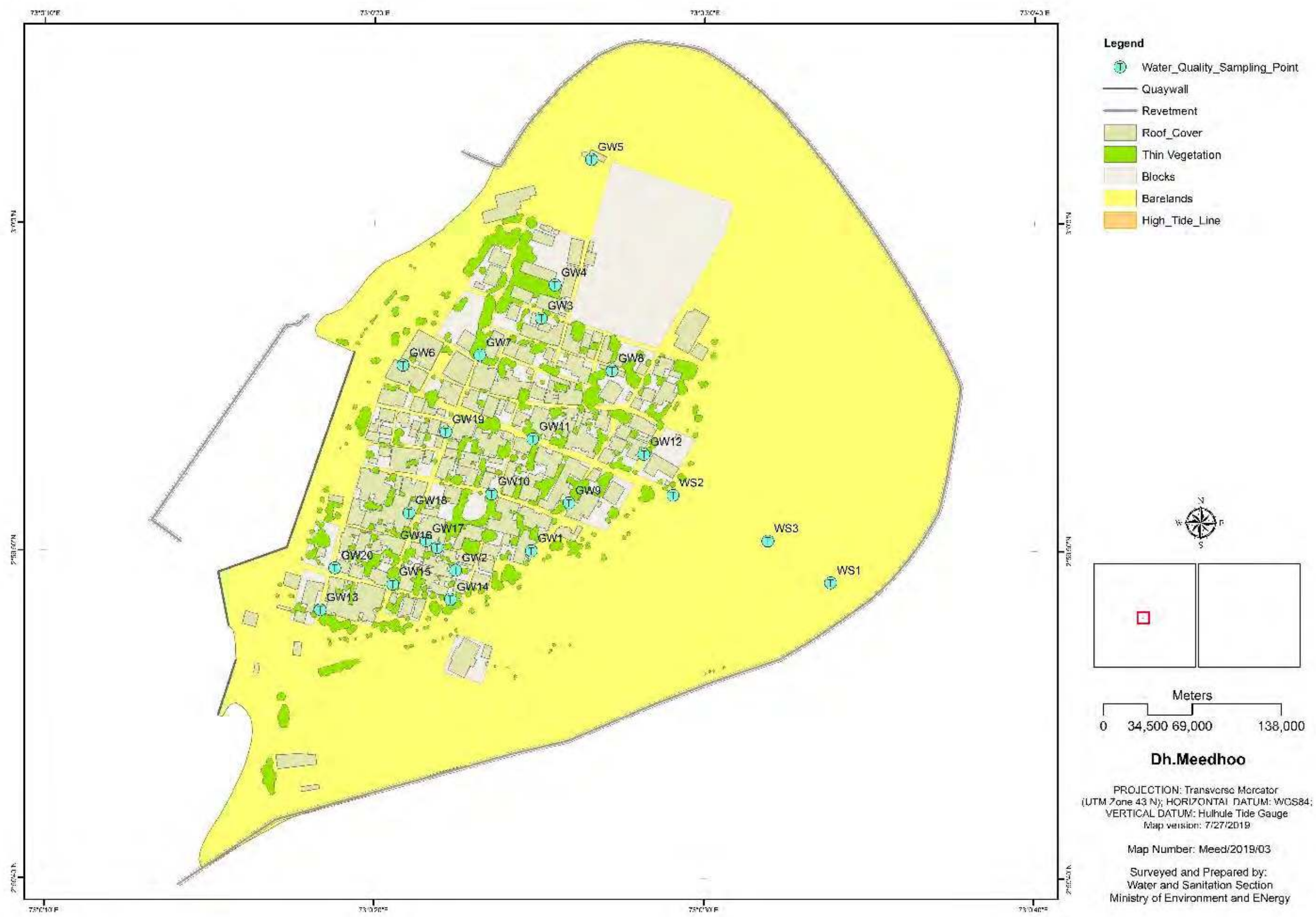


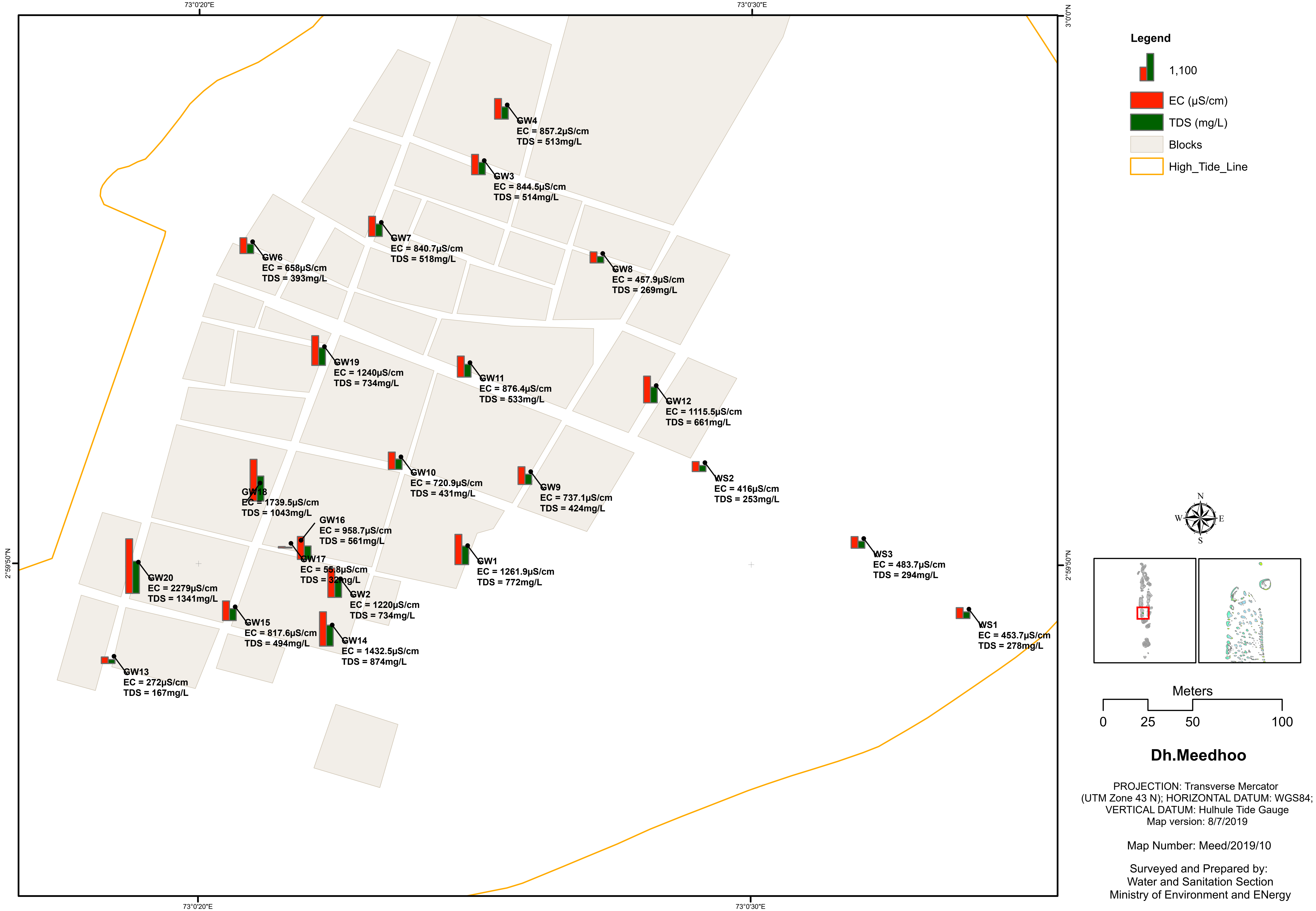
Figure 13.5: Location of groundwater sampling points in Meedhoo Island

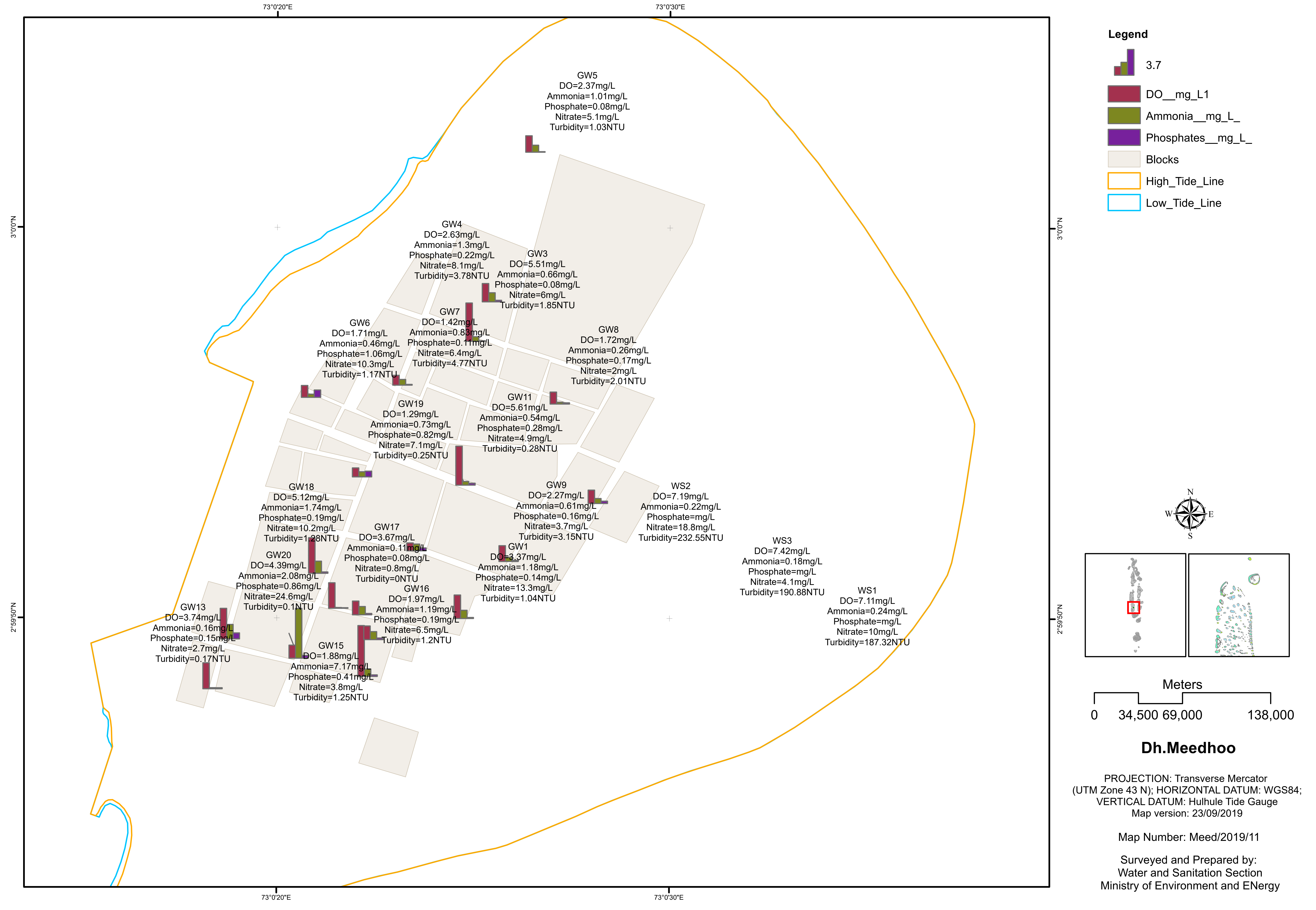
Based on the full results and the summary shown in Table 5, the following can be summarized for Meedhoo:

- Samples gw3 and gw4 were taken from different points within the school. Sample gw5 was taken from the shed used by construction workers away from the residential area and closer to reclaimed area. Sample gw13 was taken from Fenaka and gw7 was taken from police station. Samples WS1-WS3 were drilled and taken from the reclaimed areas. All other samples (gw1-2, gw6, gw8-12 and gw14-20) were taken from households.
- The average Electrical Conductivity (EC) of the groundwater is 887 µS/cm which is below the acceptable limit for potable water of 1,500 µS/cm (refer section 2.2). Only 2 samples (gw18 and gw20) have higher EC than the acceptable limit for potable water. The EC of the samples range from 56-2279 µS/cm. Sample gw 20 has a high EC of 2279 µS/cm as this sample was taken from a house which is within 50m from the harbor. Drilled samples from the reclaimed area (WS1, WS2 and WS3) have the lowest EC.

- Sample gw16 and gw17 were tested from the same house which used a water filter to filter the groundwater to use for drinking and cooking purposes. Samples gw16 and gw17 were samples taken before and after filtration, respectively. Before filtration, the water had an EC of 959 μS/cm while after filtration, the water had an EC of 56 μS/cm, which is the lowest EC of a sample recorded in this survey of 13 islands.
- Total Dissolved Solids recorded ranged from 32 mg/L (gw17) to 1341 mg/L with an average of 530 mg/L.
- The pH of groundwater ranged from 7.22 to 8.74 with an average of 7.76. Three samples (gw5, WS1 and WS2) had pH higher than the WHO permissible limits of 6.5-8.5.
- Turbidity ranged from the lowest of 0 NTU to 232.55 NTU with an average of 27.71 NTU. The drilled samples (WS1-WS3) had significantly higher turbidity than other samples. The average turbidity excluding samples WS1-WS3 is 1.33 NTU, which is a significantly lower turbidity. As a guide, "crystal-clear" water has a turbidity below 1 NTU, and water becomes visibly cloudy at 4 NTU and above.
- Dissolved oxygen levels were low to moderate, with values varying from 1.13 to 7.42 mg/L. The average value was 3.60 mg/L.
- The salinity of groundwater ranged from 0.02 PSU to 1.04 PSU with an average of 0.4 PSU. Salinity is expressed in Practical Salinity Units, PSU which is equivalent to PPT.
- The average Nitrate concentration was 8.53 mg/L and therefore does not exceed the WHO guideline limit of 50 mg/L. None of the tested water samples exceeded this limit. The Nitrate concentrations ranged from 0.8 mg/L to 25.3 mg/L. From the 13 islands surveyed, the groundwater in Meedhoo had the lowest Nitrate concentration. This could be due to the fact that Meedhoo has very sparse vegetation and even household gardens are lacking compared to other islands.
- Ammonia concentrations were generally low. The average ammonia concentration was 1.07 mg/L and ranged from 0.11 mg/L to 7.17 mg/L. The average ammonia concentration does not exceed the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. Only 3 samples (gw15, gw18 and gw20) exceeded this limit. There is no apparent correlation between increasing levels of ammonia and other nutrients.
- Phosphate concentrations ranged from 0.08 mg/L to 1.06 mg/L with an average of 0.31 mg/L. There is no WHO drinking water guideline value for phosphate. However, it would normally be expected that phosphate concentrations in groundwater are less than 0.1 mg/L, where there are no impacts from human wastewater (e.g. effluent from septic tanks and 'greywater' from kitchens and bathrooms). Only 2 (gw3 and gw5) of 20 samples tested had Phosphate concentrations below 0.1 mg/L. Neither of these two samples were taken from residential areas, with gw3 being taken from the school and gw5 from shed used by construction workers.
- Total coliform levels were found to be significant and ranged from lowest count of 43 MPN/100mL to the highest count of more than 2420 MPN/100mL, with an average count of 798 MPN/100 mL. Faecal coliform levels ranged from lowest count of 6 MPN/100 mL to the highest count of 2420 MPN/100mL, with an average count of 726.75 MPN/100mL. As expected, the groundwater layer is contaminated with effluent from septic tanks.

In conclusion, Dh. Meedhoo Island contains groundwater with low Electrical Conductivity, low TDS and low turbidity excluding the drilled samples. Nitrate concentration was lower than WHO maximum guidance value, Ammonia concentrations were lower than expected in natural undisturbed groundwater, but Phosphate concentration was higher than expected in natural, undisturbed groundwater. In terms of microbiological contamination, Meedhoo Island shows pattern where all of the tested samples were contaminated but central residential areas have lower contamination compared to the remote area. Additionally, the following pages contain maps which show the main physiochemical parameters displayed on map of the island.


73°0'20"E
73°0'30"E
3°0'0"N
2°59'50"N
GW4
EC = 857.2µS/cm
TDS = 513mg/L
GW3
EC = 844.5µS/cm
TDS = 514mg/L
GW7
EC = 840.7µS/cm
TDS = 518mg/L
GW6
EC = 658µS/cm
TDS = 393mg/L
GW8
EC = 457.9µS/cm
TDS = 269mg/L
GW19
EC = 1240µS/cm
TDS = 734mg/L
GW11
EC = 876.4µS/cm
TDS = 533mg/L
GW12
EC = 1115.5µS/cm
TDS = 661mg/L
GW10
EC = 720.9µS/cm
TDS = 431mg/L
GW9
EC = 737.1µS/cm
TDS = 424mg/L
WS2
EC = 416µS/cm
TDS = 253mg/L
GW18
EC = 1739.5µS/cm
TDS = 1043mg/L
GW16
EC = 958.7µS/cm
TDS = 561mg/L
GW17
GW1
EC = 1261.9µS/cm
TDS = 772mg/L
WS3
EC = 483.7µS/cm
TDS = 294mg/L
GW20
EC = 2279µS/cm
TDS = 1341mg/L
GW2
EC = 1220µS/cm
TDS = 734mg/L
GW15
EC = 817.6µS/cm
TDS = 494mg/L
GW14
EC = 1432.5µS/cm
TDS = 874mg/L
WS1
EC = 453.7µS/cm
TDS = 278mg/L
GW13
EC = 272µS/cm
TDS = 167mg/L
Legend
1,100
EC (µS/cm)
TDS (mg/L)
Blocks
High_Tide_Line
N
W
E
S
Meters
0
25
50
100
Dh.Meedhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/7/2019
Map Number: Meed/2019/10
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


73°0'20"E
73°0'30"E
3°0'0"N
2°59'50"N
GW5
DO=2.37mg/L
Ammonia=1.01mg/L
Phosphate=0.08mg/L
Nitrate=5.1mg/L
Turbidity=1.03NTU
GW4
DO=2.63mg/L
Ammonia=1.3mg/L
Phosphate=0.22mg/L
Nitrate=8.1mg/L
Turbidity=3.78NTU
GW3
DO=5.51mg/L
Ammonia=0.66mg/L
Phosphate=0.08mg/L
Nitrate=6mg/L
Turbidity=1.85NTU
GW7
DO=1.42mg/L
Ammonia=0.83mg/L
Phosphate=0.11mg/L
Nitrate=6.4mg/L
Turbidity=4.77NTU
GW6
DO=1.71mg/L
Ammonia=0.46mg/L
Phosphate=1.06mg/L
Nitrate=10.3mg/L
Turbidity=1.17NTU
GW8
DO=1.72mg/L
Ammonia=0.26mg/L
Phosphate=0.17mg/L
Nitrate=2mg/L
Turbidity=2.01NTU
GW11
DO=5.61mg/L
Ammonia=0.54mg/L
Phosphate=0.28mg/L
Nitrate=4.9mg/L
Turbidity=0.28NTU
GW19
DO=1.29mg/L
Ammonia=0.73mg/L
Phosphate=0.82mg/L
Nitrate=7.1mg/L
Turbidity=0.25NTU
GW18
DO=5.12mg/L
Ammonia=1.74mg/L
Phosphate=0.19mg/L
Nitrate=10.2mg/L
Turbidity=1.28NTU
GW9
DO=2.27mg/L
Ammonia=0.61mg/L
Phosphate=0.16mg/L
Nitrate=3.7mg/L
Turbidity=3.15NTU
WS2
DO=7.19mg/L
Ammonia=0.22mg/L
Phosphate=mg/L
Nitrate=18.8mg/L
Turbidity=232.55NTU
GW17
DO=3.67mg/L
Ammonia=0.11mg/L
Phosphate=0.08mg/L
Nitrate=0.8mg/L
Turbidity=0NTU
GW1
DO=3.37mg/L
Ammonia=1.18mg/L
Phosphate=0.14mg/L
Nitrate=13.3mg/L
Turbidity=1.04NTU
WS3
DO=7.42mg/L
Ammonia=0.18mg/L
Phosphate=mg/L
Nitrate=4.1mg/L
Turbidity=190.88NTU
GW20
DO=4.39mg/L
Ammonia=2.08mg/L
Phosphate=0.86mg/L
Nitrate=24.6mg/L
Turbidity=0.1NTU
GW16
DO=1.97mg/L
Ammonia=1.19mg/L
Phosphate=0.19mg/L
Nitrate=6.5mg/L
Turbidity=1.2NTU
WS1
DO=7.11mg/L
Ammonia=0.24mg/L
Phosphate=mg/L
Nitrate=10mg/L
Turbidity=187.32NTU
GW13
DO=3.74mg/L
Ammonia=0.16mg/L
Phosphate=0.15mg/L
Nitrate=2.7mg/L
Turbidity=0.17NTU
GW15
DO=1.88mg/L
Ammonia=7.17mg/L
Phosphate=0.41mg/L
Nitrate=3.8mg/L
Turbidity=1.25NTU
Legend
3.7
DO__mg_L1
Ammonia__mg_L_
Phosphates__mg_L_
Blocks
High_Tide_Line
Low_Tide_Line
N
E
S
W
Meters
0 34,500 69,000 138,000
Dh.Meedhoo
PROJECTION: Transverse Mercator (UTM Zone 43 N); HORIZONTAL DATUM: WGS84; VERTICAL DATUM: Hulhule Tide Gauge
Map version: 23/09/2019
Map Number: Meed/2019/11
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

13.8.3 Geophysical survey

The Resistivity tests were carried out in the locations as outlined in Figure below.

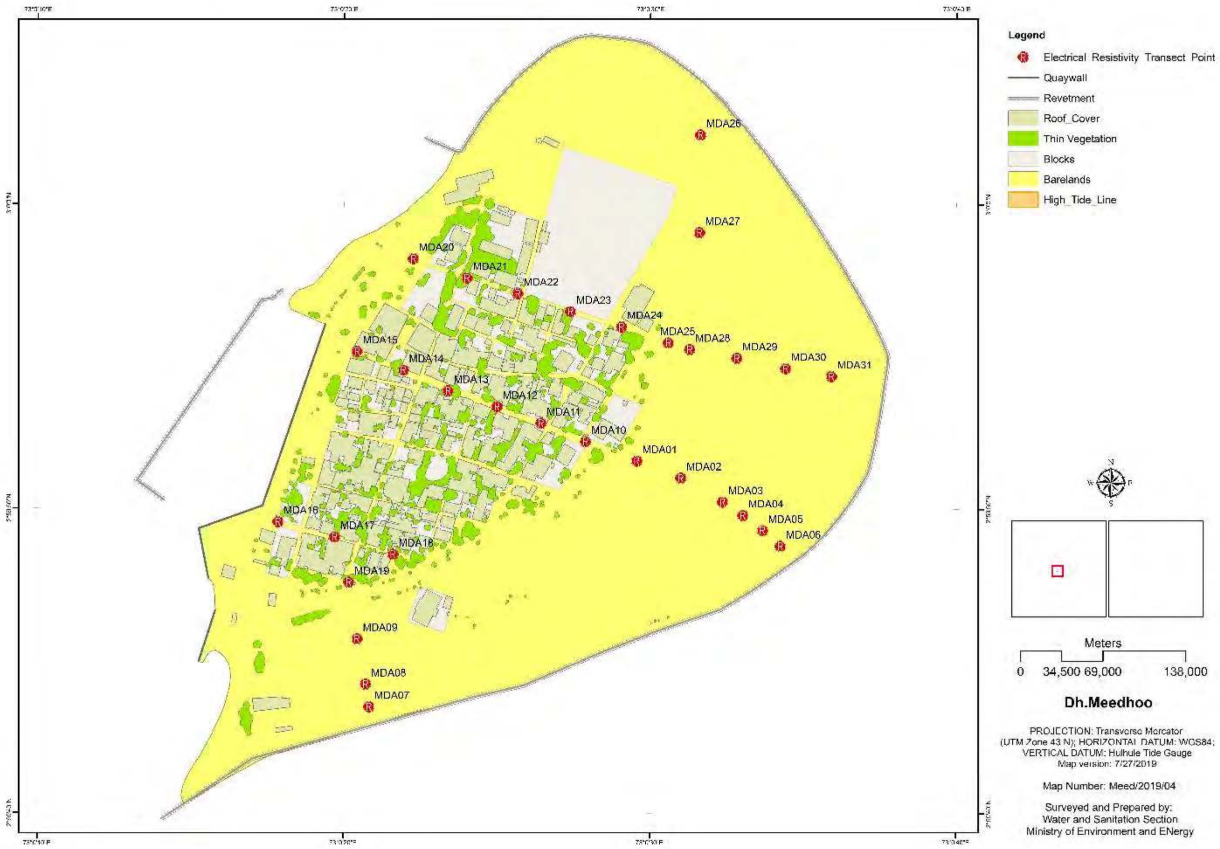


Figure 13.6: Location of ER points in Meedhoo Island

13.8.4 Aerial surveys

Based on the aerial survey, a multiple dataset consisting of roof cover, thick vegetation area, thin vegetation area, bare lands and shorelines were extracted. This data is shown in Figure 13.7 and the Table 13.7 shows the different area distribution.

Figure 13.7: Area Distribution in Meedhoo Island

Table 13.7: Area Distribution in Meedhoo

	Area (Square Meters)	Percentage (%) of total area
Roof cover	37,863.97	11.9%
Vegetation (Thick)	0	0%
Vegetation (Light)	21,023.02	6.6%
Bare lands	259,935	81.5%
Farm Lands	-	
Wetlands (Inland)	-	-

13.8.5 Water Demand

The only source of natural water is rainwater collected from the rooftops of households and institutions and groundwater extracted from shallow wells.

13.8.6 Freshwater lens

Based on the ER survey the depth to groundwater level and the freshwater-saline water interface was determined for a set of transverse transects as shown in Figure 13.8. Plots in the Figure 13.9 Figure 8.9 show the cross sections of each transect line. The dotted lines in the plots indicating a simple interpolation of levels to mean sea level in the island boundaries. These cross sections were used to identify the spatial extent and volume of the freshwater lens while they were also useful in deriving implications on the stress level of the aquifer based on the observed, localized drawdown effect in the groundwater table and up-coning in the freshwater-saline interface, defining the upper and lower boundaries of the freshwater lens in an island.

The area covered by freshwater for each transect line has been calculated. To estimate the total volume of available freshwater lens, the cross-section area of freshwater extent under each transect was multiplied by the distance between two transects. The sum of these lengths represents the cumulative length of the island and thus, the above estimation could represent the total volume of the freshwater lens sandwiched between the groundwater table on top and freshwater-saline water interface in the bottom. Then the actual groundwater storage within this freshwater lens was calculated by multiplying the estimated total lens volume with the porosity of the topsoil in the island.

This estimation represents the total available freshwater volume within the freshwater lens at any given time (time of the measurement). The measurements were carried out towards the end of the dry period and the freshwater lens is presumed to be undergoing a ‘stressed’ condition due to continued groundwater abstractions despite reduced recharge in the dry period. Falkland (1994) method can be used to estimate the freshwater lend thickness under salient conditions using average annual rainfall, length and width of the island, and the comparison was used as a measure of stress level of the freshwater lens.

Table 13.8 illustrate the freshwater volume calculation for the island. The area covered by freshwater for each transect line has been calculated. To estimate the total volume of available freshwater lens, the cross-section area of freshwater extent under each transect was multiplied by the distance between two transects. The sum of these lengths represents the cumulative length of the island and thus, the above estimation could represent the total volume of the freshwater lens sandwiched between the groundwater table on top and freshwater-saline water interface in the bottom. Then the actual groundwater storage within this freshwater lens was calculated by multiplying the estimated total lens volume with the porosity of the topsoil in the island.

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Table 13.8: Freshwater Volume Calculation for Meedhoo Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
1	Start		0	0	0	0			
			16	1.403	0	0	0		
	MDA07	ER	18	1.5656	0.07	0.07	0		
	MDA08	ER	41	1.5103	0.14	-0.96	12		
	MDA09	ER	88	1.3308	0.15	-1.63	68		
	MDA19	ER	145	0.8914	0.309	-3.16	149		
	MDA17	ER	193	0.9771	0.264	-2.043	140		
			313	0.859	0	0	139		
	End		330	0	0	0	0		
	Total						508	293	148624

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
2	Start		0	0	0	0	0		
			27	0	0	0	0		
	MDA06	ER	22	1.7645	0.105	0.105	0		
	MDA05	ER	42	1.6224	0.122	0.122	0		
	MDA03	ER	68	1.8261	0.256	-1.424	22		
	MDA02	ER	92	1.8374	0.326	-1.55	43		
	MDA01	ER	143	1.8578	0.378	-1.992	108		
	MDA01	ER	186	1.8578	0.378	-1.992	101		
	MDA10	ER	243	1.1044	0.522	-3.05	168		
	MDA11	ER	290	0.9814	0.477	-2.96	167		
	MDA12	ER	338	1.01	0.372	-2.67	156		
	MDA13	ER	390	1.137	0.44	-3.1	169		
	MDA14	ER	439	1.1006	0.34	-2.86	168		
	MDA15	ER	489	0.9785	0.106	-2.081	134		
			504	0	0	0	16		
	End		530	0	0	0	0		
	Total						1251	182	228341
3	Start		0	0	0	0			
			28	0	0	0			
	MDA31	ER	55	1.6614	0.1	-1.3	18		
	MDA30	ER	101	1.7697	0.2	-1.67	76		
	MDA29	ER	152	1.85	0.28	-1.85	101		
	MDA28	ER	199	1.8503	0.37	-2.2	111		
	MDA25	ER	223	1.6697	0.37	-3.19	74		
	MDA24	ER	271	1.1246	0.516	-3.51	183		
	MDA23	ER	324	0.8828	0.352	-3.76	216		
	MDA22	ER	383	0.8271	0.352	-2.96	217		
	MDA21	ER	434	1.1547	0.34	-3.59	186		
	MDA20	ER	492	1.1485	0.246	-2.6	197		
			537	0	0	0	64		
	End		566	0	0	0	0		
	Total						1444	283	408551
									785516

Volume of lens = 785516 m^3

Groundwater Storage = Porosity (15%) x Lens volume (m^3) = 117827 m^3

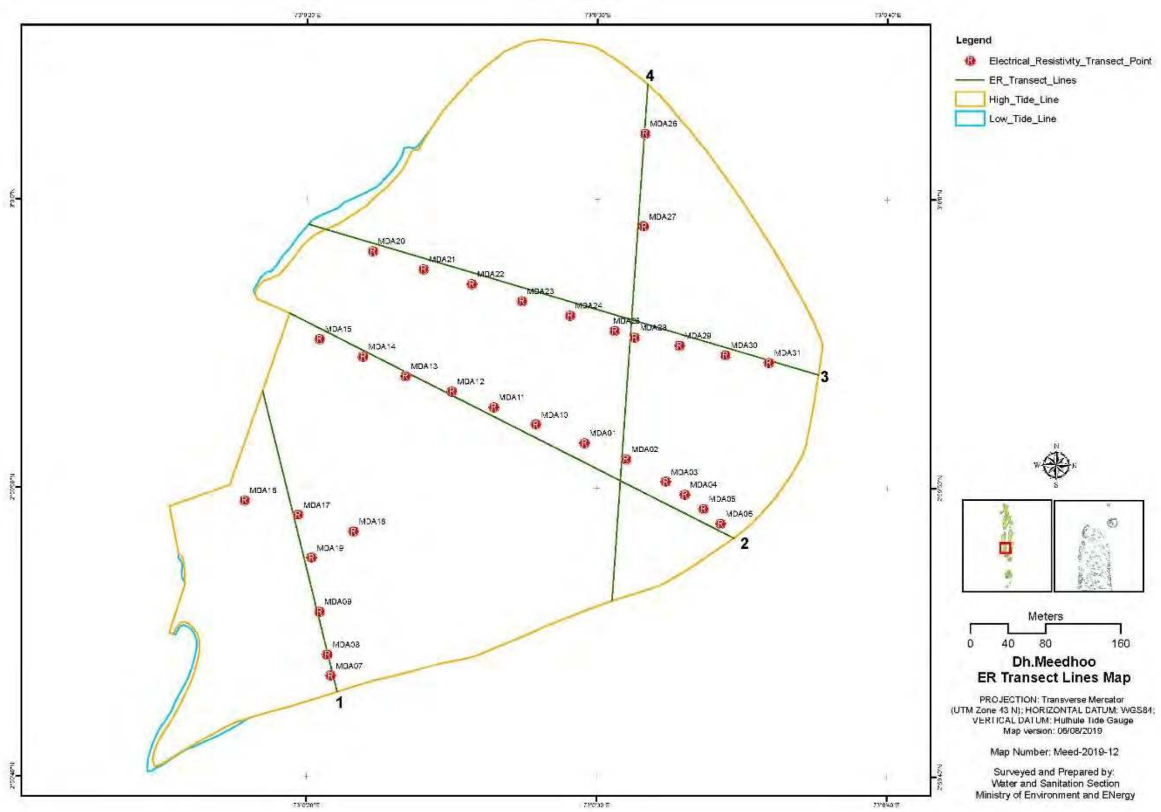

Figure 13.8: ER transect lines in Meedhoo Island

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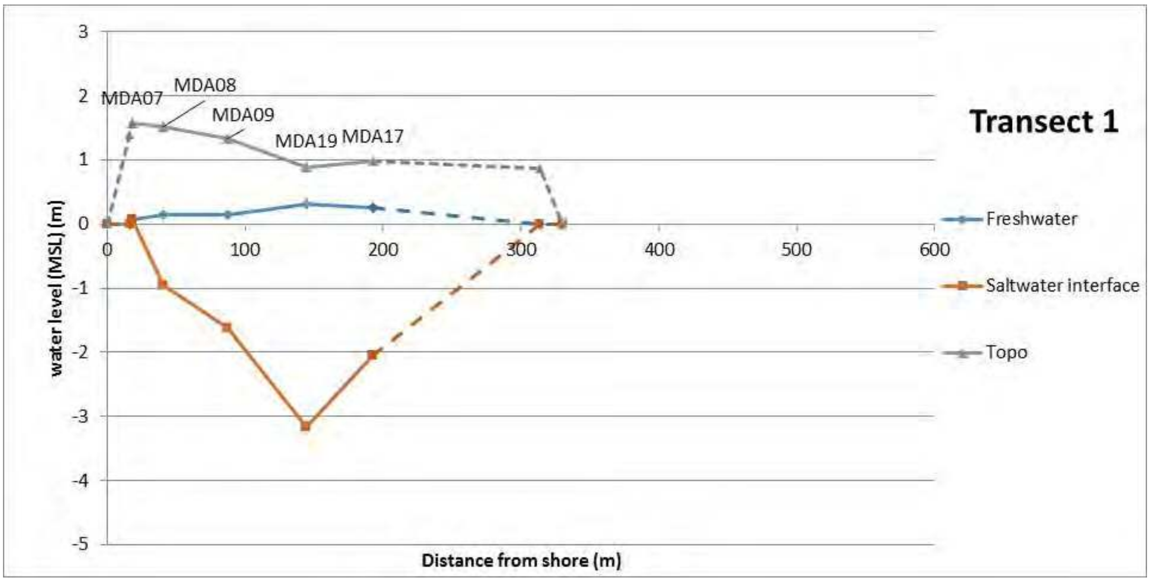
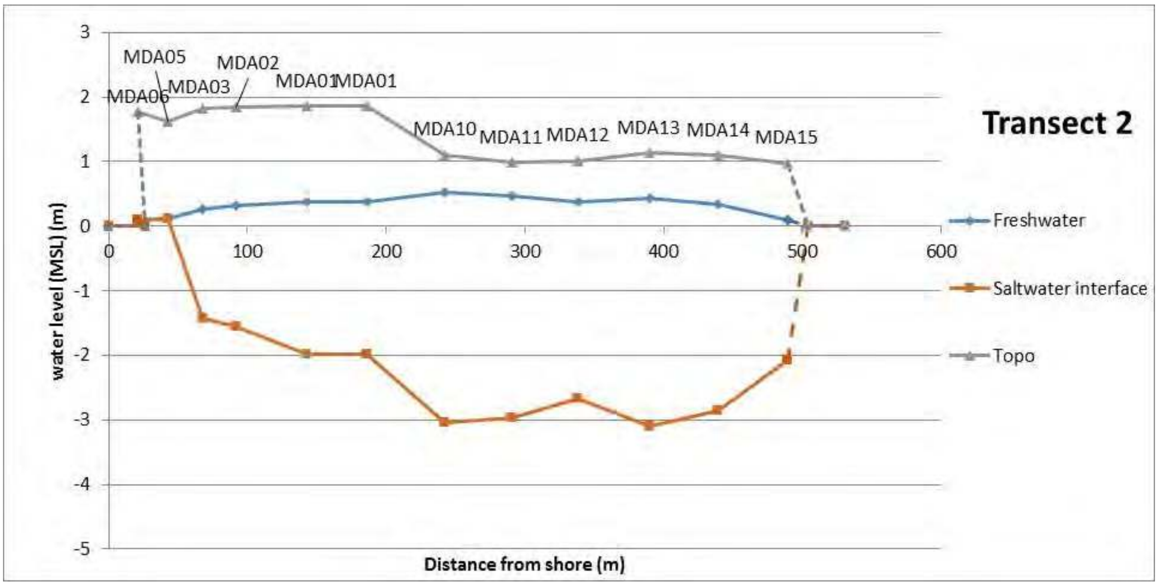
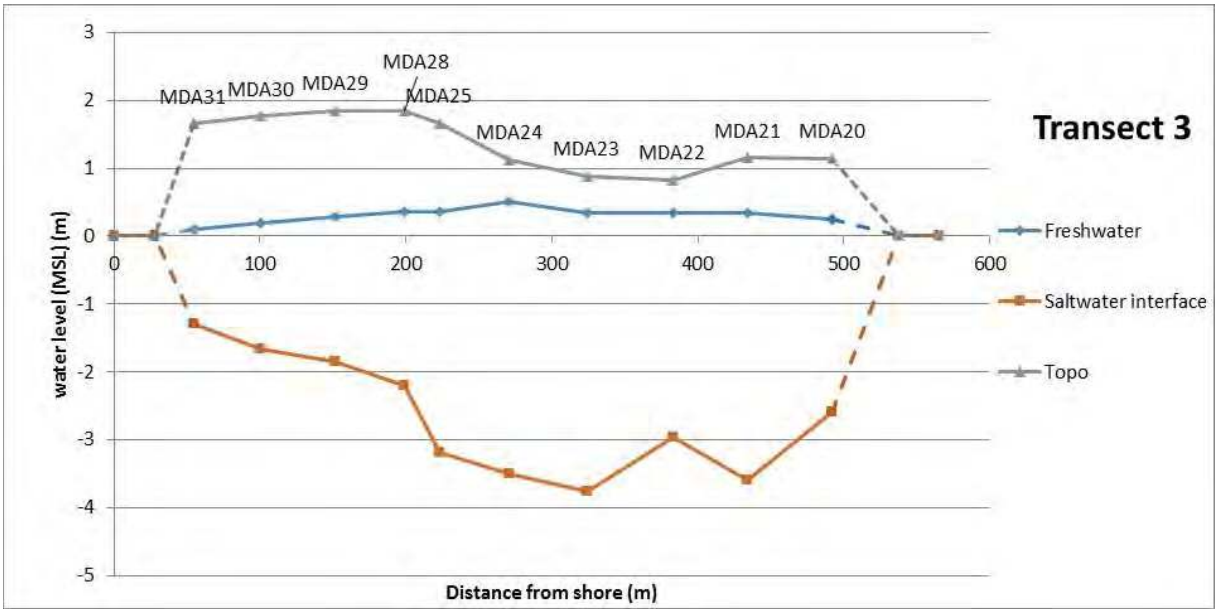
Table 13.9: ER Survey Results of Longitudinal Sections for Meedhoo Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)
4	Start		0	0	0	0
			28	1.001	0	0
	MDA26	ER	52	1.9053	0.245	-1.005
	MDA27	ER	153	1.8712	0.37	-2
	MDA28	ER	269	1.8503	0.37	-2.2
	MDA02	ER	398	1.8374	0.326	-1.55
			524	1.506	0	0
	End		551	0	0	0


Transcect 1
MDA07
MDA08
MDA09
MDA19
MDA17
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saltwater interface
Topo


Transect 2
MDA05
MDA02
MDA06
MDA03
MDA01
MDA01
MDA10
MDA11
MDA12
MDA13
MDA14
MDA15
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saltwater interface
Topo


Transect 3
MDA28
MDA31
MDA30
MDA29
MDA25
MDA24
MDA23
MDA22
MDA21
MDA20
water level (MSL) (m)
Distance from shore (m)
Freshwater
Saltwater interface
Topo

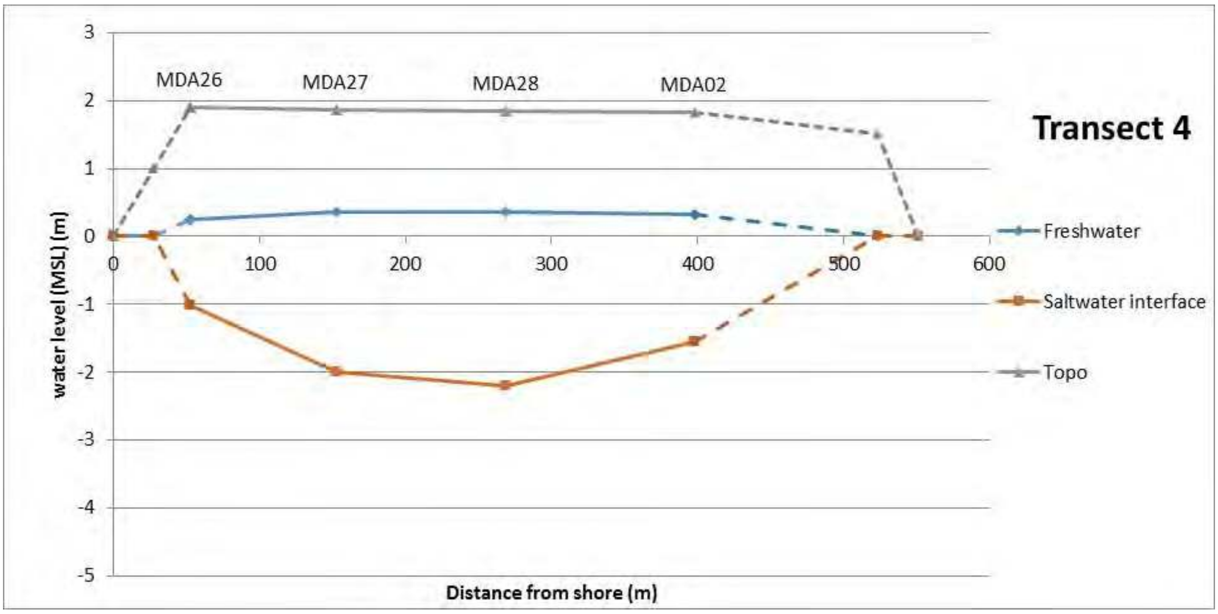


Figure 13.9: Cross-sections of transect lines in Meedhoo Island

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented below.

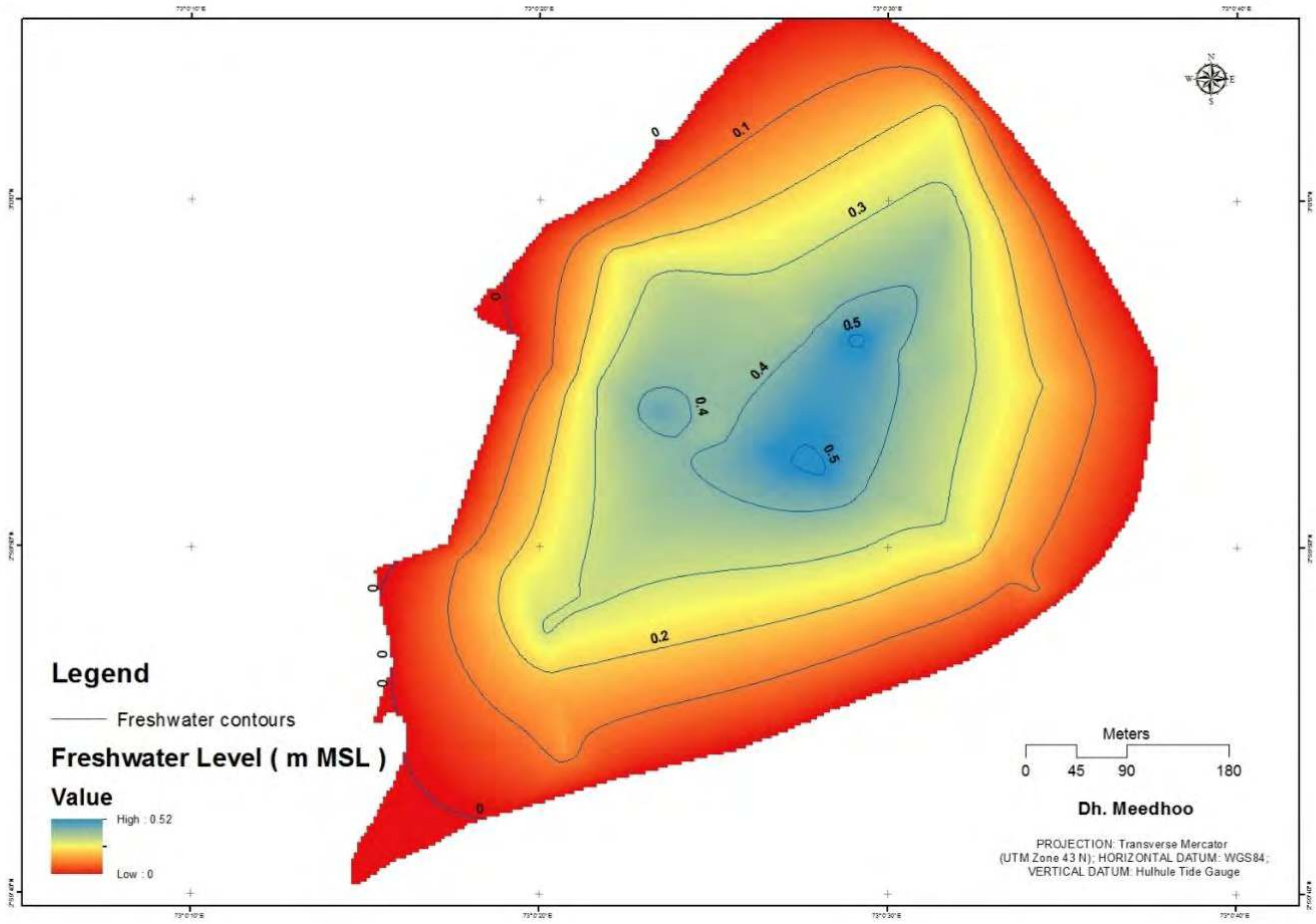


Figure 13.10: Freshwater Level in Meedhoo Island

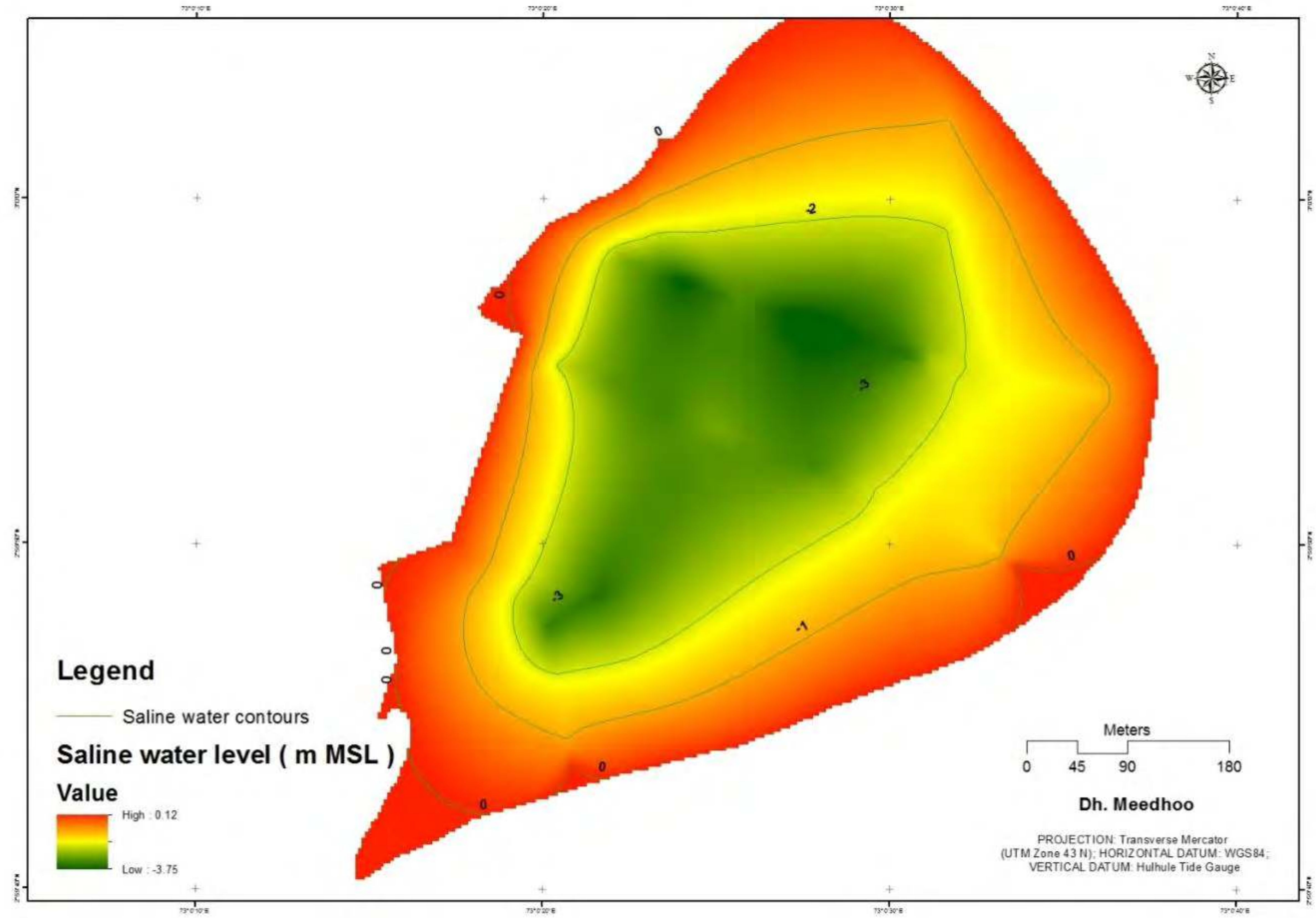


Figure 13.11: Saline water Level in Meedhoo Island

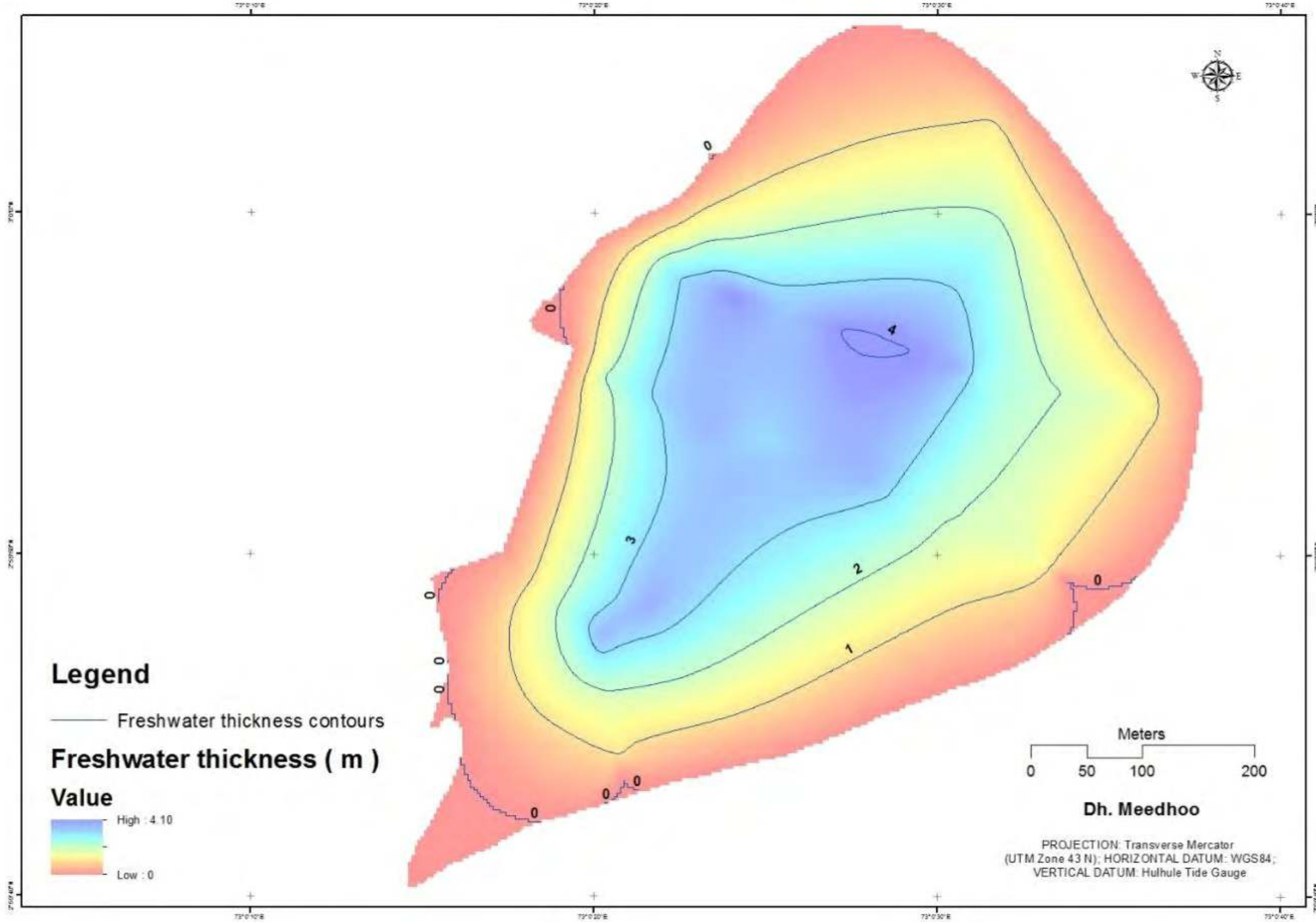


Figure 13.12: Freshwater thickness in Meedhoo Island

The maximum freshwater thickness of the island is 4.10 m. According to Falkland, 1994, the freshwater level thickness of the island is 10 m. The relevant calculations are as follows;

Average Annual Rainfall = 2150 mm/yr

Width of the island = 530 m

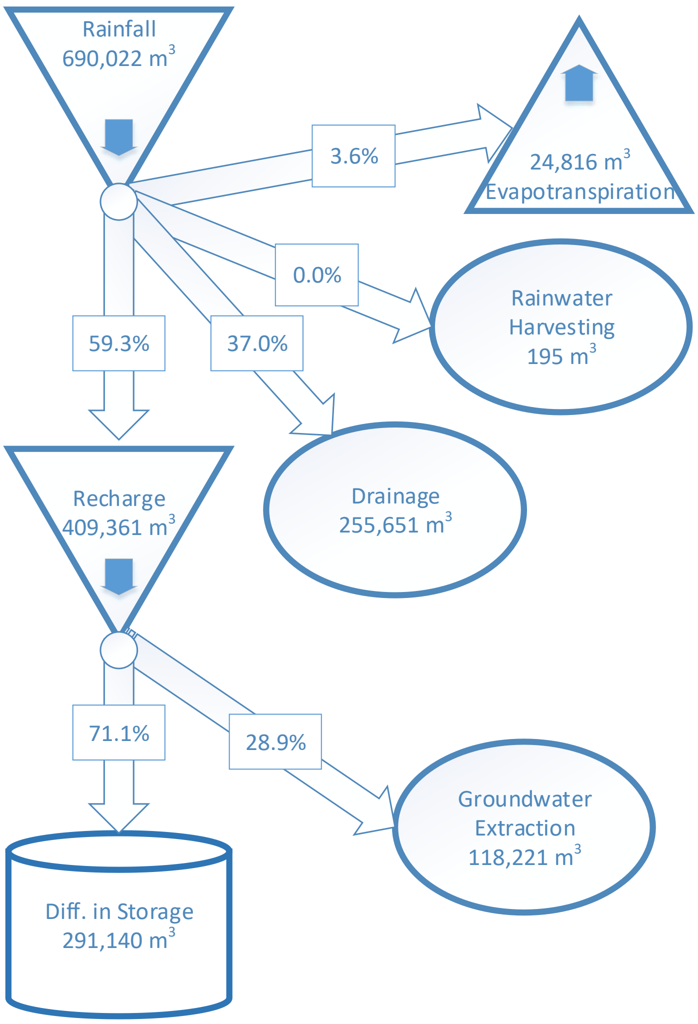
Length of the island = 842 m

Freshwater lens Thickness (m)

= (6.94*log(width of the island)-14.38)*Average Annual Rainfall = 10 m

13.8.7 Water balance and recharge

An annual estimation is carried out based on water balance method. Rainwater harvesting is calculated using number of rainwater harvesting units in the island. According to the spatial mean annual rainfall of Maldives, the island is reported as 2150 mm/year. Evapotranspiration was estimated using crop water requirement for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. The groundwater extractions were estimated from amount of water usage in different sectors (residential, resorts, restaurants, agriculture and farming).The difference between recharge and groundwater extraction is taken to estimate different in storage.



sland

13.8.8 Sustainable yield of the lens

Sustainable yield of the water lens refers to the safe extraction potential of a given groundwater aquifer without significantly affecting its quality or quantity. This parameter is an important factor in the

sustainable development of islands as it allows planning and design of water and sanitation intervention in islands.

The island has a sustainable yield of 798 m^3 per day which was calculated subtracting groundwater extraction from recharge volume derived from water balance (

Figure 8.13). According to Metai & Unit, n.d., based on geophysical investigations and drilling programme concluded that the safe sustainable yield was about 10% of mean annual rainfall. Such that the expected sustainable yield for the island should be 189 m^3 per day.

13.8.9 Permeability test

Permeability tests were carried out in the locations as outlined in Figure 13.14

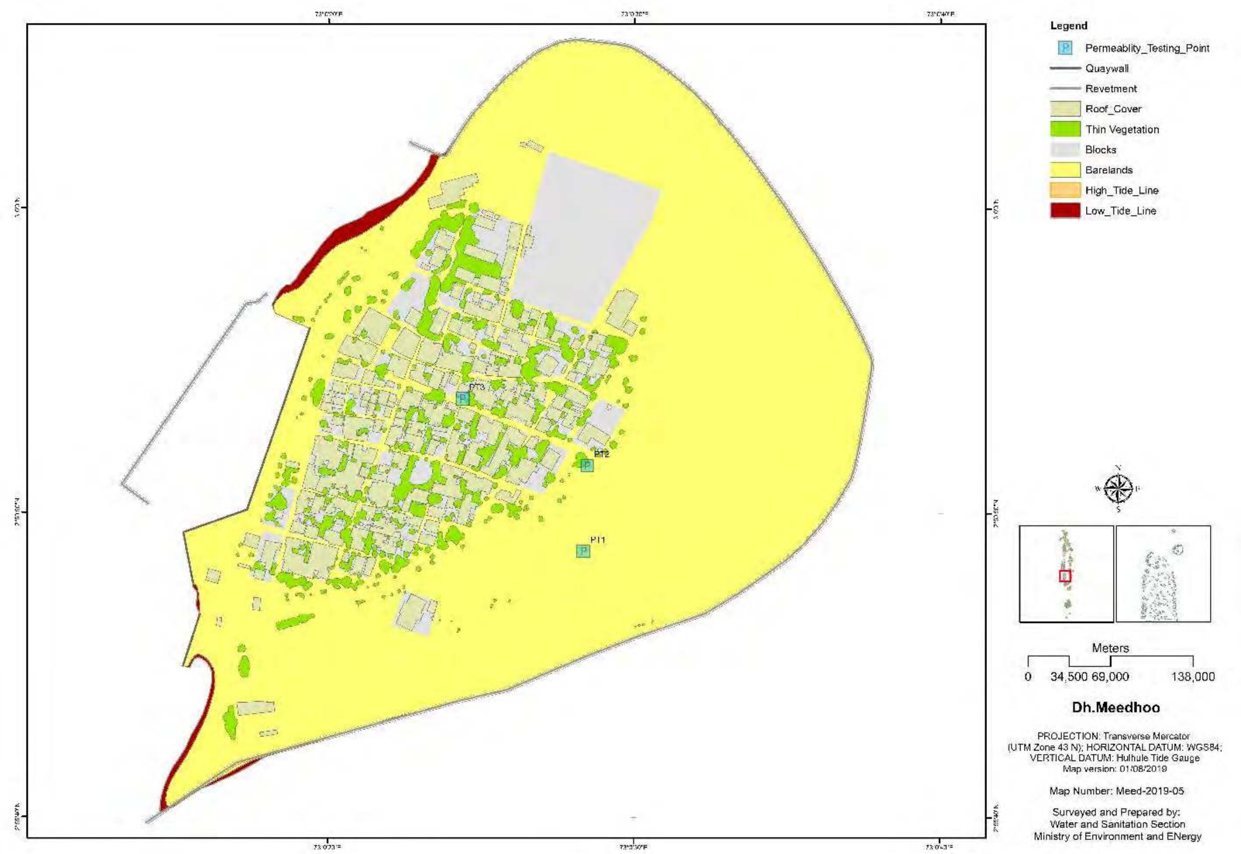


Figure 13.14: Locations of permeability tests in Meedhoo Island

The estimated permeability values for the above test locations are presented below.

Table 13.10: Estimated Permeability Values

r_e	0.026
r1	0.0285

Point	H	Tu	Cs	H/re	Q	K (m/s)	K (m/day)		Q (l/min)	Q (m^3/s)
PT1	0.91	1.5	55	35.0	3.3E-05	2.88E-05	2.49		2	3.33E-05
PT2	0.45	0.45	35	17.3	1.3E-05	5.57E-05	4.81		0.77	1.28E-05
PT3	0.5	0.6	40	19.2	1.3E-04	3.64E-04	31.49		7.57	0.000126

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m^3/s), H = Height of water in well (m), l = length of perforated section (m), r_1 = outside radius of casing (radius of hole in consolidated material) (m), r_e = effective radius of well = r_1 (area of perforations) / (outside area of perforated section of casing) : $r_1 = r_e$ in consolidated material that will stand open and is not cast, C_u and C_s =Conductivity Coefficients, and T_u = distance from water level in casing to water table (m).

13.8.10 Groundwater availability

1) The selected Meedhoo island has dimensions of width = 593 m and length = 885 m, with a total land area of 31.88 ha, a population of 929 persons, and a land use of built-up area 3.78 ha (11.9%), thick vegetation 0.00 ha (0.0%), light vegetation 2.10 ha (6.6%), and barelands 25.99 ha (81.5%).

2) In order to recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of freshwater lens (FWL) and its associated recharge-discharge characteristics, 31 number of Electrical Resistivity (ER) location readings along 04 representatively selected transects were collected.

3) Soil overburden permeability tests (constant head) were carried out at 03 locations. In addition, groundwater level was also recorded at 16 locations where groundwater water quality samples were tested.

4) Permeability tests were carried out at representatively selected 03 number of locations. The measured permeability (K m/day) values ranged from a minimum of 2.49 m/day to a maximum of 31.49 m/day, with an average of 12.93 ± 16.11 m/day (Mean ± 1 Standard Deviation).

5) The ground elevation values ranged from a minimum of 0.61 m MSL to a maximum of 2.26 m MSL, with an average of 1.44 ± 0.37 m MSL (Mean ± 1 Standard Deviation).

6) The upper boundary of the freshwater lens (FWL) varied from a minimum of 0.07 m MSL to a maximum of 0.52 m MSL, with an average of 0.28 ± 0.13 m MSL (Mean ± 1 Standard Deviation).

7) The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -3.76 m MSL to a maximum of 0.12 m MSL, with an average of -2.06 ± 1.12 m MSL (Mean ± 1 Standard Deviation).

8) Accordingly, the freshwater lens (FWL) thickness values ranged from a minimum of 0.00 m to a maximum of 4.11 m, with an average of 2.34 ± 1.22 m (Mean ± 1 Standard Deviation).

9) The groundwater profile in the island is characterised by a relatively Very Low (0.03%) Rainwater Harvesting, relatively Very High (37.05%) Drainage, relatively Very High (59.33%) Recharge, while the water use shows relatively High (28.88%) Groundwater extraction, leading to relatively Low (71.12%) Difference in Balance Storage.

10) The freshwater lens (FWL) volume calculated based on ER transect test data is 117,827 m^3 with a maximum FWL thickness of 4.11 m. The potential maximum FWL volume and thickness estimated based on Falkland (1994) method are 47,574 m^3 and 9.74 m.

13.8.11 Conclusive Comments and Recommendations

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 798 m^3 per day, while it is 189 m^3 per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 329 m^3 per day and this exceeds the allowable Safe Yield in the island by 174% (Moderately stressed) with moderate up-coning and moderate drawdown in freshwater lens cross-sections. At present, there exists an island-wide sewerage network but no water supply network. The water samples tested were found to be Moderately Odorous with 75.0% or 15/20 samples tested producing odour. The Hydrological condition of the freshwater lens aquifer can be categorised as Moderate based on above measurements and findings while Water quality aspects can be regarded as Contaminated with an Average Electrical Conductivity (EC) of 952.84 ± 498.45 µS/cm with measured values ranging from a minimum of 55.80 µS/cm to a maximum of 2,279.00 µS/cm, and an Average Ammonia Concentration of 1.20 ± 1.49 mg/L with measured values ranging from a minimum of 0.11 mg/L to a maximum of 7.17 mg/L.

The Availability of space for incorporating recharge measures and related infrastructure is High (Reclaimed area) while therefore the Potential for Recharging is considered to be High. Overall recommendation for groundwater recharging would be to use recharging trenches and ponds.

14 FIYOARI ISLAND

14.1 General overview of the island

The island of Fiyoaree is located at 2°10’5”N and 73°3’59”E in the Gaafu Dhaalu Administrative Atoll. The island is about 1650 m long and 652 m wide, giving it an area of 80.63 ha. The island has a population of 737 people, via the 2014 Census. The island has a harbor on the Eastern side of the island. The following table outlines some basic information about the island and the following figure outlines the location of Fiyoaree.

Table 14.1: Basic statistical information on Fiyoari island in Gaaf Dhaalu Atoll.

Name of the island	GDh.Fiyoaree
Longitude and Latitude	73°3’58.9”E, 2°10’4.7”N
Area	79.9 ha
Population (Census, 2014)	737
Distance from Atoll Capital (GDh.Thinadhoo)	37.46 km
Distance from Male’	439 km
Harbour	Present
Island sewerage network	No
Water supply network	No
Other infrastructure	None

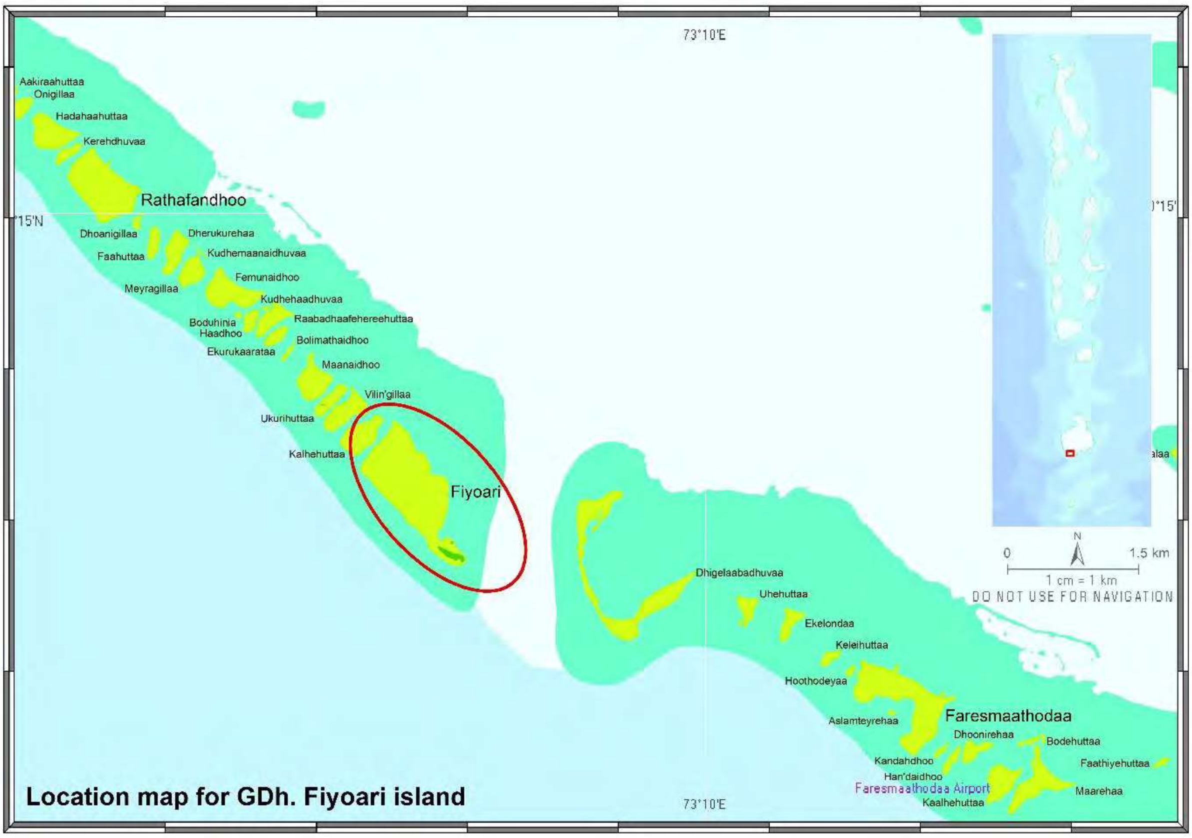


Figure 14.1: Location map for Fiyoari Island, Gaaf Dhaalu Atoll.

14.2 Geology and vegetation

The island is approximately 1650 m long and 652 m wide, with an area of 80.63 ha. Of this around half of the land is covered in vegetation which is mostly concentrated at the Northern and Southern ends of the island, with homes and roads having been built in the middle of the island. Various farming activities take place on the island, mostly between the patches of thick vegetation at the Northern and Southern ends of the island. The island has two mangroves located at the Southern end of the island, one measuring at around 270 by 60 meters, while another smaller one has a diameter of about 30m.

14.3 Topography

Fiyoari has a topography that ranges from 0.08 meters to 2.61 meters above Mean Sea Level, with an average of 1.04 meters above MSL. The topography contour map is found in Figure 14.2.

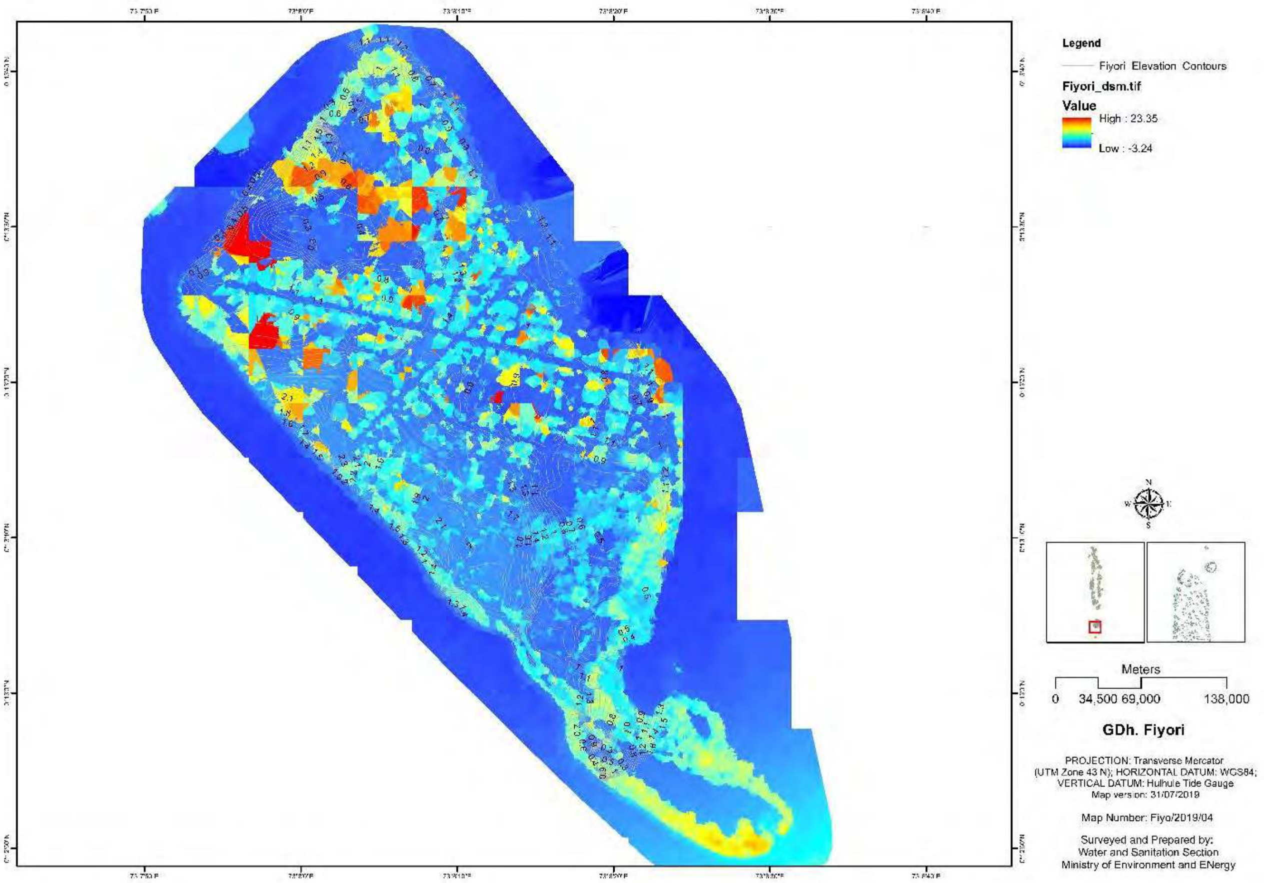


Figure 14.2: Topographic Contour Map of Fiyoari

14.4 Climate

Fiyoaree experiences the typical two monsoons namely, north east monsoon from November to April and South-west monsoons from April to November. There are no specific wind and rainfall data available for Fiyoaree as there are no weather monitoring stations on the island.

14.5 Demography

Via the 2014 Census Fiyoaree has a registered population of 737 people, though this figure may be inaccurate as the island council reports a total population of 1665 people in 2019. For the total population there are 35 more males than females (52% of the population). This gap shrinks to only 7 people when only the Maldivian population is considered, as the foreign population is predominantly male (79% of them being male).The following table and graphs illustrate the demographic breakdown of Fiyoaree.

Table 14.2: Demographic Breakdown of Fiyoari Island

Atoll	locality	Resident population (Census, 2014)								
		Total			Maldivians			Foreigners		
		Both sexes	Male	Female	Both sexes	Male	Female	Both sexes	Male	Female
GDh	Fiyoaree	737	386	351	689	348	341	48	38	10

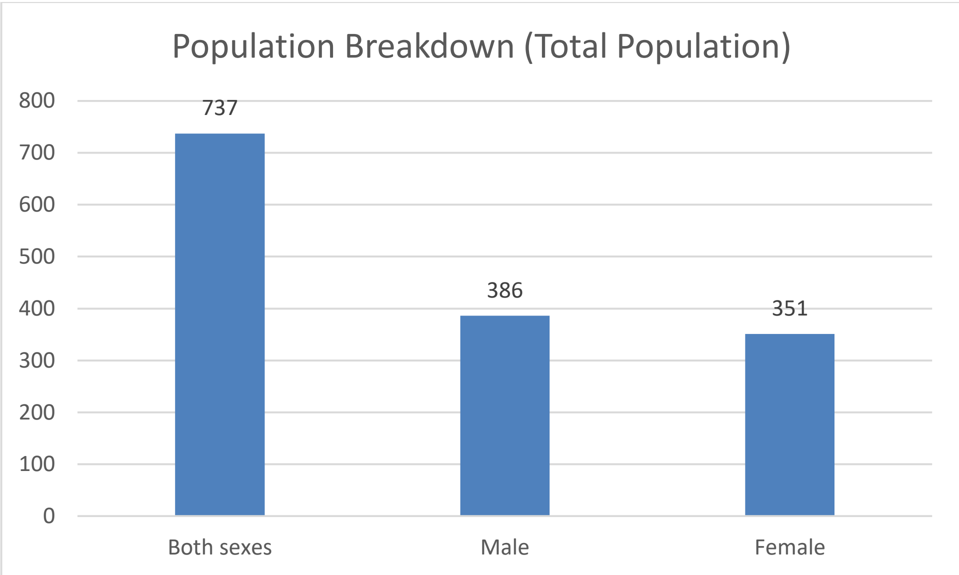


Figure 14.3: Population breakdown of Fiyoari (Maldivians & Foreigners)

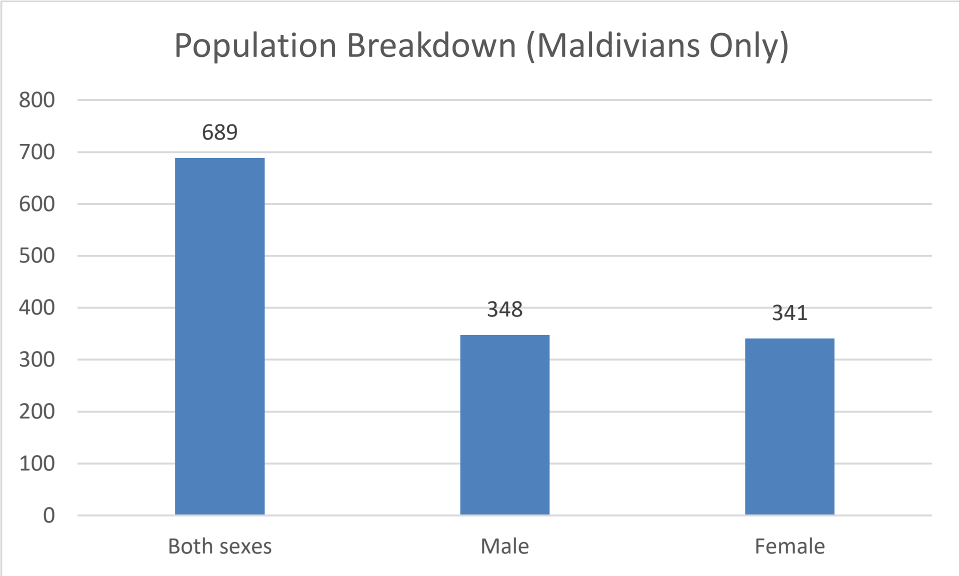


Figure 14.4: Population breakdown of Fiyoari (Maldivians)

14.6 Socio-economic condition

Farming is a significant part of Fiyoaree Island's economy, with several large farms throughout the island.

14.7 Existing water and sanitation situation

The island does not currently have an island wide sewerage system nor a water supply system. The primary form of sanitation on the island is via the use of septic tanks. Each household has one or two septic tanks. 13.6% of the surveyed households clean their septic tanks by periodically disposing the septic waste to sea, while 68.2% of households bury septic waste in other parts of their house plot and island and the remaining claim not to have cleaned their septic tanks. On average, there is an approximate distance of 5.76 meters between septic tanks and nearest well.

The primary source of drinking water is rainwater that is collected in either household or community tanks. The primary source of water used for cooking is also rainwater. As this tends to run out during the dry season for several households, they borrow rainwater from neighbouring houses or take water from the community tanks in the mosques. There are plans for both a water supply system and an island wide sewerage system in the 2019 budget, and rainwater facilities are currently in the process of being established.

14.8 Results

14.8.1 Water sources and water use

Based on domestic, commercial, institutional and industrial water usage, a total of 311,779 liters of groundwater are estimated to be used every day. Otherwise stated, 187 liters of groundwater are used per capita per day. The respective water use situations are detailed in the following sections.

14.8.1.1 Domestic water use situation

Based on the questionnaire to collect data on domestic water consumption, a summary of results are present in this section.

According to the survey, 100% of the households surveyed uses HDPE rainwater tanks as their main storage for water. A total of 82% households use rainwater for drinking and 95.5% use it for cooking. 18% of households use bottled mineral water for drinking. None of the surveyed houses use rainwater for bathing or washing.

None (0%) of the households use groundwater as drinking. Groundwater is mainly used for non-potable use in all the households surveyed, apart from one single house which uses groundwater for cooking. The following table summarizes the groundwater and rainwater use data for Fiyoari Island.

Table 14.3: Groundwater and rainwater use data for Fiyoari

Rainwater	
Households with rainwater tanks	100%
Rainwater use for drinking	82%
Rainwater use for cooking	95.5%
Rainwater use for bathing and washing	0%
Groundwater	
Groundwater as drinking source	0%
Groundwater for cooking	4.5%
Groundwater for non-potable use	100%
Total number of households surveyed	(10.05%)
Percentage of wells surveyed fitted with pumps	95.5%

Based on the survey questionnaire, average daily water demand per capita for domestic purposes has been estimated based on the average amount of water used per person for showering, toilet flushing, laundry and gardening, this data is shown in table 14.4. The total domestic water use is estimated to be 182 liters per capita per day.

Table 14.4: Domestic Water Usage in Fiyoari

Shower/ Liters per capita per day	Toilet/ Liters per capita per day	Laundry/ Liters per capita per day	Gardening/ Liters per capita per day	Total/ Liters per capita per day
122	29	10	21	**182**

14.8.1.2 Commercial water use situation

Based on the questionnaire to collect data on commercial water consumption, a summary of results are present in this section. Based on information from the island council, Fiyoari has a total of 3 restaurants and 0 guesthouses. 2 restaurants were surveyed.

For the restaurants, the main use of groundwater was for mopping, gardening, dishwashing and toilet use. From the survey data, the total groundwater consumption for 2 restaurants was estimated to be 709 liters per day, therefore the total commercial groundwater consumption for the island considering 3 restaurants is 1063 liters per day.

14.8.1.3 Institutional water use situation

Based on the questionnaire to collect data on institutional water consumption, a summary of results are present in this section. Three institutions were surveyed for this study namely the school, health center and council office. Groundwater in the institutions in Fiyoari Island are mainly used for gardening, mopping floors and flushing toilets. Additionally, the health center also uses groundwater for laundering. A total of approximately 1075 liters of groundwater are estimated to be used per day by the institutions. Therefore, a total of approximately 0.65 liters of groundwater are estimated to be used per capita per day by the institutions of Fiyoari Island.

Table 14.5: Water Usage in Institutions in Fiyoari

	Water Flushed (Liters per	Gardening (Liters per day)	Mopping (Liters per day)	Laundry (L)	Total Water Usage (Liters per day)	Institutional Groundwater Usage (Liters per day)	Institutional Groundwater Usage (Liters per capita per day)
School	552	-	30	-	582	1075	0.65
Health Center	157	180	80	76	493		
Council	0.00	-	-	-	-		

14.8.1.4 Industrial water use situation

There are farms on the South East and North West of the island, having a total area of 52,600 square meters. The size of one designated farmland ranges from approximately 236 square meters to 1520 square meter, averaging 836 square meters. Most farmers use water hose connected to the well through pumps for irrigation. All farms used groundwater. 6790 liters of groundwater are estimated to be used every day for farming.

14.8.2 Groundwater quality

Groundwater quality measurements were made at selected wells in Fiyoari for both physical and microbiological testing.

The following Table 14.6 summarizes the water quality results.

Table 14.6: Summary of groundwater quality tests from Fiyoari, July 2019

Sample No	Odour	Physical Appearance
gw1	yes	Clear with particles
gw2	yes	Clear with particles
gw3	yes	Clear with particles
gw4	yes	Clear with particles
gw5	yes	Clear with particles
gw6	yes	Clear with particles
gw7	no	Clear with particles
gw8	no	Clear with particles
gw9	no	Clear with particles
gw10	no	Pale yellow with particles
gw11	no	Clear with particles
gw12	yes	Brown with particles

Sample No	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
gw1	1107.8	660	7.29	0.33	1.48	29.7	0.5	8.5	1.74	0.33		
gw2	1057.7	646	7.37	7.65	2.29	28.4	0.49	5.8	5.7	0.14		
gw3	1278.2	706	7.33	1.68	3.54	34.2	0.53	7.6	2.46	0.15	>2420	>2420
gw4	921.2	561	7.51	0.15	5.18	28.6	0.42	22.1	1.14	0.14		
gw5	1599.8	914	7.47	0.84	1.35	32.2	0.69	11.5	1.66	0.23	34	15
gw6	311.3	183	7.98	0.48	2.95	30.4	0.13	1.7	1.05	0.25		
gw7	578.7	344	7.59	0.00	3.87	29.9	0.25	5.3	0.12	0.51		
gw8	669.3	397	7.36	0.93	2.17	30.1	0.29	3.2	0.4	0.11	205	20
gw9	1183.2	684	7.19	0.07	2.65	31.6	0.51	57.1	0.58	1.38		
gw10	839.8	492	8.29	1.75	8.91	30.8	0.36	8.5	0.52	0.38		
gw11	744.4	437	7.44	0.78	1.68	30.6	0.32	5.0	0.56	0.22	2411	35
gw12	1682.6	1014	7	6.93	2.15	29.2	0.78	7.4	27.46	0.3		

	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)
WHO Standards	Suggested maximum limit of freshwater for potable purposes = 1500 µS/cm Suggested maximum limit of freshwater for non-potable purposes = 2500 µS/cm	-	-	-	-	-

	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
WHO Values	-	Guideline Value = 50 mg/L-NO3	Natural Level of Ammonia < 0.2 mg/L Threshold odour concentration = 1.5 mg/L Taste threshold = 35 mg/L	-	-	-

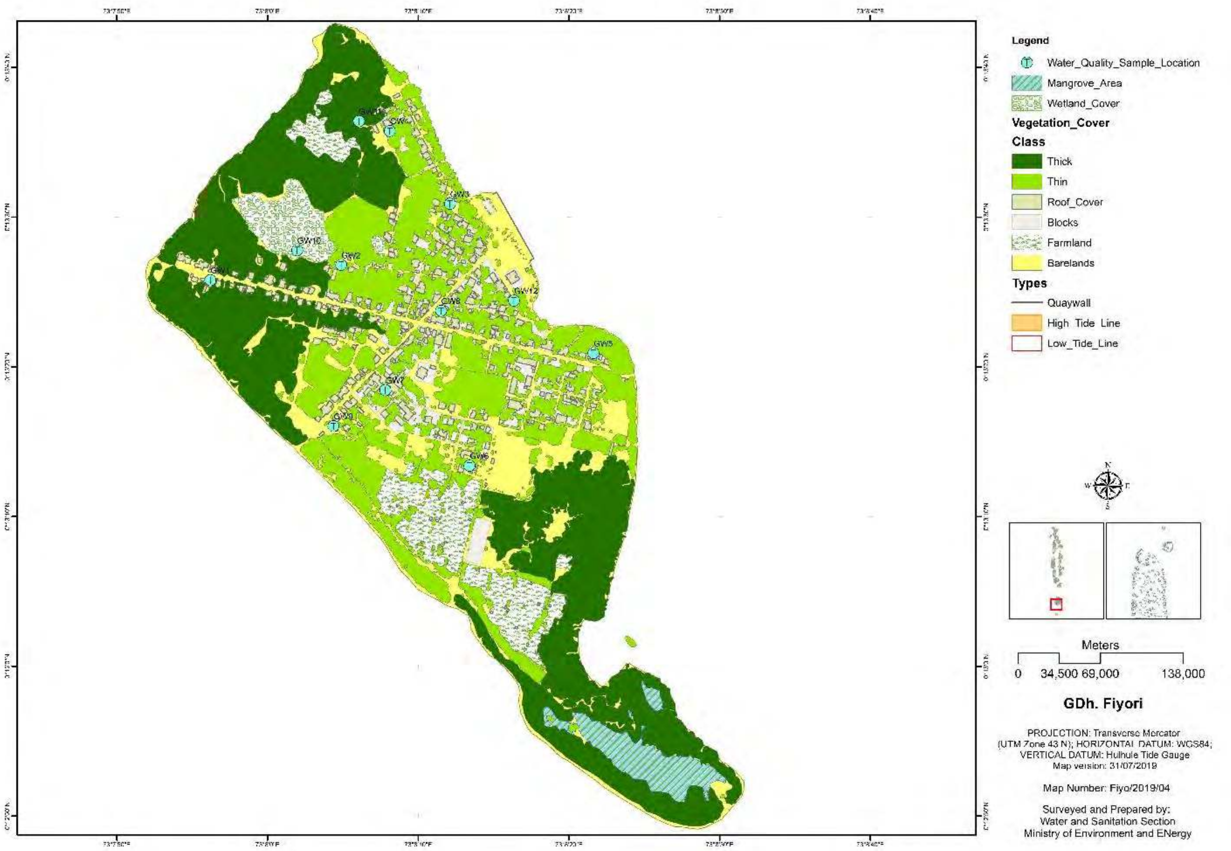


Figure 14.5: Location of groundwater sampling points in Fiyoari Island

Based on the full results and the summary shown in Table 14.6, the following can be summarized for Fiyoari:

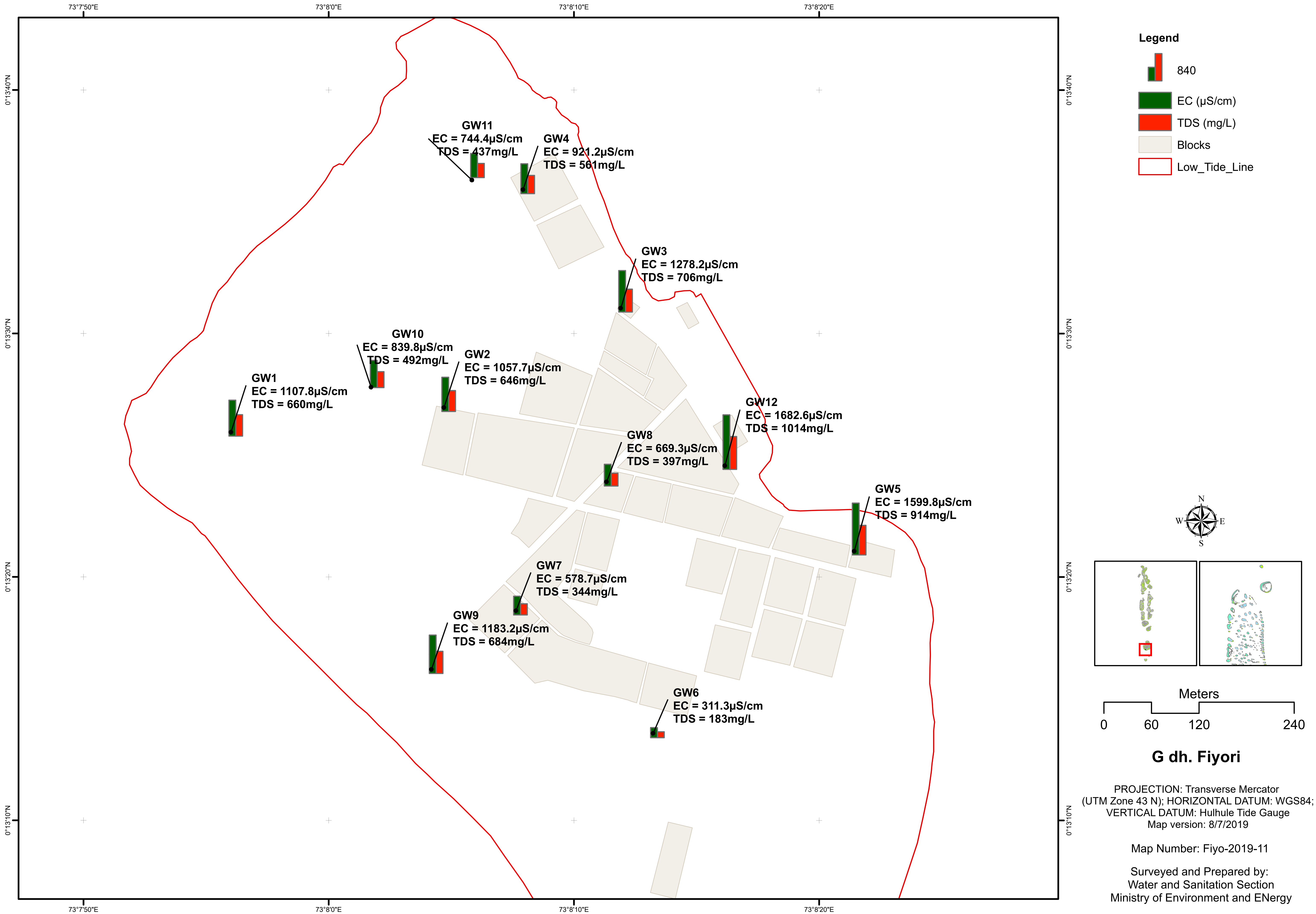
- Sample gw3 was taken from a mosque and gw10 from a well nearby the wetland. All other samples were taken from households.
- The average Electrical Conductivity (EC) of the groundwater is 997 µS/cm which is below the acceptable limit for potable water of 1,500 µS/cm (refer section 2.2). The EC of the samples range from 311 µS/cm to 1683 µS/cm. Only 2 samples (gw5 and gw12) have a higher EC than the acceptable limit for potable water. However both of these samples are still below 2500 µS/cm, the maximum limit of freshwater for non-potable purposes (refer section 2.2). These samples have higher EC than others as they were taken less than 40m from the shoreline. The EC of the samples is lower in the center of the island.
- Total Dissolved Solids recorded ranged from 183 mg/L to 1014 mg/L with an average of 587 mg/L.
- The pH of groundwater ranged from 7.0 to 8.29 with an average of 7.49.
- Turbidity ranged from 0 NTU to 7.65 NTU with an average turbidity of 1.80 NTU.
- Dissolved oxygen levels were low to moderate, with values varying from 1.35 to 8.91 mg/L. The average DO level was 3.19 mg/L.
- The salinity of groundwater ranged from 0.13 PSU to 0.78 PSU with an average of 0.44 PSU. Salinity is expressed in Practical Salinity Units, PSU which is equivalent to PPT.
- The average Nitrate concentration was 11.97 mg/L and therefore does not exceed the WHO guideline limit of 50 mg/L. None of the tested water samples exceeded this limit. The Nitrate concentrations ranged from 1.68 mg/L to 57.1 mg/L.
- The average ammonia concentration was 3.62 mg/L and ranged from 0.12 mg/L to 27.46 mg/L. The average ammonia concentration exceeds the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. Sample gw12 had a significantly higher concentration of ammonia at 27.46 mg/L. The average ammonia concentration excluding

gw12 was 1.45 mg/L which does not exceed the WHO guideline value of maximum ammonia concentration.

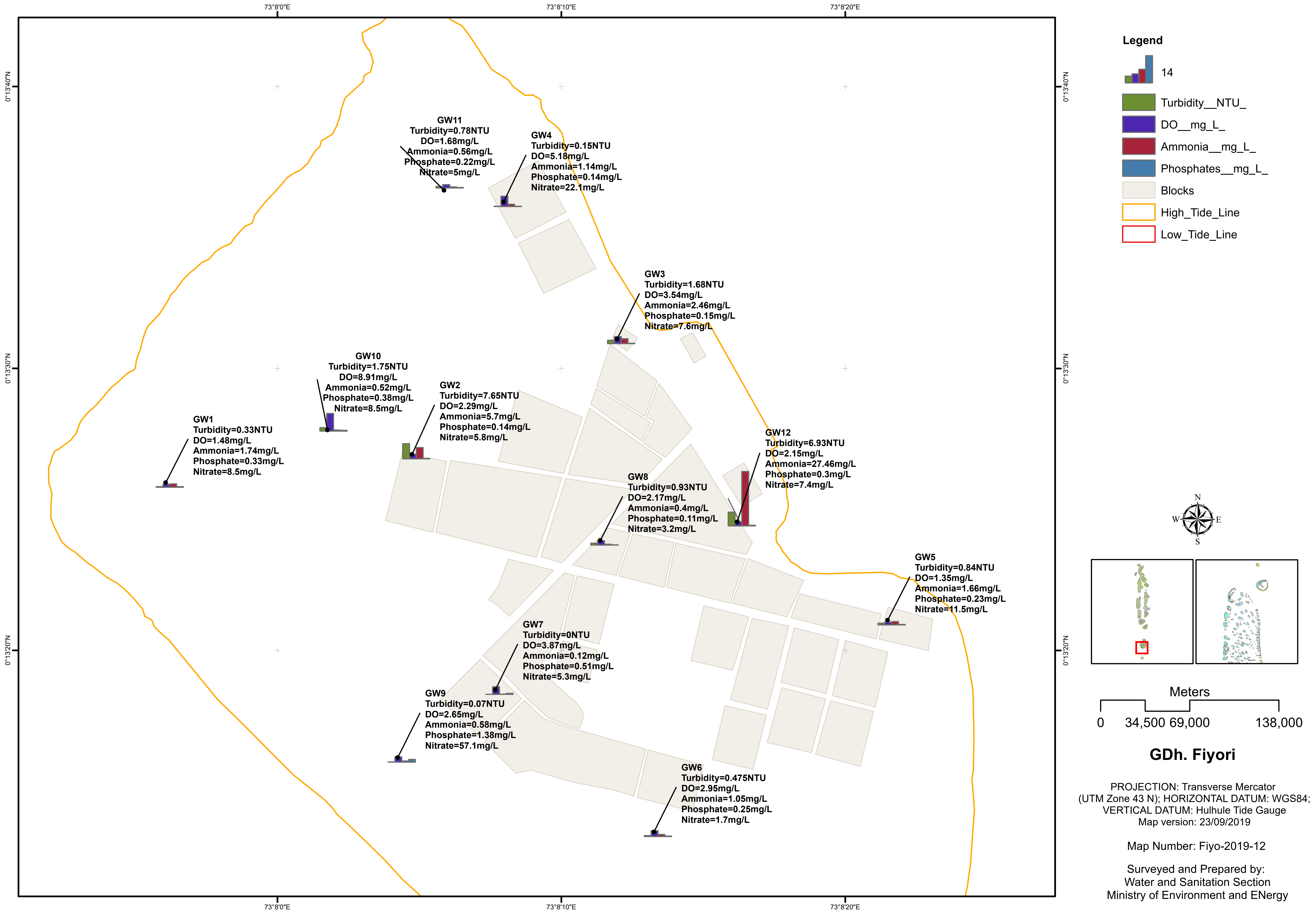
- Phosphate concentrations ranged from 0.11 mg/L to 1.38 mg/L with an average of 0.35 mg/L. There is no WHO drinking water guideline value for phosphate. However, it would normally be expected that phosphate concentrations in groundwater are less than 0.1 mg/L, where there are no impacts from human wastewater (e.g. effluent from septic tanks and 'greywater' from kitchens and bathrooms). None of the samples tested had Phosphate concentrations below 0.1 mg/L.
- Total coliform levels were found to be significant and ranged from lowest count of 34 MPN/100mL to the highest count of more than 2420 MPN/100mL, with an average count of 1268 MPN/100mL. Faecal coliform levels ranged from lowest count of 15 MPN/100 mL to the highest count of more than 2420 MPN/100mL, with an average count of 623 MPN/100mL. As expected, the groundwater layer is contaminated with effluent from septic tanks. Sample gw3 which was taken from mosque well was observed to have higher contamination than other samples taken from residential areas.

In conclusion, Fiyoari Island contains groundwater with generally low Electrical Conductivity and TDS, low turbidity and Nitrate concentration lower than WHO maximum guidance value but Phosphate and Ammonia concentrations higher than expected in natural, undisturbed groundwater. In terms of microbiological contamination, all the water sampled in Fiyoari Island was found to be contaminated.

Additionally, the following pages contain maps which show the main physiochemical parameters displayed on map of the island.



73°7'50"E
73°8'0"E
73°8'10"E
73°8'20"E
0°13'40"N
0°13'30"N
0°13'20"N
0°13'10"N
GW11
EC = 744.4µS/cm
TDS = 437mg/L
GW4
EC = 921.2µS/cm
TDS = 561mg/L
GW3
EC = 1278.2µS/cm
TDS = 706mg/L
GW10
EC = 839.8µS/cm
TDS = 492mg/L
GW2
EC = 1057.7µS/cm
TDS = 646mg/L
GW1
EC = 1107.8µS/cm
TDS = 660mg/L
GW12
EC = 1682.6µS/cm
TDS = 1014mg/L
GW8
EC = 669.3µS/cm
TDS = 397mg/L
GW5
EC = 1599.8µS/cm
TDS = 914mg/L
GW7
EC = 578.7µS/cm
TDS = 344mg/L
GW9
EC = 1183.2µS/cm
TDS = 684mg/L
GW6
EC = 311.3µS/cm
TDS = 183mg/L
Legend
840
EC (µS/cm)
TDS (mg/L)
Blocks
Low_Tide_Line
N
W
E
S
Meters
0
60
120
240
G dh. Fiyori
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/7/2019
Map Number: Fiyo-2019-11
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


73°8'0"E
73°8'10"E
73°8'20"E
0°13'40"N
0°13'30"N
0°13'20"N
GW11
Turbidity=0.78NTU
DO=1.68mg/L
Ammonia=0.56mg/L
Phosphate=0.22mg/L
Nitrate=5mg/L
GW4
Turbidity=0.15NTU
DO=5.18mg/L
Ammonia=1.14mg/L
Phosphate=0.14mg/L
Nitrate=22.1mg/L
GW3
Turbidity=1.68NTU
DO=3.54mg/L
Ammonia=2.46mg/L
Phosphate=0.15mg/L
Nitrate=7.6mg/L
GW10
Turbidity=1.75NTU
DO=8.91mg/L
Ammonia=0.52mg/L
Phosphate=0.38mg/L
Nitrate=8.5mg/L
GW2
Turbidity=7.65NTU
DO=2.29mg/L
Ammonia=5.7mg/L
Phosphate=0.14mg/L
Nitrate=5.8mg/L
GW1
Turbidity=0.33NTU
DO=1.48mg/L
Ammonia=1.74mg/L
Phosphate=0.33mg/L
Nitrate=8.5mg/L
GW12
Turbidity=6.93NTU
DO=2.15mg/L
Ammonia=27.46mg/L
Phosphate=0.3mg/L
Nitrate=7.4mg/L
GW8
Turbidity=0.93NTU
DO=2.17mg/L
Ammonia=0.4mg/L
Phosphate=0.11mg/L
Nitrate=3.2mg/L
GW5
Turbidity=0.84NTU
DO=1.35mg/L
Ammonia=1.66mg/L
Phosphate=0.23mg/L
Nitrate=11.5mg/L
GW7
Turbidity=0NTU
DO=3.87mg/L
Ammonia=0.12mg/L
Phosphate=0.51mg/L
Nitrate=5.3mg/L
GW9
Turbidity=0.07NTU
DO=2.65mg/L
Ammonia=0.58mg/L
Phosphate=1.38mg/L
Nitrate=57.1mg/L
GW6
Turbidity=0.475NTU
DO=2.95mg/L
Ammonia=1.05mg/L
Phosphate=0.25mg/L
Nitrate=1.7mg/L
Legend
14
Turbidity__NTU_
DO__mg_L_
Ammonia__mg_L_
Phosphates__mg_L_
Blocks
High_Tide_Line
Low_Tide_Line
N
W
E
S
Meters
0 34,500 69,000 138,000
GDh. Fiyori
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 23/09/2019
Map Number: Fiyo-2019-12
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

14.8.3 Geophysical survey

The Resistivity tests were carried out in the locations as outlined in Figure 14.6 below.

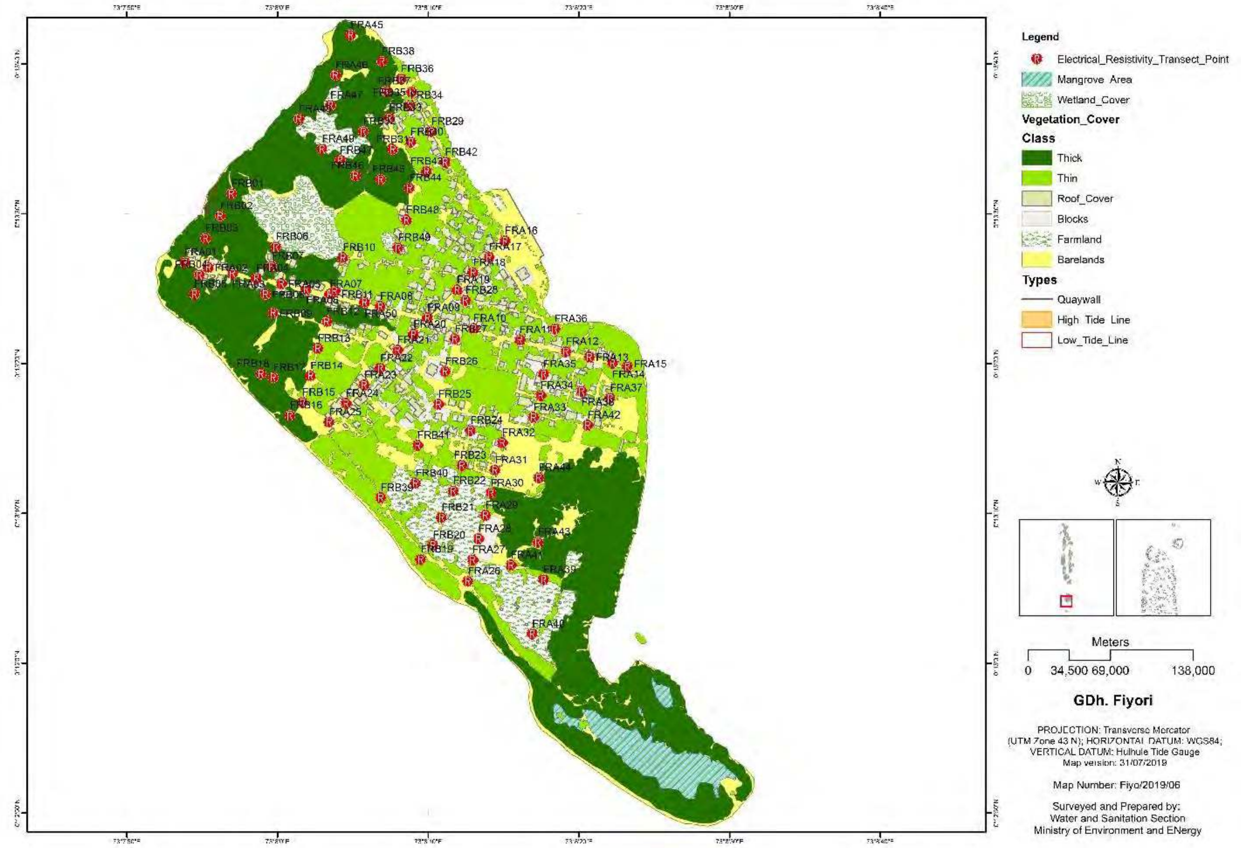


Figure 14.6: Location of ER points in Fiyoari Island

14.8.4 Aerial surveys

Based on the aerial survey, a multiple dataset consisting of roof cover, thick vegetation area, thin vegetation area, bare lands and shorelines were extracted. This data is shown in Figure 14.7 and the Table 14.7 shows the different area distribution.

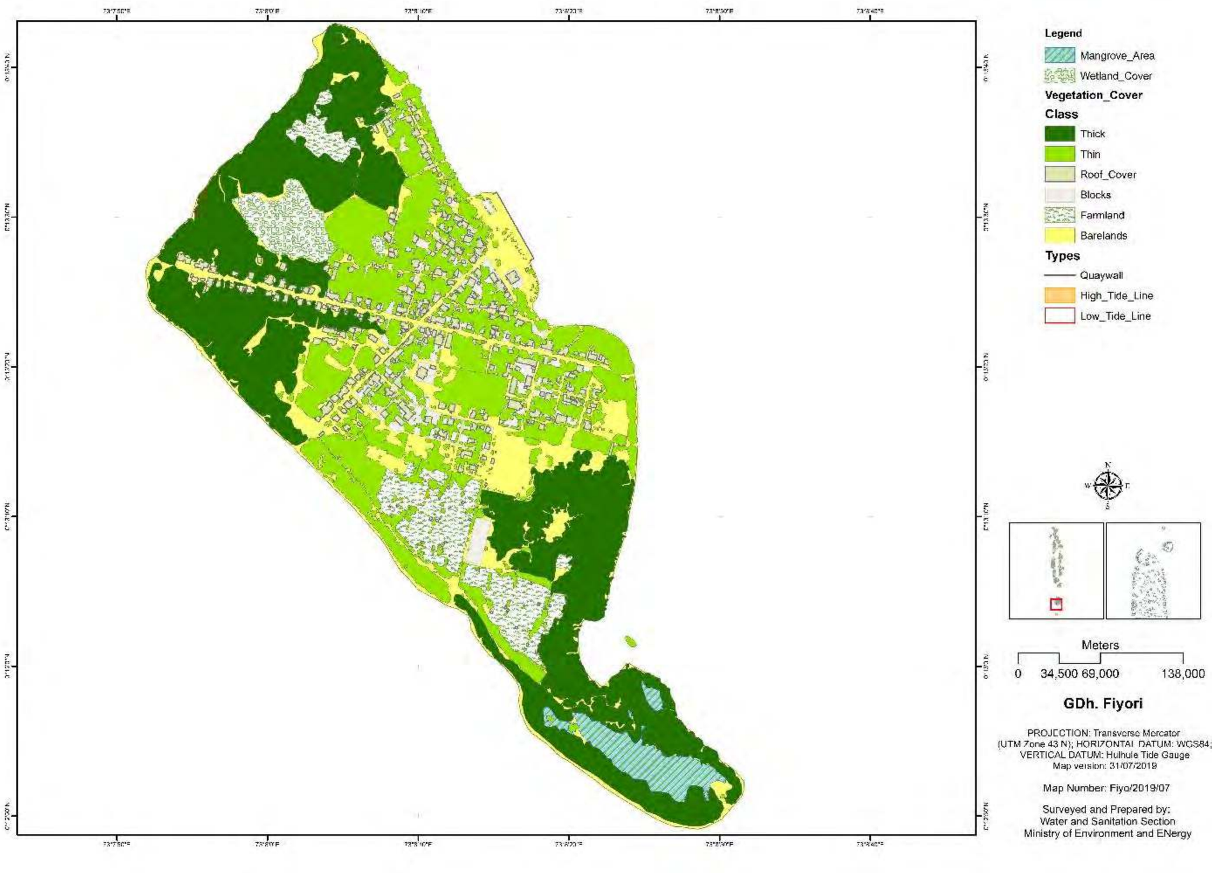


Figure 14.7: Area Distribution in Fiyoari Island

Table 14.7: Area Distribution in Fiyoari

	Area (Square Meters)	Percentage (%) of total area
Roof cover	46,751	5.80%
Vegetation (Thick)	290,535	36.03%
Vegetation (Light)	209,532	25.99%
Bare lands	164,103	20.35%
Farm Lands	52,636	6.53%
Wetlands (Inland)	20,711	2.57%
Mangrove	22,074	2.74%

14.8.5 Water Demand

The only source of natural water is rainwater collected from the rooftops of households and institutions and groundwater extracted from shallow wells.

14.8.6 Freshwater lens

Based on the ER survey the depth to groundwater level and the freshwater-saline water interface was determined for a set of transverse transects as shown in Figure 14.8. Plots in the Figure 14.9 shows the cross sections of each transect line. The dotted lines in the plots indicating a simple interpolation of levels to mean sea level in the island boundaries. These cross sections were used to identify the spatial extent and volume of the freshwater lens while they were also useful in deriving implications on the stress level of the aquifer based on the observed, localized drawdown effect in the groundwater table and up-coning in the freshwater-saline interface, defining the upper and lower boundaries of the freshwater lens in an island.

The The area covered by freshwater for each transect line has been calculated. To estimate the total volume of available freshwater lens, the cross-section area of freshwater extent under each transect was multiplied by the distance between two transects. The sum of these lengths represents the cumulative length of the island and thus, the above estimation could represent the total volume of the freshwater lens sandwiched between the groundwater table on top and freshwater-saline water interface in the bottom. Then the actual groundwater storage within this freshwater lens was calculated by multiplying the estimated total lens volume with the porosity of the topsoil in the island.

This estimation represents the total available freshwater volume within the freshwater lens at any given time (time of the measurement). The measurements were carried out towards the end of the dry period and the freshwater lens is presumed to be undergoing a ‘stressed’ condition due to continued groundwater abstractions despite reduced recharge in the dry period. Falkland (1994) method can be used to estimate the freshwater lend thickness under salient conditions using average annual rainfall, length and width of the island, and the comparison was used as a measure of stress level of the freshwater lens.

Table 14.8 illustrate the freshwater volume calculation for the island. The area covered by freshwater for each transect line has been calculated. To estimate the total volume of available freshwater lens, the cross-section area of freshwater extent under each transect was multiplied by the distance between two transects. The sum of these lengths represents the cumulative length of the island and thus, the above estimation could represent the total volume of the freshwater lens sandwiched between the groundwater table on top and freshwater-saline water interface in the bottom. Then the actual groundwater storage within this freshwater lens was calculated by multiplying the estimated total lens volume with the porosity of the topsoil in the island.

This estimation represents the total available freshwater volume within the freshwater lens at any given time (time of the measurement). The measurements were carried out towards the end of the dry period and the freshwater lens is presumed to be undergoing a ‘stressed’ condition due to continued groundwater abstractions despite reduced recharge in the dry period. Falkland (1994) method can be used to estimate the freshwater lend thickness under salient conditions using average annual rainfall, length and width of the island, and the comparison was used as a measure of stress level of the freshwater lens.

Table 14.8: Freshwater Volume Calculation for Fiyoari Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
1	Start		0	0	0	0			
			34	0.306	0	0	0		
	FRA40	ER	95	0.856	0.13	-0.94	32		
	FRA39	ER	211	1.028	0.25	-1.37	156		
	FRA42	ER	466	1.013	0.26	-1.41	419		
	FRA37	ER	531	0.786	0.18	-1.02	94		
	FRA14	ER	604	0.971	0.2	-0.87	82		
			642	0.456	0	0	20		
	End		675	0	0	0	0		
	Total						805	137	110028
2	Start		0	0	0	0			

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
			31	1.223	0	0	0		
	FRA26	ER	53	2.067	0.22	-0.38	6		
	FRA27	ER	98	2.052	0.21	-0.39	27		
	FRA28	ER	142	2.035	0.32	-0.66	35		
	FRA29	ER	192	1.882	0.41	-0.59	49		
	FRA30	ER	240	1.599	0.35	-0.87	53		
	FRA31	ER	288	1.278	0.31	-1.1	64		
	FRA32	ER	345	1.093	0.35	-1.48	93		
	FRA33	ER	407	0.863	0.38	-1.46	113		
	FRA34	ER	458	0.845	0.39	-1.64	100		
	FRA35	ER	502	0.885	0.22	-1.78	88		
	FRA36	ER	596	0.749	0.1	-1.08	150		
			612	0.777	0	0	9		
	End		627	0	0	0	0		
	Total						787	139	109081
3	Start		0	0	0	0			
			35	2.271	0	0	0		
	FRB19	ER	35	2.237	0.4	-0.62	0		
	FRB20	ER	70	2.155	0.41	-0.81	40		
	FRB21	ER	130	2.007	0.39	-0.82	73		
	FRB22	ER	190	1.797	0.34	-0.97	76		
	FRB23	ER	245	1.559	0.35	-0.87	69		
	FRB24	ER	318	1.472	0.35	-1.2	102		
	FRB11	ER	526	1.089	0.38	-1.39	345		
			672	0.213	0	0	129		
	End		708	0	0	0	0		
	Total						833	140	116686
4	Start		0	0	0	0			
			33	0.844	0	0	0		
	FRA25	ER	77	1.999	0.38	-0.71	24		
	FRA24	ER	129	1.807	0.4	-0.87	61		
	FRA23	ER	182	1.617	0.34	-0.74	63		
	FRA22	ER	229	1.432	0.51	-1.27	68		
	FRA21	ER	281	1.503	0.43	-1.58	98		
	FRA20	ER	327	1.357	0.46	-1.46	90		
	FRA09	ER	372	1.184	0.42	-1.52	86		
	FRA19	ER	455	1.106	0.41	-1.53	160		
	FRA18	ER	503	1.100	0.35	-0.9	78		
	FRA17	ER	549	0.890	0.16	-1.1	57		
	FRA16	ER	596	0.868	0.11	-0.96	55		

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m²)	Length (m)	Volume (m³)
			619	0.506	0	0	12		
	End		652	0	0	0	0		
	Total						853	166	141634
5	Start		0	0	0	0			
			14	0.977	0	0			
	FRB16	ER	28	1.954	0.31	-0.41	5		
	FRB15	ER	64	2.161	0.4	-0.73	33		
	FRB14	ER	117	1.827	0.39	-1.06	68		
	FRB13	ER	172	1.659	0.38	-1.1	80		
	FRB12	ER	232	0.803	0.3	-1.55	101		
	FRA50	ER	295	0.955	0.32	-1.63	120		
	FRA49	ER	433	0.666	0.15	-1.29	234		
	FRA48	ER	493	1.948	0.31	-0.8	76		
	FRB44	ER	552	0.785	0.3	-1.2	77		
	FRB43	ER	600	0.893	0.32	-1.1	71		
	FRB42	ER	637	0.671	0.3	-0.91	48		
			653	0.314	0	0	10		
	End		667	0	0	0	0		
	Total						922	161	148496
6	Start		0	0	0	0			
			35	0.190	0	0	0		
	FRB08	ER	161	0.884	0.28	-1.21	94		
	FRA04	ER	192	1.004	0.3	-1.17	45		
	FRA07	ER	222	1.083	0.38	-1.39	48		
	FRA46	ER	465	0.514	0.26	-1.25	399		
	FRB31	ER	556	0.764	0.32	-1.2	138		
	FRB34	ER	651	0.733	0.32	-1.2	145		
			660	0.586	0	0	7		
	End		695	0	0	0	0		
	Total						876	142	124397
7	Start		0	0	0	0			
			36	0.349	0	0	0		
	FRA01	ER	104	1.012	0.3	-0.26	19		
	FRB03	ER	170	0.848	0.28	-1.07	63		
	FRB02	ER	223	0.895	0.24	-1.1	72		
	FRB01	ER	277	0.941	0.32	-1.17	76		
	FRA48	ER	478	1.948	0.31	-0.8	261		
	FRA47	ER	538	0.761	0.3	-1.28	80		
	FRA46	ER	596	0.514	0.26	-1.25	89		
	FRA45	ER	685	0.684	0.23	-1.32	137		

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
			702	0.342	0	0	13		
	End		718	0	0	0	0		
	Total						811	93	75531
									825854

Volume of lens = 825,854 m^3

Groundwater Storage = Posity (15%) x Lens volume (m^3)= 123,878 m^3

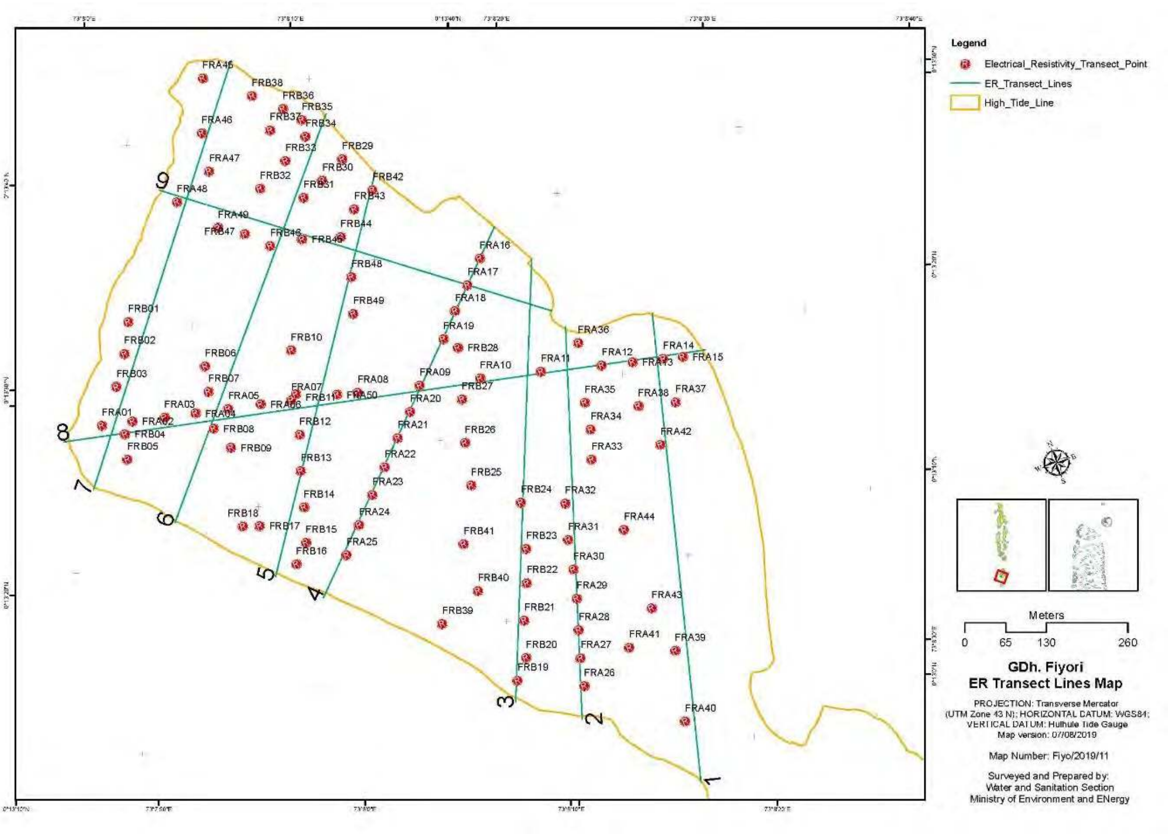
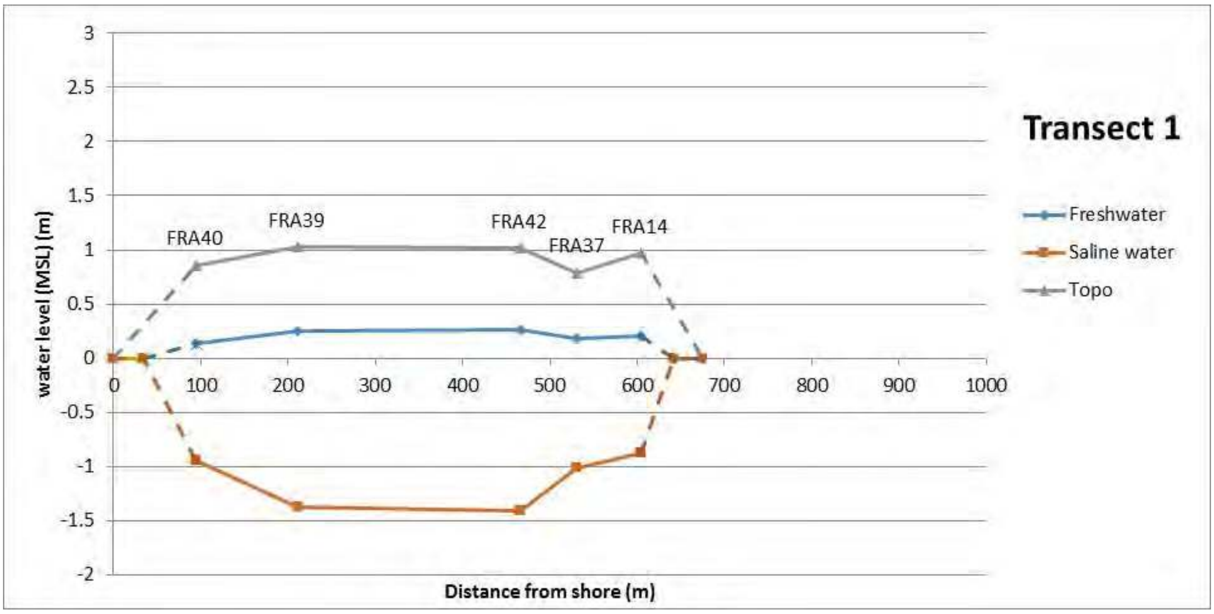
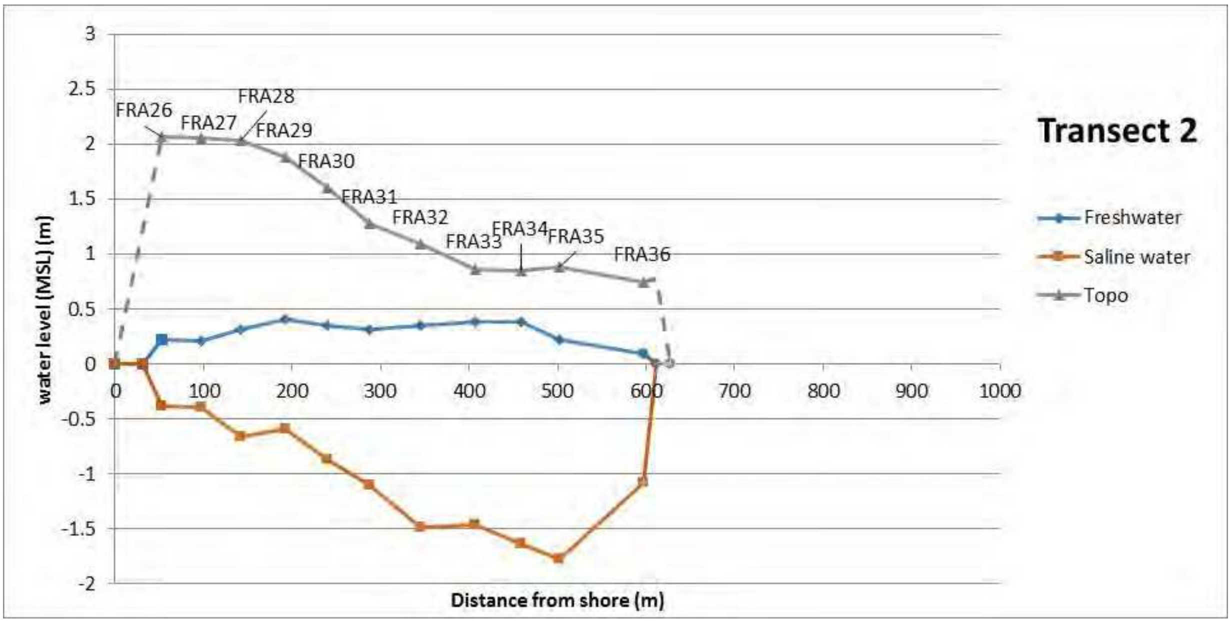


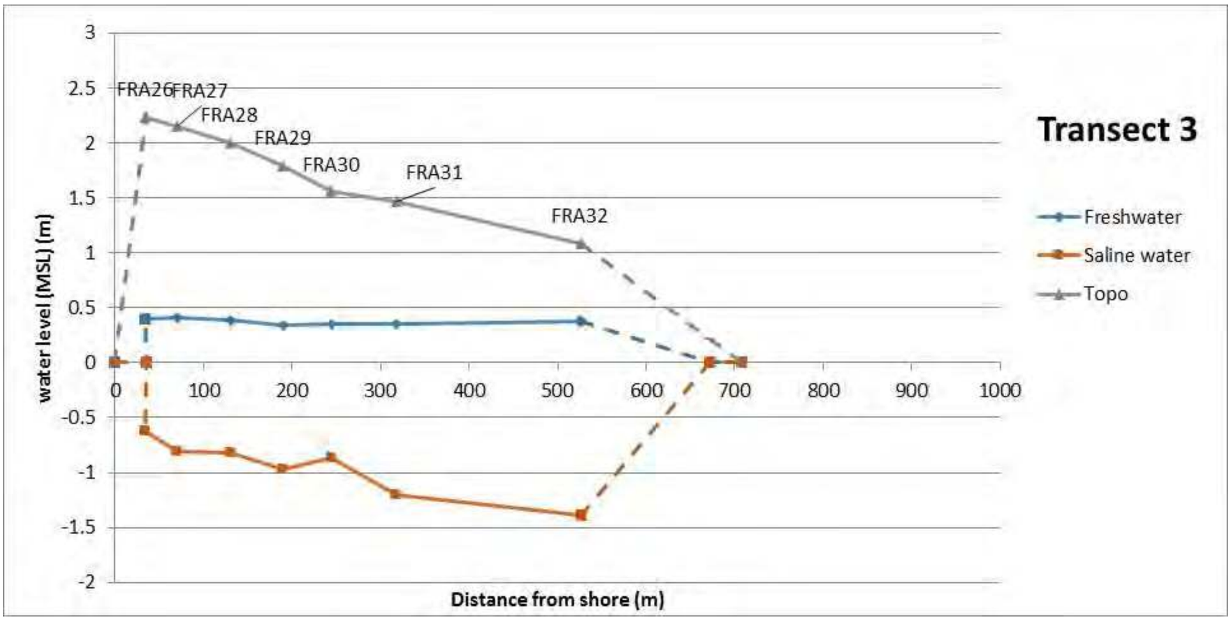
Figure 14.8: ER transect lines in Fiyoari Island

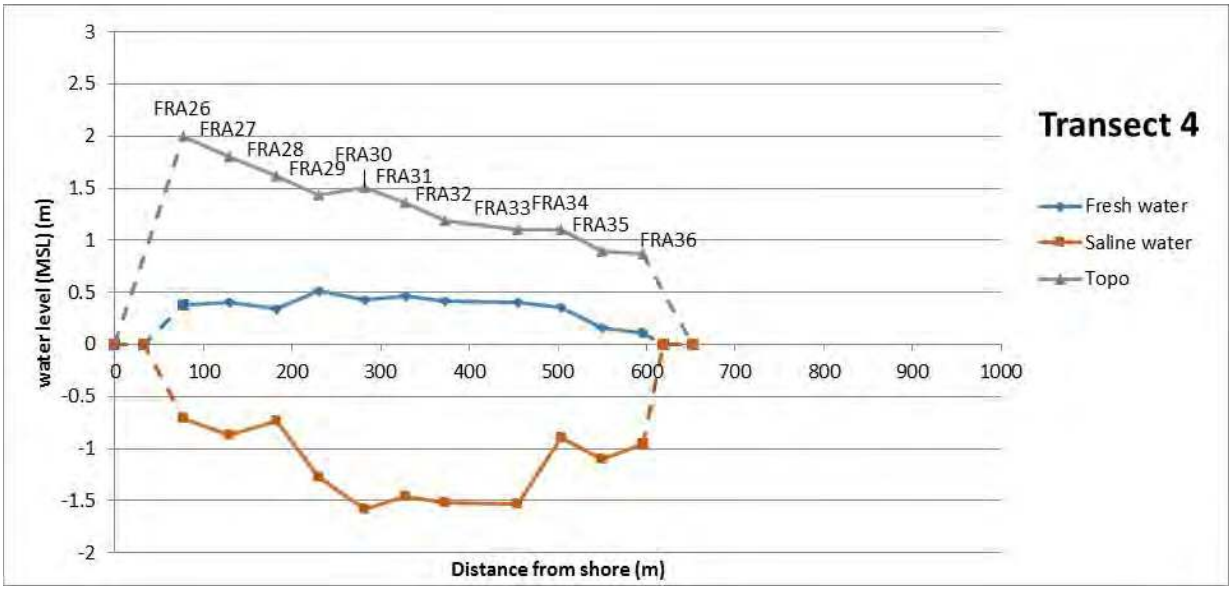
Table 14.9: ER Survey Results of Longitudinal Sections for Fiyoari Island

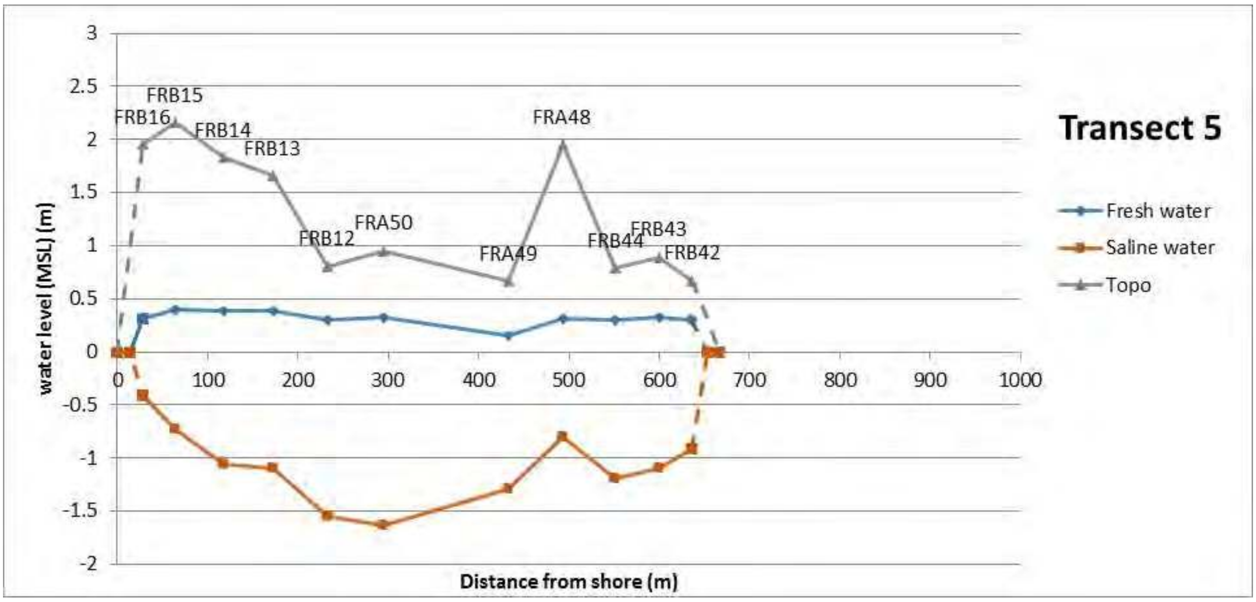
Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)
	Start		0	0	0	0
			49	0.823	0	0
	FRA01	ER	60	1.012	0.3	-0.26
	FRA02	ER	98	0.914	0.28	-1
	FRA03	ER	163	0.870	0.31	-1.03
	FRA04	ER	211	1.004	0.3	-1.17
	FRA05	ER	262	1.083	0.39	-1.35
	FRA06	ER	316	1.165	0.41	-1.2
	FRA07	ER	367	1.083	0.38	-1.39
8	FRA50	ER	439	0.955	0.32	-1.63
	FRA08	ER	474	1.044	0.31	-1.62
	FRA09	ER	570	1.184	0.42	-1.52
	FRA10	ER	670	0.896	0.3	-1.6
	FRA11	ER	769	0.826	0.25	-1.32
	FRA13	ER	867	0.763	0.22	-1.18
	FRA14	ER	916	0.971	0.2	-0.87
	FRA15	ER	947	1.250	0.18	-1
			965	0.625	0	0
	End		984	0	0	0
	Start		0	0	0	0
			33	2.080	0	0
	FRA48	ER	31	1.948	0.31	-0.8
	FRA49	ER	106	0.666	0.15	-1.29
	FRA47	ER	148	0.761	0.3	-1.28
9	FRA46	ER	196	0.514	0.26	-1.25
	FRA45	ER	239	0.684	0.23	-1.32
	FRA44	ER	297	0.628	0.2	-1.65
	FRA17	ER	514	0.890	0.16	-1.1
			622	0.208	0	0
	End		654	0	0	0

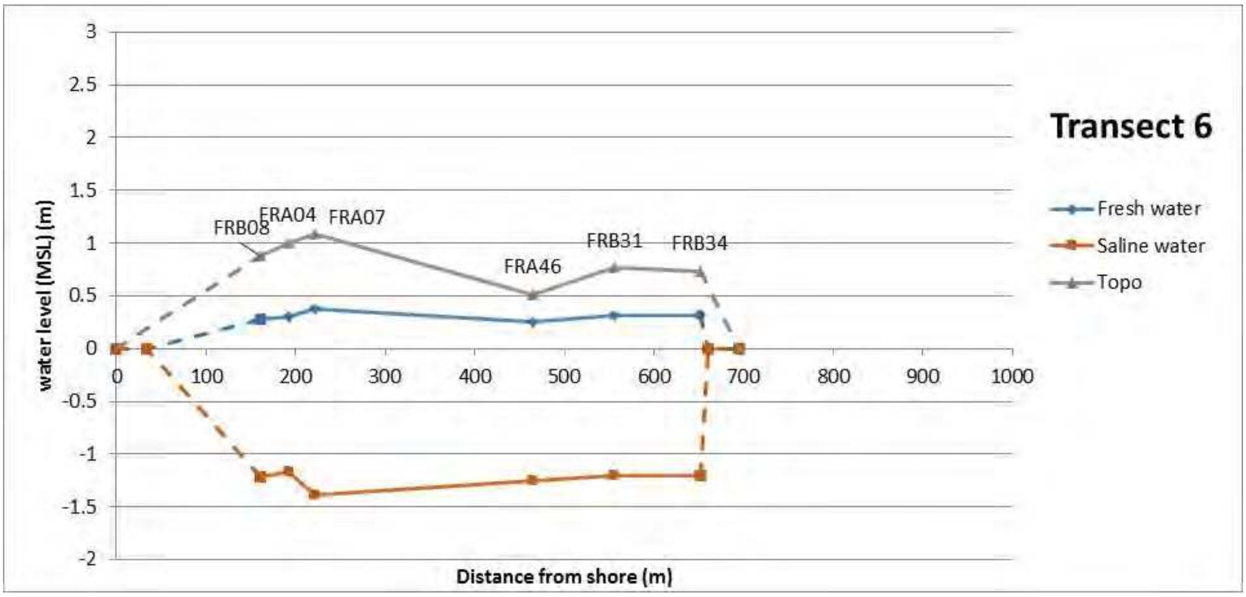

Transcect 1
Freshwater
Saline water
Topo
FRA40
FRA39
FRA42
FRA37
FRA14
water level (MSL) (m)
Distance from shore (m)

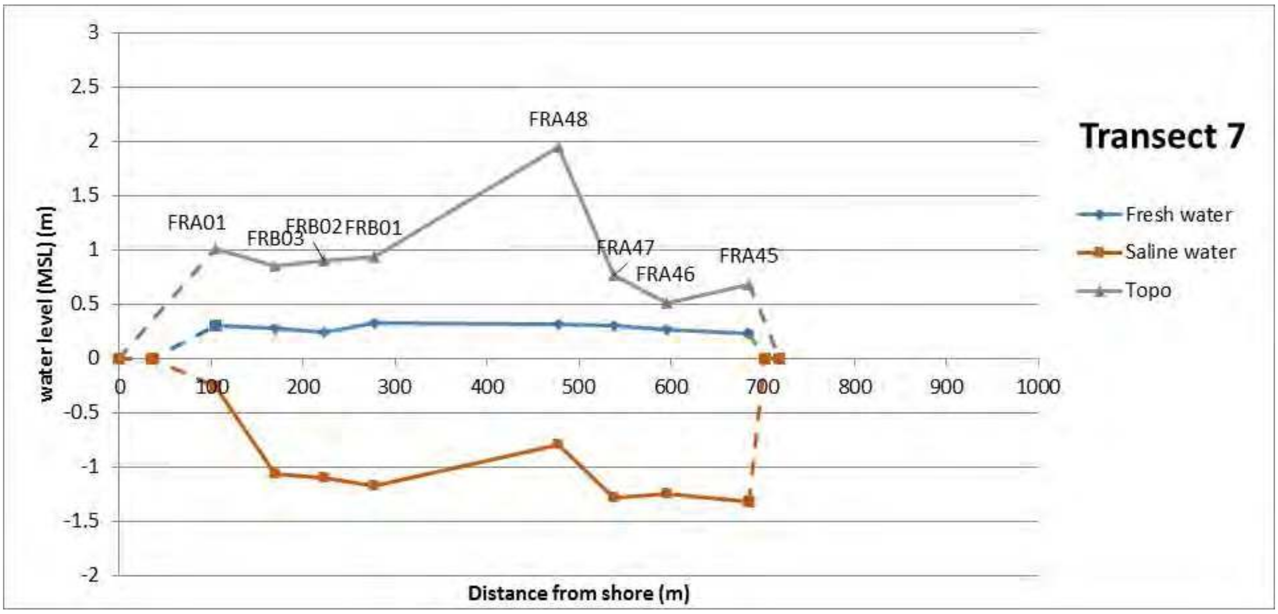

Transect 2
Freshwater
Saline water
Topo
FRA26
FRA27
FRA28
FRA29
FRA30
FRA31
FRA32
FRA33
FRA34
FRA35
FRA36
water level (MSL) (m)
Distance from shore (m)

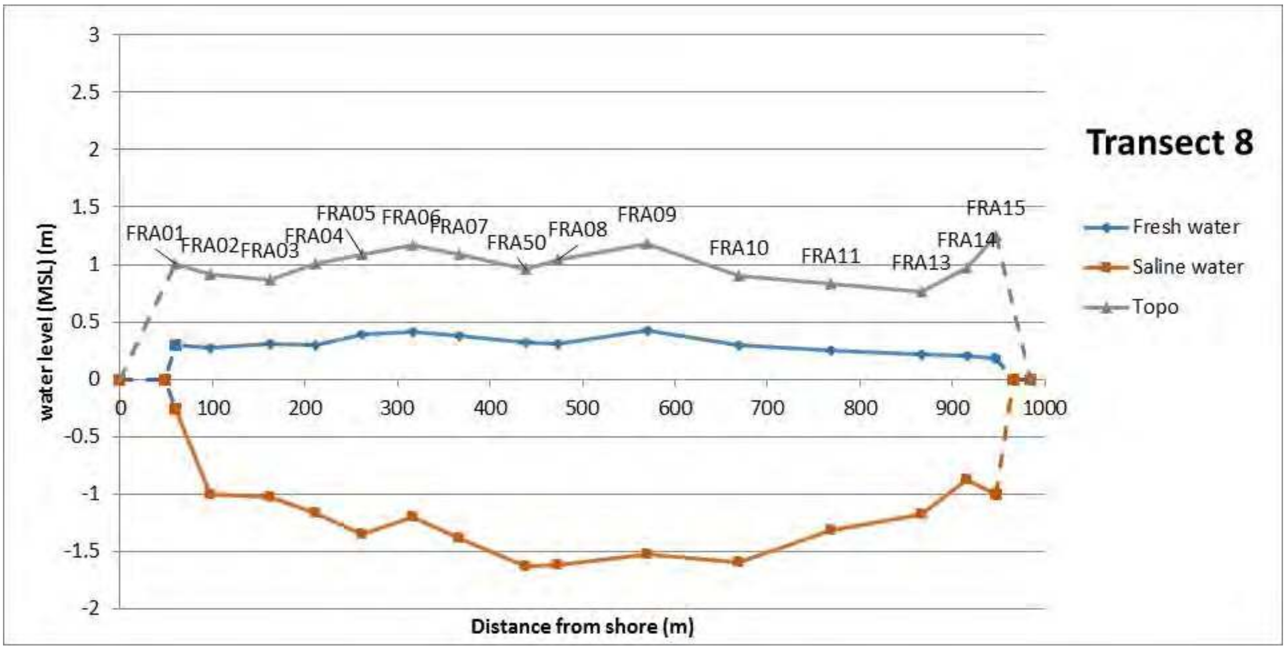

Transect 3
Freshwater
Saline water
Topo
FRA26
FRA27
FRA28
FRA29
FRA30
FRA31
FRA32
water level (MSL) (m)
Distance from shore (m)


Transect 4
Fresh water
Saline water
Topo
FRA26
FRA27
FRA28
FRA29
FRA30
FRA31
FRA32
FRA33
FRA34
FRA35
FRA36
water level (MSL) (m)
Distance from shore (m)


Transect 5
Fresh water
Saline water
Topo
FRB15
FRB16
FRB14
FRB13
FRB12
FRA50
FRA49
FRA48
FRB44
FRB43
FRB42
water level (MSL) (m)
Distance from shore (m)


Transect 6
Fresh water
Saline water
Topo
FRB08
FRA04
FRA07
FRA46
FRB31
FRB34
water level (MSL) (m)
Distance from shore (m)


Transect 7
water level (MSL) (m)
Distance from shore (m)
Fresh water
Saline water
Topo
FRA01
FRB03
FRB02
FRB01
FRA48
FRA47
FRA46
FRA45


Transect 8
water level (MSL) (m)
Distance from shore (m)
Fresh water
Saline water
Topo
FRA01
FRA02
FRA03
FRA04
FRA05
FRA06
FRA07
FRA50
FRA08
FRA09
FRA10
FRA11
FRA13
FRA14
FRA15

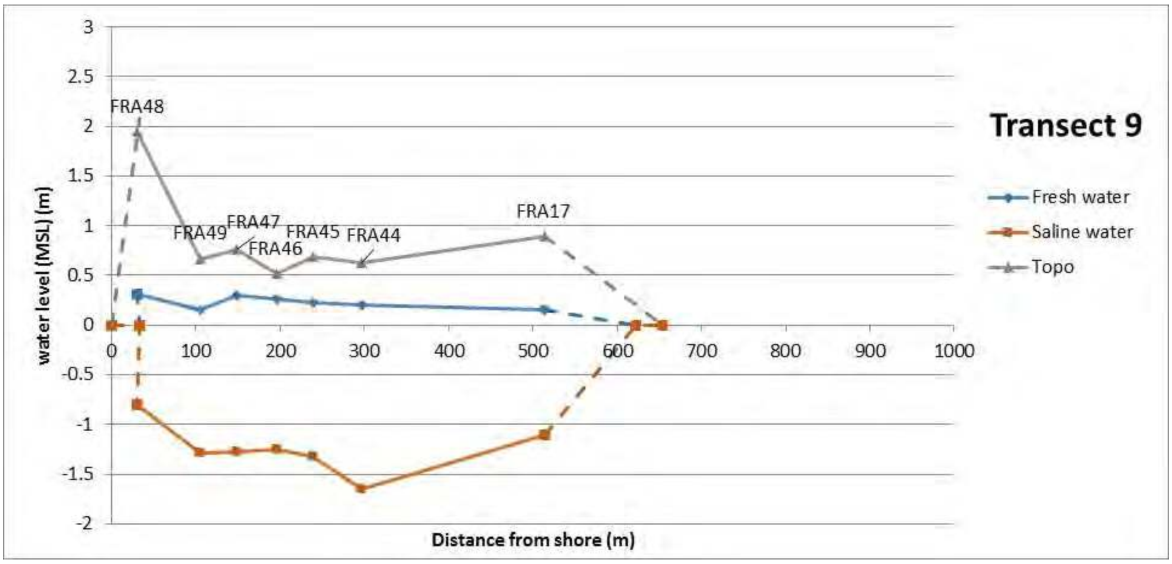


Figure 14.9: Cross-sections of transect lines in Fiyoari Island

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented below.

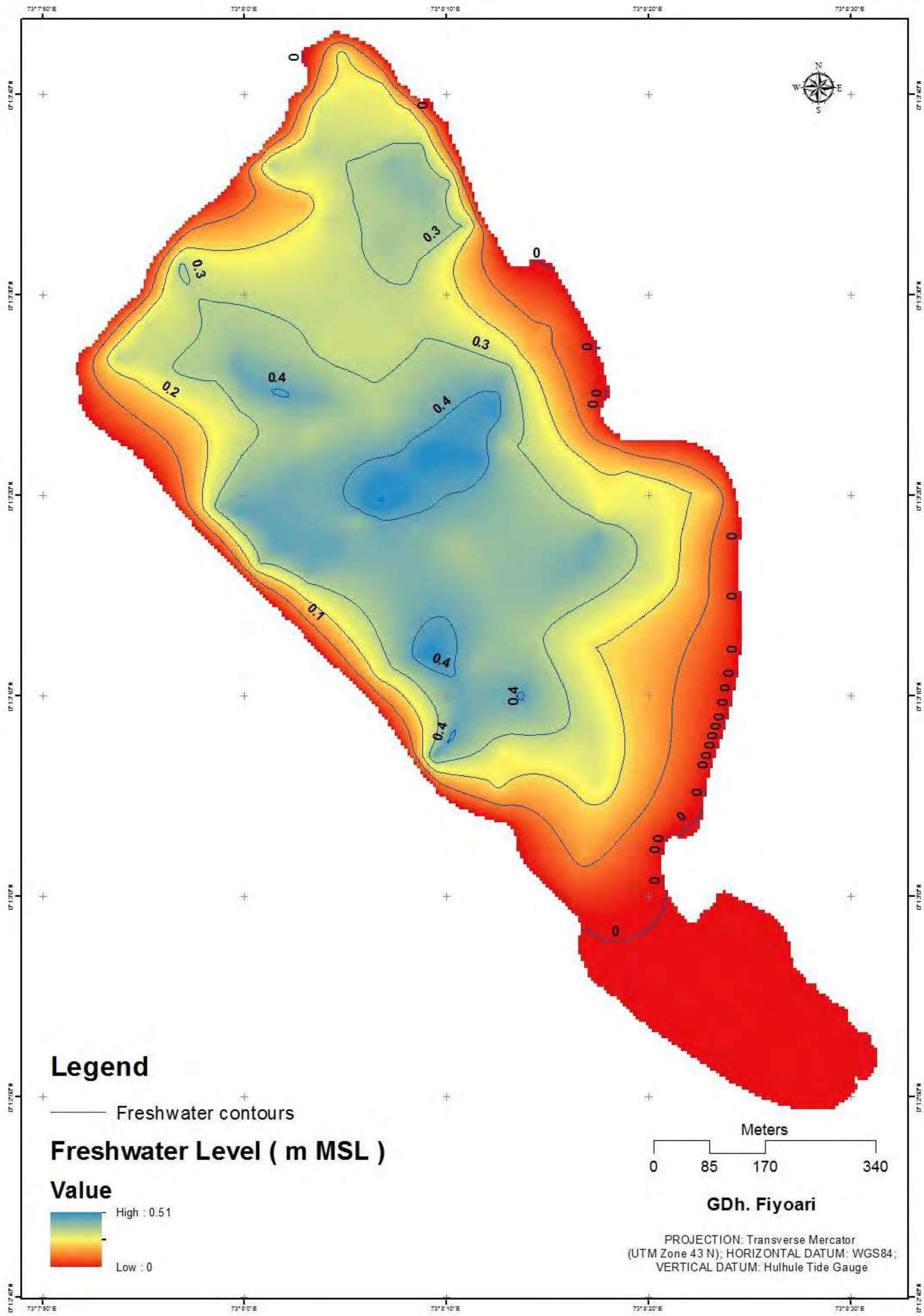


Figure 14.10: Freshwater Level in Fiyoari Island

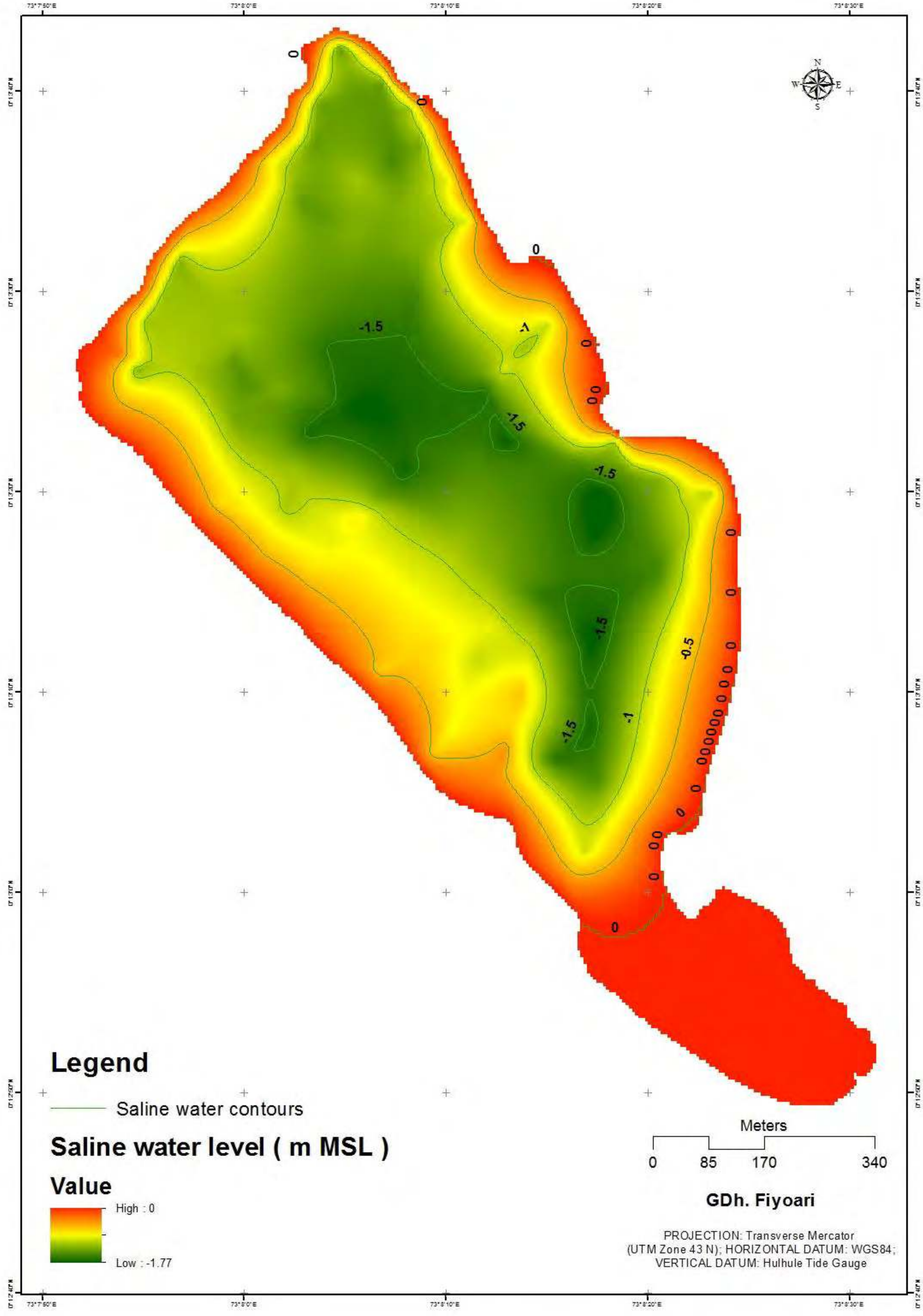


Figure 14.11: Saline water Level in Fiyoari Island

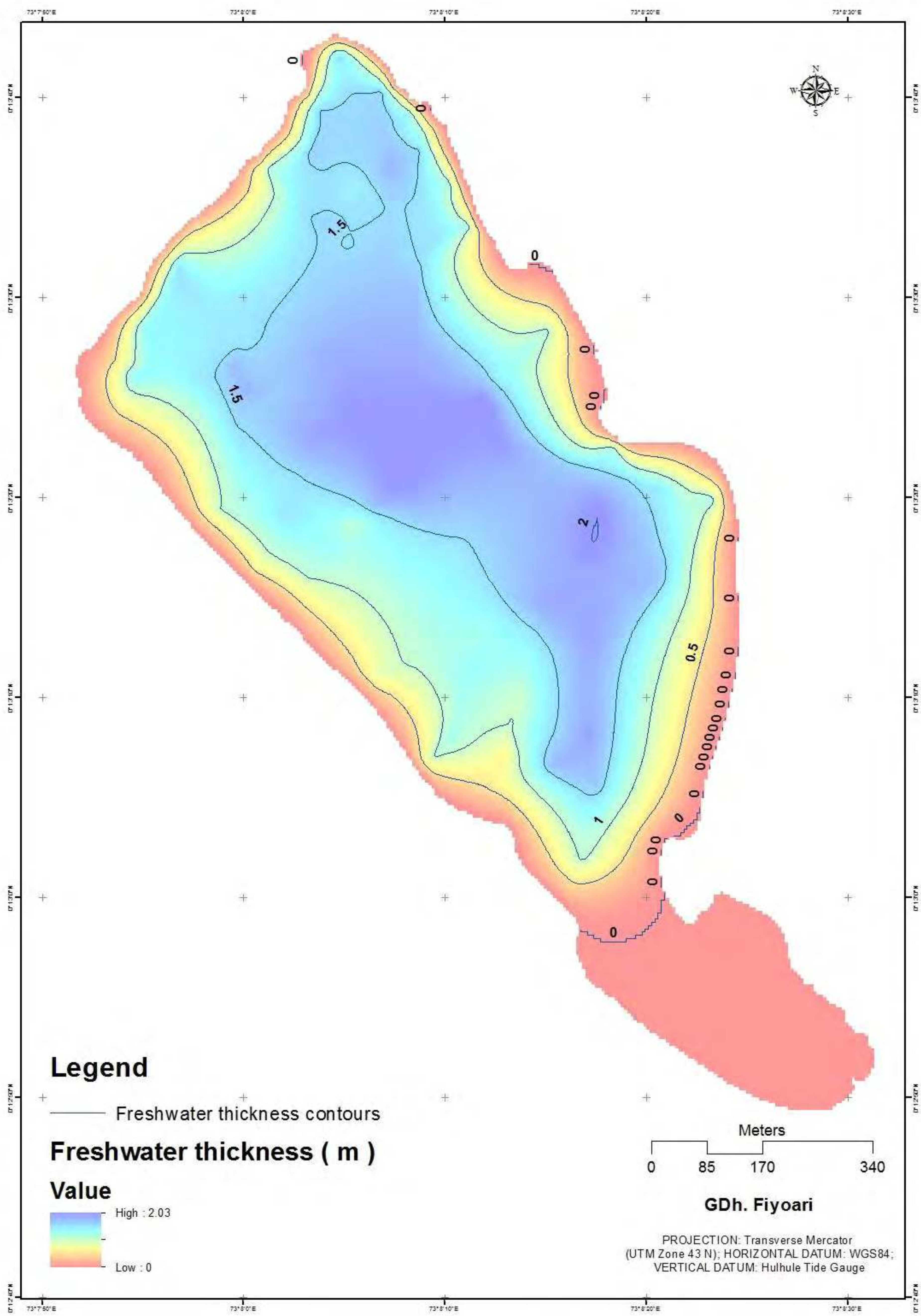


Figure 14.12: Freshwater thickness in Fiyoari Island

The maximum freshwater thickness of the island is 2.03 m. According to Falkland, 1994, the freshwater level thickness of the island is 12 m. The relevant calculations are as follows;

Average Annual Rainfall = 2250 mm/yr

Width of the island = 652 m

Length of the island = 1120 m

Freshwater lens Thickness (m)

= (6.94*log(width of the island)-14.38)*Average Annual Rainfall = 12 m

14.8.7 Water balance and recharge

An annual estimation is carried out based on water balance method. Rainwater harvesting is calculated using number of rainwater harvesting units in the island. According to the spatial mean annual rainfall of Maldives, the island is reported as 2250 mm/year. Evapotranspiration was estimated using crop water requirement for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. The groundwater extractions were estimated from amount of water usage in different sectors (residential, resorts, restaurants, agriculture and farming).The difference between recharge and groundwater extraction is taken to estimate different in storage.

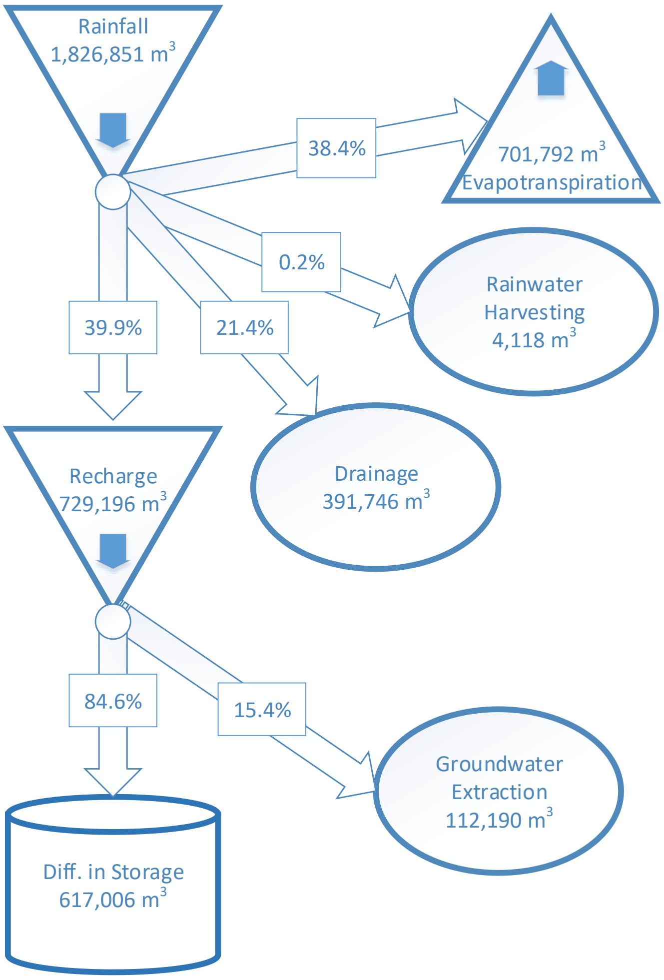


Figure 14.13: Schematic of water balance in Fiyoari Island

14.8.8 Sustainable yield of the lens

Sustainable yield of the water lens refers to the safe extraction potential of a given groundwater aquifer without significantly affecting its quality or quantity. This parameter is an important factor in the sustainable development of islands as it allows planning and design of water and sanitation intervention in islands.

The island has a sustainable yield of 1690 m^3 per day which was calculated subtracting groundwater extraction from recharge volume derived from water balance (

Figure 8.13). According to Metai & Unit, n.d., based on geophysical investigations and drilling programme concluded that the safe sustainable yield was about 10% of mean annual rainfall. Such that the expected sustainable yield for the island should be 501 m^3 per day.

14.8.9 Permeability test

Permeability tests were carried out in the locations as outlined in Figure 14.14.

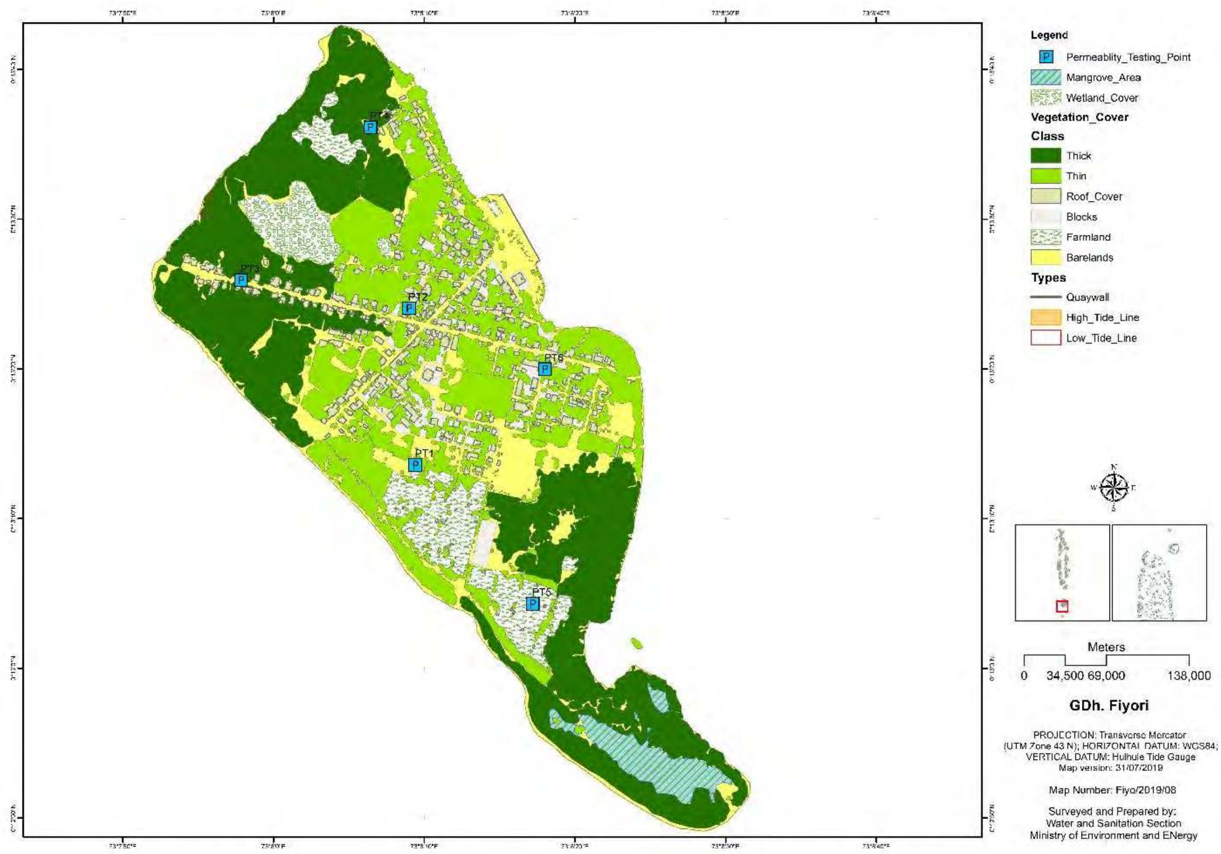


Figure 14.14: Locations of permeability tests in Fiyoari Island

The estimated permeability values for the above test locations are presented in Table 14.10.

Table 14.10: The estimated permeability Values

r_e	0.026
r1	0.0285

Point	H	Tu	Cs	H/re	Q	K (m/s)	K (m/day)	Q (l/min)	Q (m^3/s)
PT1	0.8	1.53	51	30.8	1.7E-04	1.51E-04	13.07	10	0.000167
PT2	0.5	1.2	40	19.2	2.6E-05	3.71E-05	3.20	1.54	2.57E-05
PT3	0.8	1	51	30.8	1.2E-04	1.65E-04	14.28	7.14	0.000119
PT4	0.3	0.4	27	11.5	4.7E-06	2.86E-05	2.47	0.28	4.67E-06
PT5	0.55	0.8	42	21.2	1.7E-05	3.45E-05	2.99	1	1.67E-05
PT6	0.35	0.5	28	13.5	8.33E-06	3.96E-05	3.42	0.5	8.33E-06

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m^3/s), H = Height of water in well (m), l = length of perforated section (m), r_1 = outside radius of casing (radius of hole in consolidated material) (m), r_e = effective radius of well = r_1 (area of perforations) / (outside area of perforated section of casing) : $r_1 = r_e$ in consolidated material that will stand open and is not cast, C_u and C_s =Conductivity Coefficients, and T_u = distance from water level in casing to water table (m).

14.8.10 Pumping Test

Pumping tests were carried out in the locations as outlined in Figure 14.15.

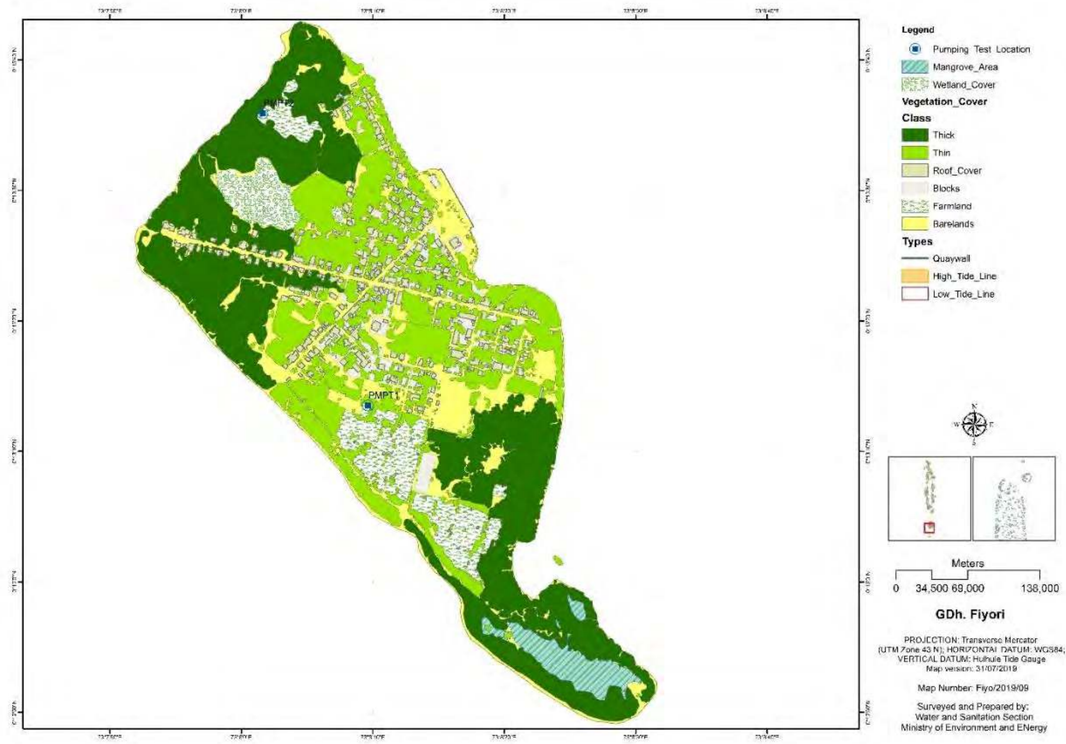


Figure 14.15: Pumping Test Locations

14.8.11 Groundwater availability

1) The selected Fiyoaree island has dimensions of width = 652 m and length = 1650 m, with a total land area of 80.63 ha, a population of 737 persons, and a land use of built-up area 4.68 ha (5.8%), thick vegetation 29.05 ha (36.0%), light vegetation 20.95 ha (26.0%), barelands (inland) 16.41 ha (20.4%), farmlands 5.26 ha (6.53%), wetlands 2.07 ha (2.57%) and mangroves 2.21 ha (2.74%)

2) In order to recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of freshwater lens (FWL) and its associated recharge-discharge characteristics, 99 number of Electrical Resistivity (ER) location readings along 09 representatively selected transects were collected.

3) Soil overburden permeability tests (constant head) were carried out at 06 locations while steady-state pumping tests were conducted at 02 locations. In addition, groundwater level was also recorded at 28 locations where groundwater water quality samples were tested.

4) Permeability tests were carried out at representatively selected 05 number of locations. The measured permeability (K m/day) values ranged from a minimum of 2.47 m/day to a maximum of 14.28 m/day, with an average of 6.57 ± 5.53 m/day (Mean ± 1 Standard Deviation).

5) The ground elevation values ranged from a minimum of 0.08 m MSL to a maximum of 2.61 m MSL, with an average of 1.04 ± 0.46 m MSL (Mean ± 1 Standard Deviation).

6) The upper boundary of the freshwater lens (FWL) varied from a minimum of 0.10 m MSL to a maximum of 0.51 m MSL, with an average of 0.31 ± 0.08 m MSL (Mean ± 1 Standard Deviation).

7) The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -1.78 m MSL to a maximum of -0.26 m MSL, with an average of -1.14 ± 0.32 m MSL (Mean ± 1 Standard Deviation).

8) Accordingly, the freshwater lens (FWL) thickness values ranged from a minimum of 0.00 m to a maximum of 2.03 m, with an average of 1.03 ± 0.71 m (Mean ± 1 Standard Deviation).

9) The groundwater profile in the island is characterised by a relatively Low Rainwater Harvesting, relatively Very Low Drainage, relatively Very High Recharge, while the water use shows relatively Low Groundwater extraction, leading to relatively Very High Difference in Balance Storage.

10) The freshwater lens (FWL) volume calculated based on ER transect test data is 123,878 m^3 with a maximum FWL thickness of 2.03 m. The potential maximum FWL volume and thickness estimated based on Falkland (1994) method are 92,475 m^3 and 11.59 m.

14.8.12 Conclusive Comments and Recommendations

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 1,690 m^3 per day, while it is 501 m^3 per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 311 m^3 per day and this is about 62% of the allowable Safe Yield in the island with minor up-coning and slight drawdown in freshwater lens cross-sections. At present, there exists no island-wide sewerage network or water supply network. The water samples tested were found to be Moderately Odorous with 58.3% or 7/12 samples tested producing odour. The Hydrological condition of the freshwater lens aquifer can be categorised as Good based on above measurements and findings while Water quality aspects can be regarded as Contaminated with an Average Electrical Conductivity (EC) of 997.83 ± 405.63 µS/cm with measured values ranging from a minimum of 311.30 µS/cm to a maximum of 1,682.60 µS/cm, and an Average Ammonia Concentration of 3.62 ± 7.66 mg/L with measured values ranging from a minimum of 0.12 mg/L to a maximum of 27.46 mg/L.

The Availability of space for incorporating recharge measures and related infrastructure is High while therefore the Potential for Recharging is considered to be High. Overall recommendation for groundwater recharging would be to use ponds, trenches, pits and laterals in built up area and impounded earth dams in open areas. In addition, recharging pits could be used for other individual households and land blocks

15 KONDEY ISLAND

15.1 General overview of the island

The island of Kondey is located at 73°32'56.7"E and 00°29'52.9"N in the Gaafu Alif Administrative Atoll. The island is around 2205 m long and 700 m wide, with an area of 105.76 ha. Via the 2014 Census the island has a registered population of 272 people. The island has a harbour on its Western side. The following table outlines some basic information about the island and the following map outlines the location of Kondey.

Table 15.1: Basic statistical information on Kondey island in Gaaf Alif Atoll.

Name of the island	GA.Kondey
Longitude and Latitude	73°32'56.7"E, 00°29'52.9"N
Area	119.5 ha
Population (Census, 2014)	272
Distance from Atoll Capital (GA.Villingili)	31.1 km
Distance from Male'	406.5 km
Harbour	Present
Island sewerage network	No
Water supply network	No
Other infrastructure	None

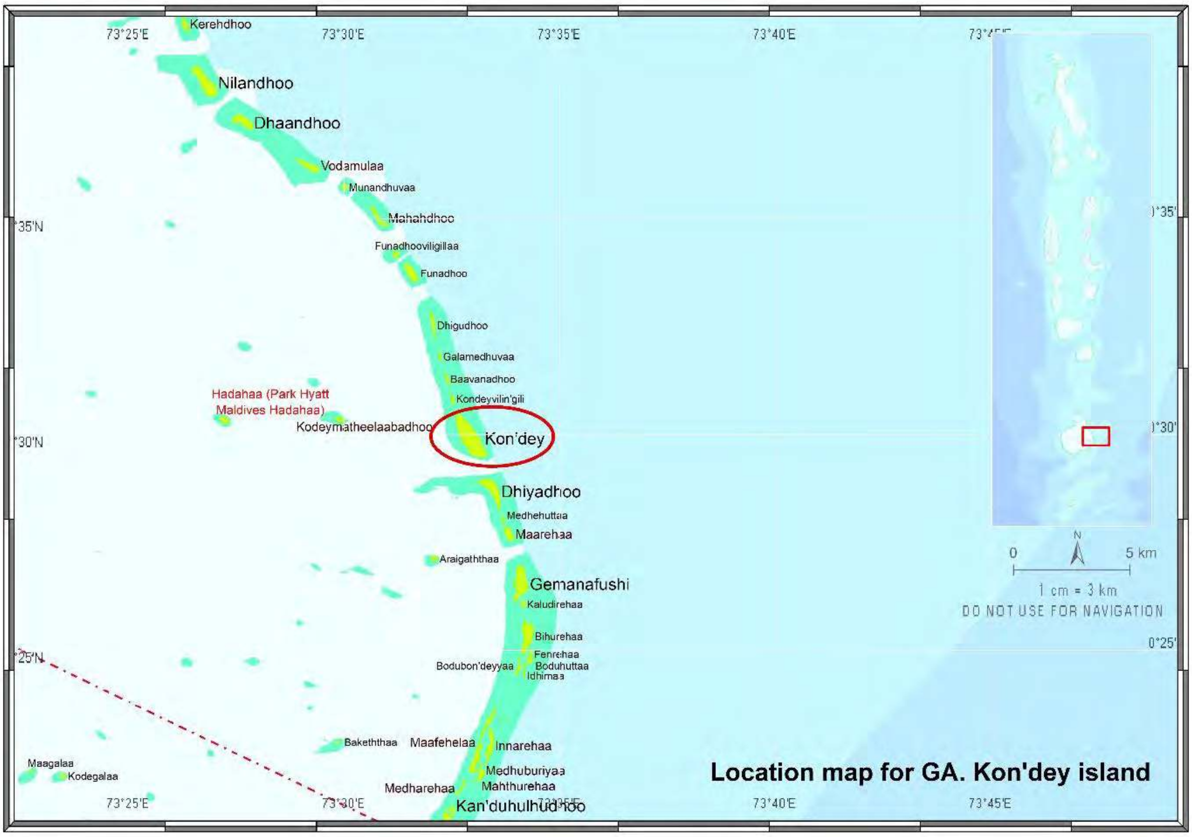


Figure 15.1: Location map for Kondey Island, Gaaf Alif Atoll.

15.2 Geology and vegetation

The island is around 2205 m long and 700 m wide, with an area of 105.76 ha. Over four-fifths of this land is covered in vegetation. The vegetation covers both the Northern and Southern halves of the island, with an area in between the vegetation where people live. Farming activities take place within the vegetation of the island.

15.3 Topography

Kondey has a topography that ranges from 0.22 meters to 2.44 meters above Mean Sea Level (MSL) with an average of 1.34 meters above MSL. The topography contour map is found in Figure 15.2.

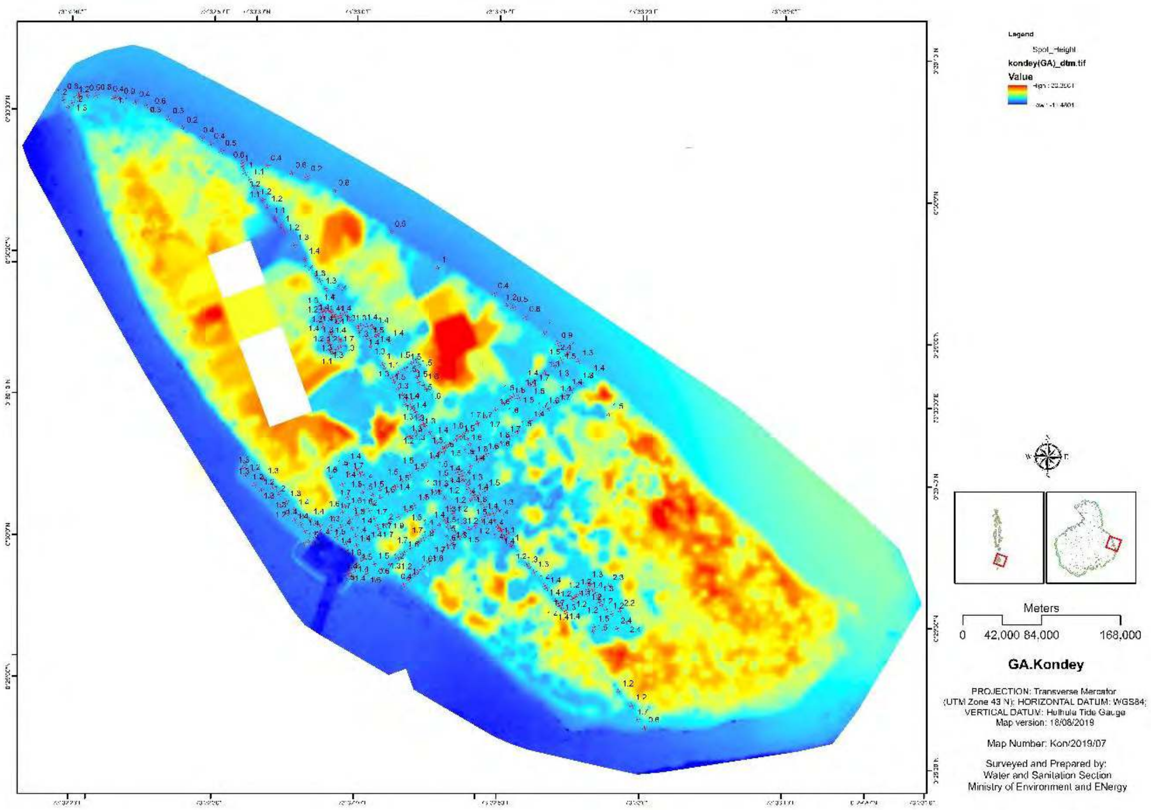


Figure 15.2: Digital Terrain Model of Kondey Island with spot heights

15.4 Climate

Kondey experiences the typical two monsoons namely, north east monsoon from November to April and South-west monsoons from April to November. There are no specific wind and rainfall data available for Kondey as there are no weather monitoring stations on the island.

15.5 Demography

Kondey has a registered population of 272 people via the 2014 Census, although this number may be inaccurate as the island council reports a population of 575 people in 2019. The island has more males than females, for both the local population (53% being male) and the foreign population (57% being male). The following graphs illustrate the demographic breakdown of Kondey.

Table 15.2: Demographic Breakdown of Kondey Island

Atoll	locality	Resident population (Census, 2014)								
		Total			Maldivians			Foreigners		
		Both sexes	Male	Female	Both sexes	Male	Female	Both sexes	Male	Female
GA	Kondey	272	145	127	258	137	121	14	8	6

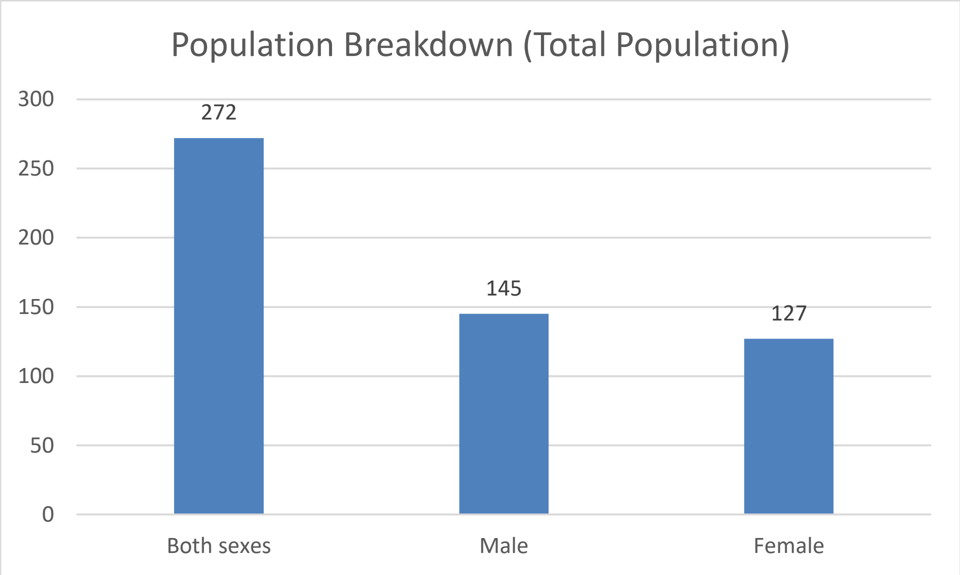


Figure 15.3: Population breakdown of Kondey (Maldivians & Foreigners)

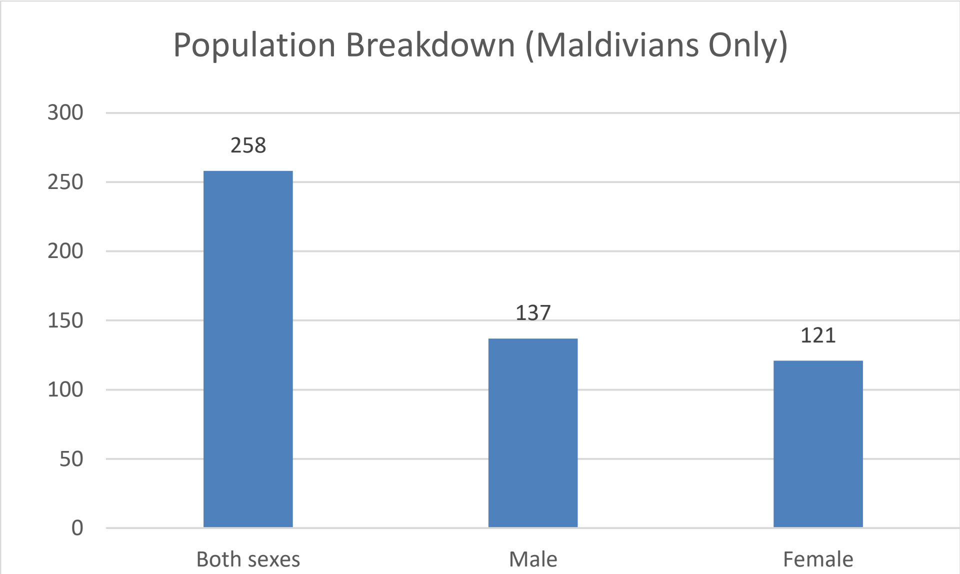


Figure 15.4: Population breakdown of Kondey (Maldivians)

15.6 Socio-economic condition

With several farms scattered throughout the islands vegetation, farming is a significant part of Kondey's economy.

15.7 Existing water and sanitation situation

The island does not currently have either an island wide sewerage system or a water supply network. The main form of waste disposal on the island is via the use of septic tanks connected to the households. Each household has one or two septic tanks. 83.3% of households bury septic waste in other parts of their house plot and island and the remaining claim not to have cleaned their septic tanks. On average, there is an approximate distance of 7.16 meters between septic tanks and nearest well.

The primary source of drinking water on the island is rainwater collected in either household or community rainwater tanks. The rainwater tends to run out during the dry season in several households, at which point water is often taken from neighbouring households or community tanks. There are no plans as of now to develop a sewerage network in the island.

15.8 Results

15.8.1 Water sources and water use

Based on domestic, commercial, institutional and industrial water usage, a total of 138,309 liters of groundwater are estimated to be used every day. Therefore 242 liters of groundwater are used per capita per day. The respective water use situations are detailed in the following sections.

15.8.1.1 Domestic water use situation

Based on the questionnaire to collect data on domestic water consumption, a summary of results are present in this section.

According to the survey, 100% of the households surveyed uses HDPE rainwater tanks as their main storage for water. A total of 100% households use rainwater for drinking and 100% use it for cooking. None of the surveyed houses use rainwater for bathing or washing.

None (0%) of the households use groundwater as drinking. Groundwater is mainly used for non-potable use in all the households surveyed.

The following table summarizes the groundwater and rainwater use data for Kondey Island.

Table 15.3: Groundwater and rainwater use data for Kondey

Rainwater	
Households with rainwater tanks	6 of 6 i.e. 100%
Rainwater use for drinking	83%
Rainwater use for cooking	100%
Rainwater use for bathing and washing	0%
Groundwater	
Groundwater as drinking source	0%
Groundwater for cooking	0%
Groundwater for non-potable use	100%
Total number of households surveyed	6 (10%)
Percentage of wells surveyed fitted with pumps	100%

Based on the survey questionnaire, average daily water demand per capita for domestic purposes has been estimated based on the average amount of water used per person for showering, toilet flushing, laundry and gardening, this data is shown in Table 15.4. The total domestic water use is estimated to be 230 liters per capita per day.

Table 15.4: Domestic Water Usage in Kondey

Shower/ Liters per capita per day	Toilet/ Liters per capita per day	Laundry/ Liters per capita per day	Gardening/ Liters per capita per day	**Total/ Liters per capita per day**
139	30	15	46	**230**

15.8.1.2 Commercial water use situation

Based on the questionnaire to collect data on commercial water consumption, a summary of results are present in this section. Based on information from the island council, Kondey has a total of 1 restaurants and 0 guesthouses. 1 restaurant was surveyed.

For the restaurant, the main use of groundwater was for mopping, gardening, dishwashing and toilet use. From the survey data, the total groundwater consumption for this restaurant was estimated to be 825 liters per day, therefore the total commercial groundwater consumption for the island considering is also 825 liters per day.

15.8.1.3 Institutional water use situation

Based on the questionnaire to collect data on institutional water consumption, a summary of results are present in this section. Two institutions were surveyed for this study namely the school and council office. Groundwater in the institutions in Kondey Island are mainly used for gardening, mopping floors and flushing toilets. A total of approximately 1011 liters of groundwater are estimated to be used per day by the school and council office. Considering other institutions such as health center and powerhouse, the total groundwater usage of all the institutions in Kondey is estimated to be 2022 liters. Therefore, a total of approximately 3.52 liters of groundwater are estimated to be used per capita per day by the institutions of Kondey Island.

Table 15.5: Water Usage in Institutions Surveyed in Kondey

<table>
<tr><th></th><th>Water Flushed (Liters per day)</th><th>Gardening (Liters per day)</th><th>Mopping (Liters per day)</th><th>Total Water Usage (Liters per day)</th><th>Institutional Groundwater Usage (Liters per day)</th><th>Institutional Groundwater Usage (Liters per capita per day)</th></tr>
<tr><td>Council Office</td><td>79</td><td>124</td><td>18</td><td>221</td><td rowspan="2">1011</td><td rowspan="2">1.76</td></tr>
<tr><td>School</td><td>149.91</td><td>540</td><td>100</td><td>790</td></tr>
</table>

15.8.2 Groundwater quality

Groundwater quality measurements were made at selected wells in Kondey for both physical and microbiological testing.

The following Table 15.6 summarizes the water quality results.

Table 15.6: Summary of groundwater quality tests from Kondey, July 2019

Sample No	Odour	Physical Appearance
gw1	no	Clear with particles
gw2	no	Clear with particles
gw3	no	Clear with particles
gw4	no	Clear with particles
gw5	no	Clear with particles
gw6	yes	Clear with particles
gw7	no	Pale yellow with particles
gw8	yes	Pale yellow with particles
gw9	no	Clear with particles
gw10	yes	Clear with particles
gw11	no	Clear with particles
gw12	yes	Clear with particles
gw13	no	Clear with particles

Sample No	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100 ml)	Faecal Coliform (MPN/100 ml)
gw1	661.6	391	7.27	0.20	2.17	30.2	0.29	3.7	0.11	0.18		
gw2	453.2	272	7.74	0.00	3.35	29.4	0.20	45.5	0.23	0.20		
gw3	651.1	375	7.51	0.15	2.49	31.8	0.28	20.6	0.23	0.17		
gw4	669.4	397	7.69	4.24	1.35	30.1	0.29	5.7	0.20	0.42		
gw5	736.6	437	7.28	0.19	1.66	30.1	0.32	14.0	0.42	0.21		
gw6	647.8	391	7.39	0.79	1.91	29.0	0.29	5.0	0.68	0.14	>2420	1414
gw7	656.8	395	7.63	0.72	4.85	29.3	0.29	38.1	0.42	0.17		
gw8	793.1	476	7.47	0.67	2.78	29.3	0.35	6.2	8.62	0.18		
gw9	627.5	370	7.48	2.99	3.61	30.4	0.27	4.3	0.19	0.21		
gw10	698.3	418	7.24	0.50	1.41	29.4	0.31	12.7	0.88	0.10	>2420	816
gw11	360.6	193	8.72	24.44	22.63	36.4	0.14	4.4	0.14	0.21		
gw12	759.8	433	7.35	0.34	1.64	32.4	0.32	12.1	0.73	0.37		
gw13	563.1	357	7.52	0.88	5.16	26.3	0.26	3.6	0.06	0.27	>2420	1120

	EC (µS/cm)	TDS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	Temp (°C)
WHO Standards	Suggested maximum limit of freshwater for potable purposes = 1500 µS/cm Suggested maximum limit of freshwater for non-potable purposes = 2500 µS/cm	-	-	-	-	-

	Salinity (PSU)	Nitrates (mg/L-NO3)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
WHO Values	-	Guideline Value = 50 mg/L-NO3	Natural Level of Ammonia < 0.2 mg/L Threshold odour concentration = 1.5 mg/L Taste threshold = 35 mg/L	-	-	-

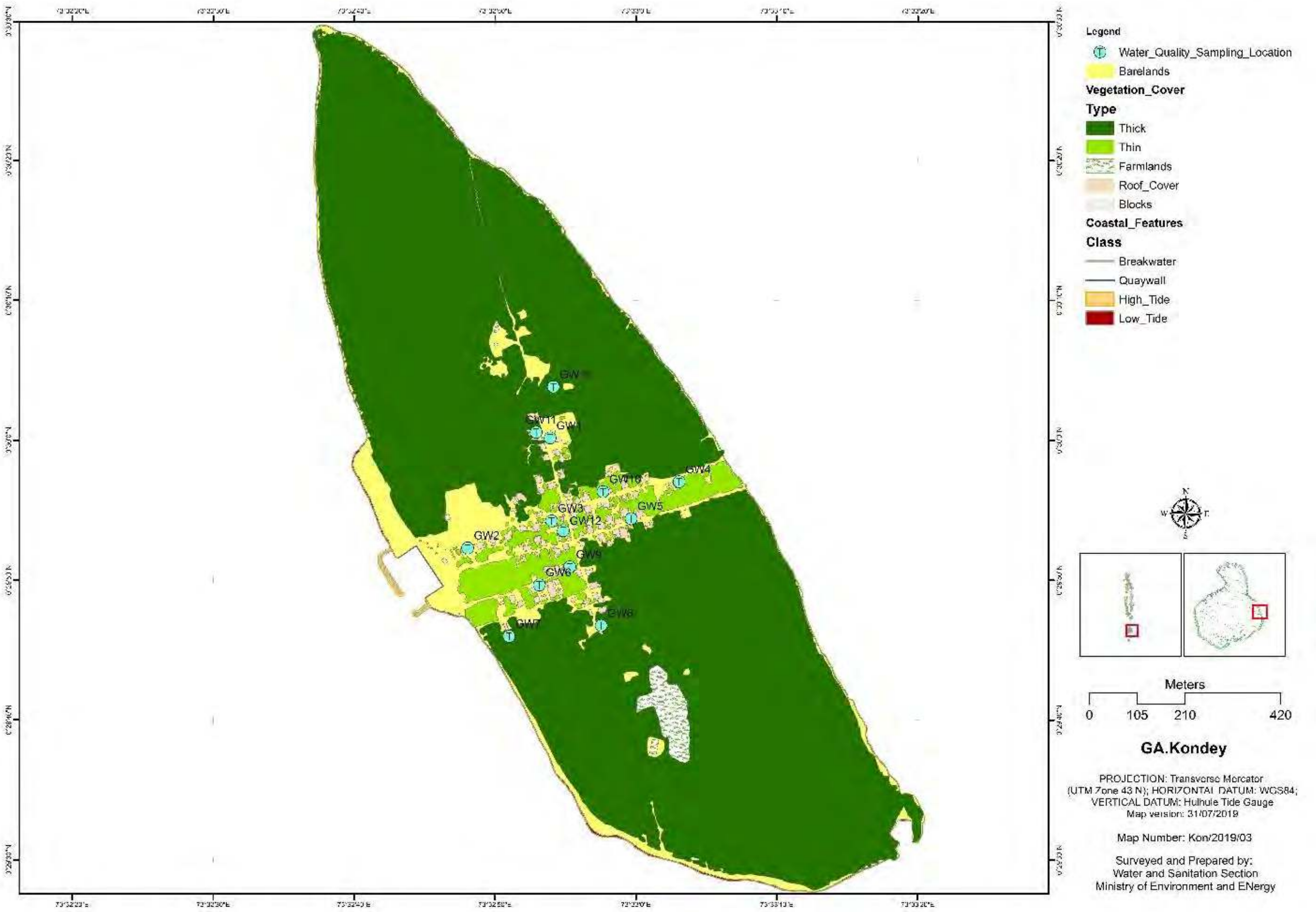


Figure 15.5: Location of groundwater sampling points in Kondey Island

Based on the full results and the summary shown in Table 5, the following can be summarized for Kondey:

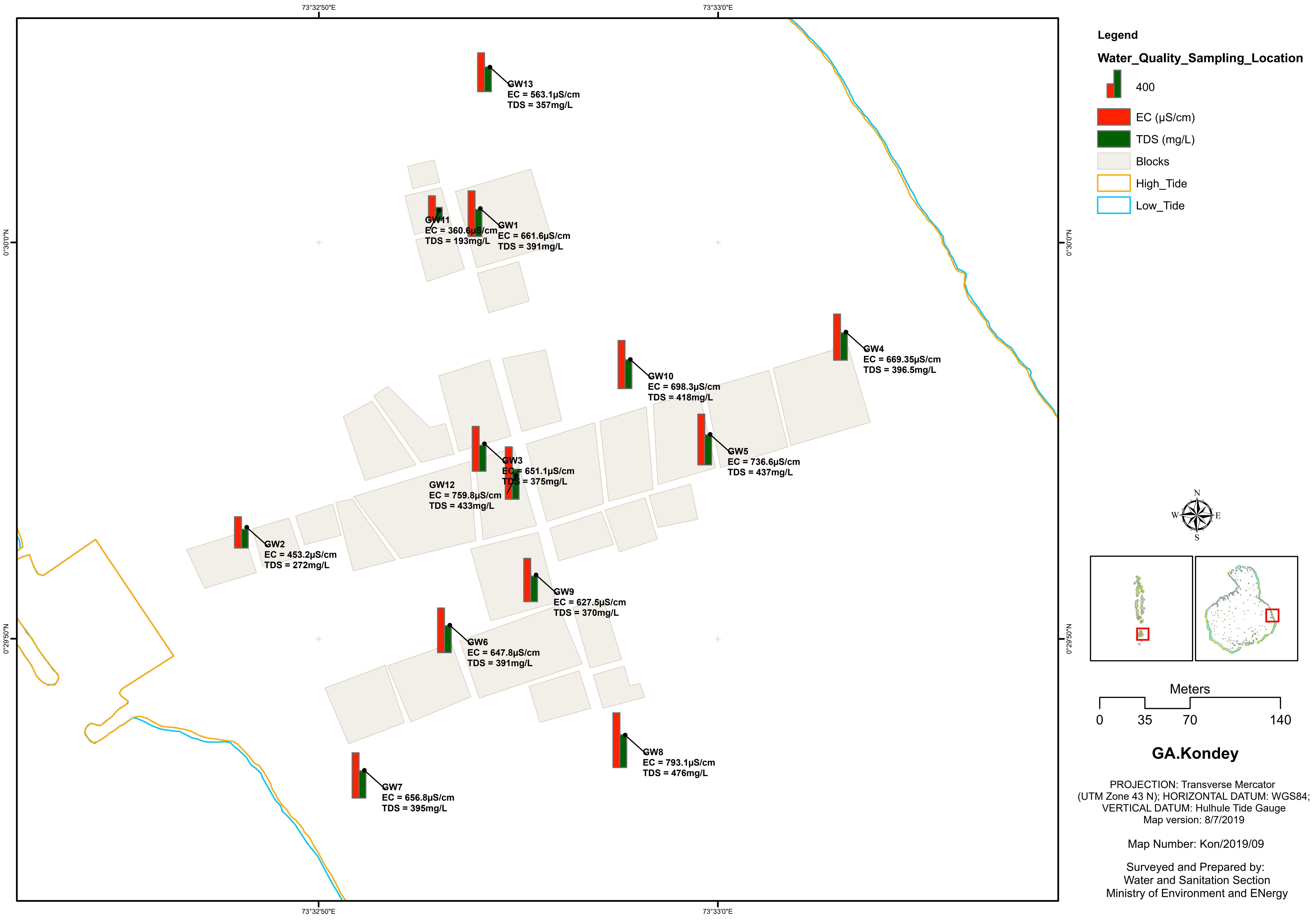
- Samples gw1 was taken from the school. gw2 was taken from the health center, gw4 was taken from Fenaka, gw7 from an abandoned well near abandoned construction area and gw13 were taken from wells within farming areas. All other samples (gw3, gw5 and gw8-gw12) were taken from households.
- The average Electrical Conductivity (EC) of the groundwater is 637 µS/cm which is below the acceptable limit for potable water of 1,500 µS/cm (refer section 2.2). All the samples tested has EC within the acceptable limit for potable water. The EC of the samples range from

361-793 µS/cm. From the 13 islands surveyed, groundwater from Kondey island had the lowest EC.

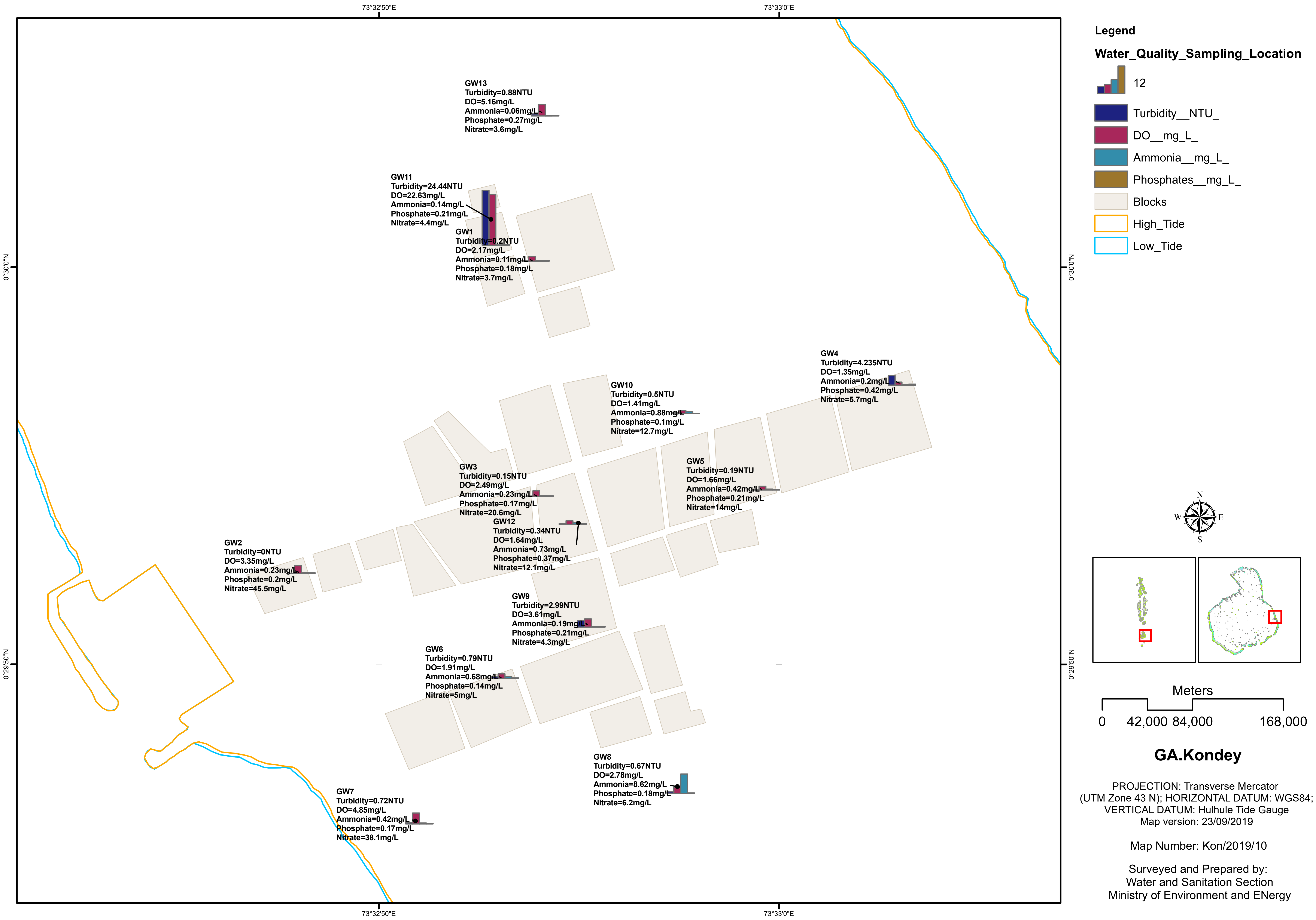
- Total Dissolved Solids recorded ranged from 193 mg/L to 476 mg/L with an average of 530 mg/L.
- The pH of groundwater ranged from 7.24 to 8.72 with an average of 7.56.
- Turbidity ranged from the lowest of 0 NTU to 24.44 NTU with an average of 2.77 NTU. As a guide, "crystal-clear" water has a turbidity below 1 NTU, and water becomes visibly cloudy at 4 NTU and above. Sample gw11 had a significantly higher turbidity compared to other samples as the sample was taken from a well which had a very rigorous oxygen filter connected. Therefore the water taken from the well was very cloudy even after several minutes of letting the water settle.
- Dissolved oxygen levels ranged from 1.35 to 22.63 mg/L. The average value was 4.23 mg/L. Sample gw11 had significantly higher DO compared to other samples as the sample was taken from a well which had a very rigorous oxygen filter connected.
- The salinity of groundwater ranged from 0.14 PSU to 0.35 PSU with an average of 0.28 PSU. Salinity is expressed in Practical Salinity Units, PSU which is equivalent to PPT.
- The average Nitrate concentration was 13.5 mg/L and therefore does not exceed the WHO guideline limit of 50 mg/L. None of the tested water samples exceeded this limit. The Nitrate concentrations ranged from 3.6 mg/L to 45.53 mg/L.
- Ammonia concentrations were generally low apart from one sample (gw8) with a significantly high ammonia concentration of 8.62 mg/L. The average ammonia concentration was 620.48 mg/L including gw8, but excluding it the ammonia concentration was 0.358 mg/L. The ammonia concentrations ranged from 0.06 mg/L to 8062 mg/L. The average ammonia concentration without gw8 does not exceed the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. Only gw8 exceeded this limit. Sample gw8 has a significantly high ammonia concentration. There is no apparent correlation between increasing levels of ammonia and other nutrients.
- Phosphate concentrations ranged from 0.1 mg/L to 0.42 mg/L with an average of 0.22 mg/L. There is no WHO drinking water guideline value for phosphate. However, it would normally be expected that phosphate concentrations in groundwater are less than 0.1 mg/L, where there are no impacts from human wastewater (e.g. effluent from septic tanks and 'greywater' from kitchens and bathrooms). None of the samples tested had Phosphate concentrations below 0.1 mg/L.
- Total coliform levels were alarming as all of the samples tested had total coliform levels greater than 2420 MPN/ 100mL. Faecal coliform levels ranged from lowest count of 816 MPN/100 mL to the highest count of 1414 MPN/100mL, with an average count of 1117 MPN/100mL. As expected, the groundwater layer is contaminated with effluent from septic tanks. The high total and faecal coliform levels on this island could be due to the septic tank cleaning process practiced on this island where effluent from septic tanks are disposed into another dug unlined well inside the household periphery.

In conclusion, Kondey Island contains groundwater with low Electrical Conductivity and TDS, low turbidity and Nitrate concentration lower than WHO maximum guidance value but Phosphate and Ammonia concentrations higher than expected in natural undisturbed groundwater. In terms of microbiological contamination, Kondey Island shows variable patterns where residential areas have high contamination while school and vegetated area have lower contamination.

Additionally, the following pages contain maps which show the main physiochemical parameters displayed on the island map.



73°32'50"E
73°33'0"E
0°30'0"N
0°29'50"N
GW13
EC = 563.1μS/cm
TDS = 357mg/L
GW11
EC = 360.6μS/cm
TDS = 193mg/L
GW1
EC = 661.6μS/cm
TDS = 391mg/L
GW10
EC = 698.3μS/cm
TDS = 418mg/L
GW4
EC = 669.35μS/cm
TDS = 396.5mg/L
GW3
EC = 651.1μS/cm
TDS = 375mg/L
GW12
EC = 759.8μS/cm
TDS = 433mg/L
GW5
EC = 736.6μS/cm
TDS = 437mg/L
GW2
EC = 453.2μS/cm
TDS = 272mg/L
GW9
EC = 627.5μS/cm
TDS = 370mg/L
GW6
EC = 647.8μS/cm
TDS = 391mg/L
GW8
EC = 793.1μS/cm
TDS = 476mg/L
GW7
EC = 656.8μS/cm
TDS = 395mg/L
Legend
Water_Quality_Sampling_Location
400
EC (μS/cm)
TDS (mg/L)
Blocks
High_Tide
Low_Tide
N
W
E
S
Meters
0
35
70
140
GA.Kondey
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/7/2019
Map Number: Kon/2019/09
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


73°32'50"E
73°33'0"E
0°30'0"N
0°29'50"N
GW13
Turbidity=0.88NTU
DO=5.16mg/L
Ammonia=0.06mg/L
Phosphate=0.27mg/L
Nitrate=3.6mg/L
GW11
Turbidity=24.44NTU
DO=22.63mg/L
Ammonia=0.14mg/L
Phosphate=0.21mg/L
Nitrate=4.4mg/L
GW1
Turbidity=0.2NTU
DO=2.17mg/L
Ammonia=0.11mg/L
Phosphate=0.18mg/L
Nitrate=3.7mg/L
GW4
Turbidity=4.235NTU
DO=1.35mg/L
Ammonia=0.2mg/L
Phosphate=0.42mg/L
Nitrate=5.7mg/L
GW10
Turbidity=0.5NTU
DO=1.41mg/L
Ammonia=0.88mg/L
Phosphate=0.1mg/L
Nitrate=12.7mg/L
GW3
Turbidity=0.15NTU
DO=2.49mg/L
Ammonia=0.23mg/L
Phosphate=0.17mg/L
Nitrate=20.6mg/L
GW5
Turbidity=0.19NTU
DO=1.66mg/L
Ammonia=0.42mg/L
Phosphate=0.21mg/L
Nitrate=14mg/L
GW12
Turbidity=0.34NTU
DO=1.64mg/L
Ammonia=0.73mg/L
Phosphate=0.37mg/L
Nitrate=12.1mg/L
GW2
Turbidity=0NTU
DO=3.35mg/L
Ammonia=0.23mg/L
Phosphate=0.2mg/L
Nitrate=45.5mg/L
GW9
Turbidity=2.99NTU
DO=3.61mg/L
Ammonia=0.19mg/L
Phosphate=0.21mg/L
Nitrate=4.3mg/L
GW6
Turbidity=0.79NTU
DO=1.91mg/L
Ammonia=0.68mg/L
Phosphate=0.14mg/L
Nitrate=5mg/L
GW8
Turbidity=0.67NTU
DO=2.78mg/L
Ammonia=8.62mg/L
Phosphate=0.18mg/L
Nitrate=6.2mg/L
GW7
Turbidity=0.72NTU
DO=4.85mg/L
Ammonia=0.42mg/L
Phosphate=0.17mg/L
Nitrate=38.1mg/L
Legend
Water_Quality_Sampling_Location
12
Turbidity__NTU_
DO__mg_L_
Ammonia__mg_L_
Phosphates__mg_L_
Blocks
High_Tide
Low_Tide
N
W
E
S
Meters
0
42,000 84,000
168,000
GA.Kondey
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 23/09/2019
Map Number: Kon/2019/10
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

15.8.3 Geophysical survey

The Resistivity tests were carried out in the locations as outlined in Figure below.

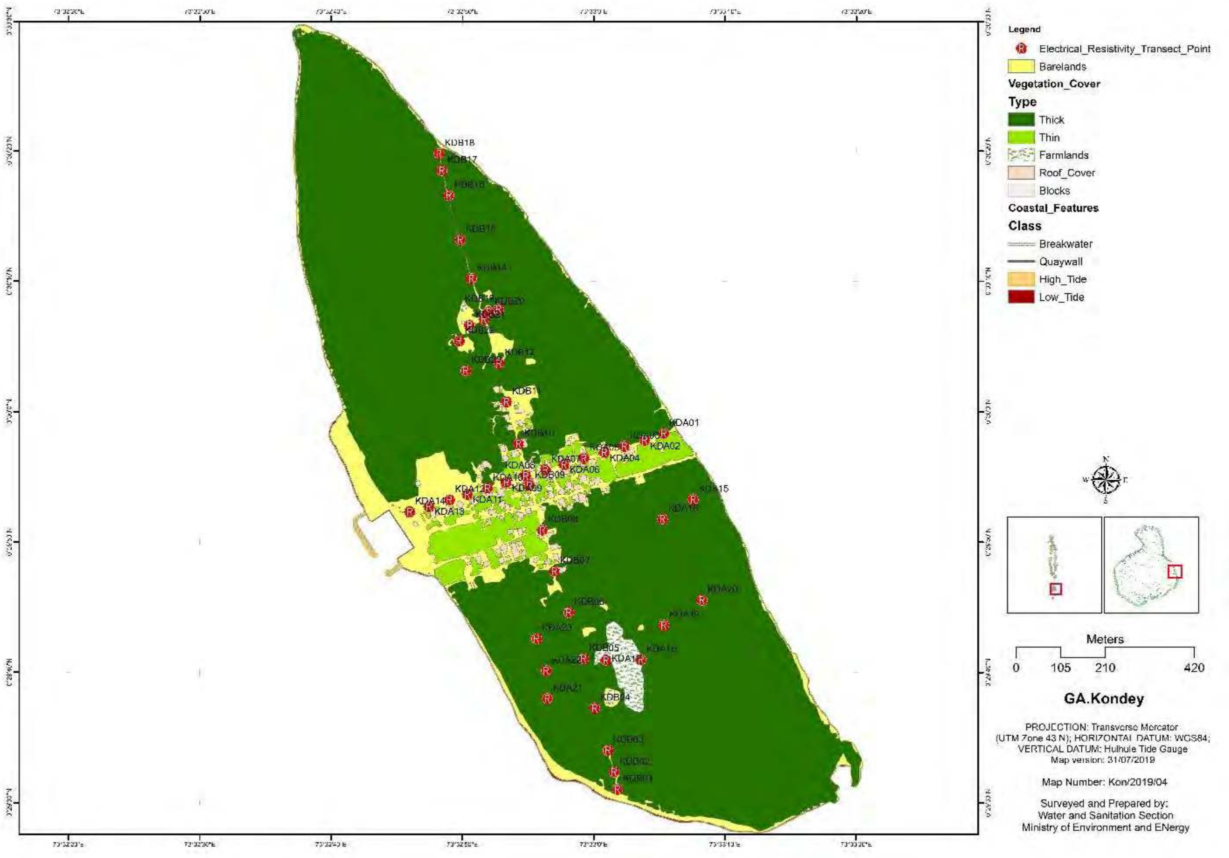


Figure 15.6: Location of ER points in Kondey Island

15.8.4 Aerial surveys

Based on the aerial survey, a multiple dataset consisting of roof cover, thick vegetation area, thin vegetation area, bare lands and shorelines were extracted. This data is shown in Figure 15.7 and the Table 15.7 shows the different area distribution.

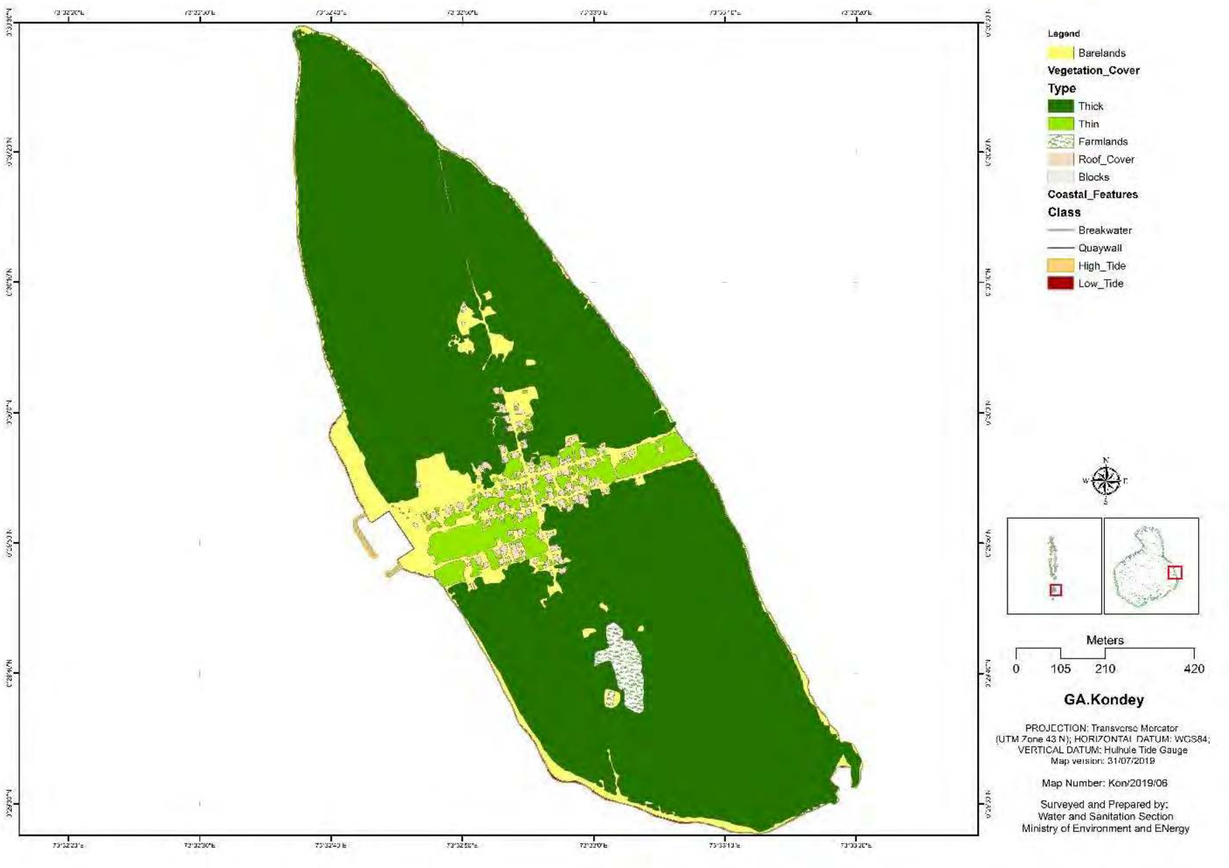


Figure 15.7: Roof Cover in Kondey Island

Table 15.7: Area Distribution in Kondey

	Area (Square Meters)	Percentage (%) of total area
Roof cover	17,454	1.7%
Vegetation (Thick)	965,062	91.3%
Vegetation (Light)	51,854	4.9%
Bare lands	10,161	1.0%
Farm Lands	13,030	1.2%
Wetlands (Inland)	-	-

15.8.5 Water Demand

The only source of natural water is rainwater collected from the rooftops of households and institutions and groundwater extracted from shallow wells.

15.8.6 Freshwater lens

Based on the ER survey the depth to groundwater level and the freshwater-saline water interface was determined for a set of transverse transects as shown in Figure 15.8. Plots in the Figure 15.9 shows the cross sections of each transect line. The dotted lines in the plots indicating a simple interpolation of levels to mean sea level in the island boundaries. These cross sections were used to identify the spatial extent and volume of the freshwater lens while they were also useful in deriving implications on the stress level of the aquifer based on the observed, localized drawdown effect in the groundwater table and up-coning in the freshwater-saline interface, defining the upper and lower boundaries of the freshwater lens in an island.

The Table 15.8 illustrates the freshwater volume calculation for the island. The area covered by freshwater for each transect line has been calculated. To estimate the total volume of available freshwater lens, the cross-section area of freshwater extent under each transect was multiplied by the distance between two transects. The sum of these lengths represents the cumulative length of the island and thus, the above estimation could represent the total volume of the freshwater lens sandwiched between the groundwater table on top and freshwater-saline water interface in the bottom. Then the actual groundwater storage within this freshwater lens was calculated by multiplying the estimated total lens volume with the porosity of the topsoil in the island.

This estimation represents the total available freshwater volume within the freshwater lens at any given time (time of the measurement). The measurements were carried out towards the end of the dry period and the freshwater lens is presumed to be undergoing a ‘stressed’ condition due to continued groundwater abstractions despite reduced recharge in the dry period. Falkland (1994) method can be used to estimate the freshwater lend thickness under salient conditions using average annual rainfall, length and width of the island, and the comparison was used as a measure of stress level of the freshwater lens.

Table 15.8: Freshwater Volume Calculation for Kondey Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)	Area(m^2)	Length (m)	Volume (m^3)
3	Start		0	0	0	0			
			20	0.843	0	0			
	KDB01	ER	40	1.685	0.785	0.785	0		
	KDB02	ER	80	1.17	0.42	-2.04	50		
	KDB03	ER	132	1.506	0.626	-1.694	123		
	KDB04	ER	239	1.338	0.458	-1.702	239		
	KDB05	ER	355	1.411	0.541	-2.459	300		
	KDB06	ER	469	1.239	-0.141	-2.661	315		
	KDB07	ER	572	1.389	0.439	-2.281	269		
	KDB09	ER	681	1.479	0.619	-2.461	316		
	KDA08	ER	706	1.447	0.197	-2.563	74		
	KDB10	ER	782	1.326	0.116	-2.414	199		
	KDB11	ER	888	1.356	0.546	-2.794	313		
	KDB12	ER	979	1.343	0.493	-3.567	336		
	KDB13	ER	1090	1.339	0.489	-3.571	449		
	KDB14	ER	1188	1.39	0.22	-2.48	331		
	KDB16	ER	1296	1.251	0.601	-0.319	196		
	KDB17	ER	1358	1.055	0.345	-1.205	77		
	KDB18	ER	1398	1.012	0.252	-1.118	58		
			1417	0.506	0	0	1150		
	End		1437	0	0	0	0		
	Total						4795	627	3008001
									3008001

Table 15.9: ER Survey Results of Longitudinal Sections for Kondey Island

Transect Line	Location	Point ID	Distance from shore (m)	Topo Level (MSL) (m)	Freshwater level (MSL) (m)	Saltwater interface (MSL) (m)
1	Start		0	0	0	0
			32	0.370	0	0
	KDA20	ER	130	1.496	0.196	-0.904
	KDA19	ER	237	1.694	0.944	-1.906
	KDA18	ER	312	1.308	0.598	-1.982
	KDA17	ER	392	1.145	0.395	-1.195
	KDB05	ER	438	1.411	0.541	-2.459
	KDA22	ER	537	1.778	1.028	-1.532
			613	1.246	0	0
	End		645	0	0	0
2	Start		0	0	0	0
			32	1.450	0	0
	KDA01	ER	32	1.431	0.591	-1.759
	KDA02	ER	79	1.36	0.46	-1.19
	KDA03	ER	130	1.475	0.745	-2.135
	KDA04	ER	179	1.612	0.652	-2.848
	KDA05	ER	229	1.691	0.371	-2.839
	KDA06	ER	278	1.73	0.69	-3.11
	KDA07	ER	324	1.563	0.263	-3.747
	KDA08	ER	372	1.447	0.197	-2.563
	KDA10	ER	419	1.512	0.542	-0.538
	KDA11	ER	468	1.526	0.476	-2.934
	KDA12	ER	513	1.667	0.367	-2.633
	KDA13	ER	563	1.459	0.699	-3.321
	KDA14	ER	610	1.31	0.56	-1.29
			617	0.222	0	0
	End		649	0	0	0

ER Survey

Volume of lens = 3,008,001 **m^3**

Groundwater Storage = Posity (20%) x Lens volume (m3) = 601600 **m^3**

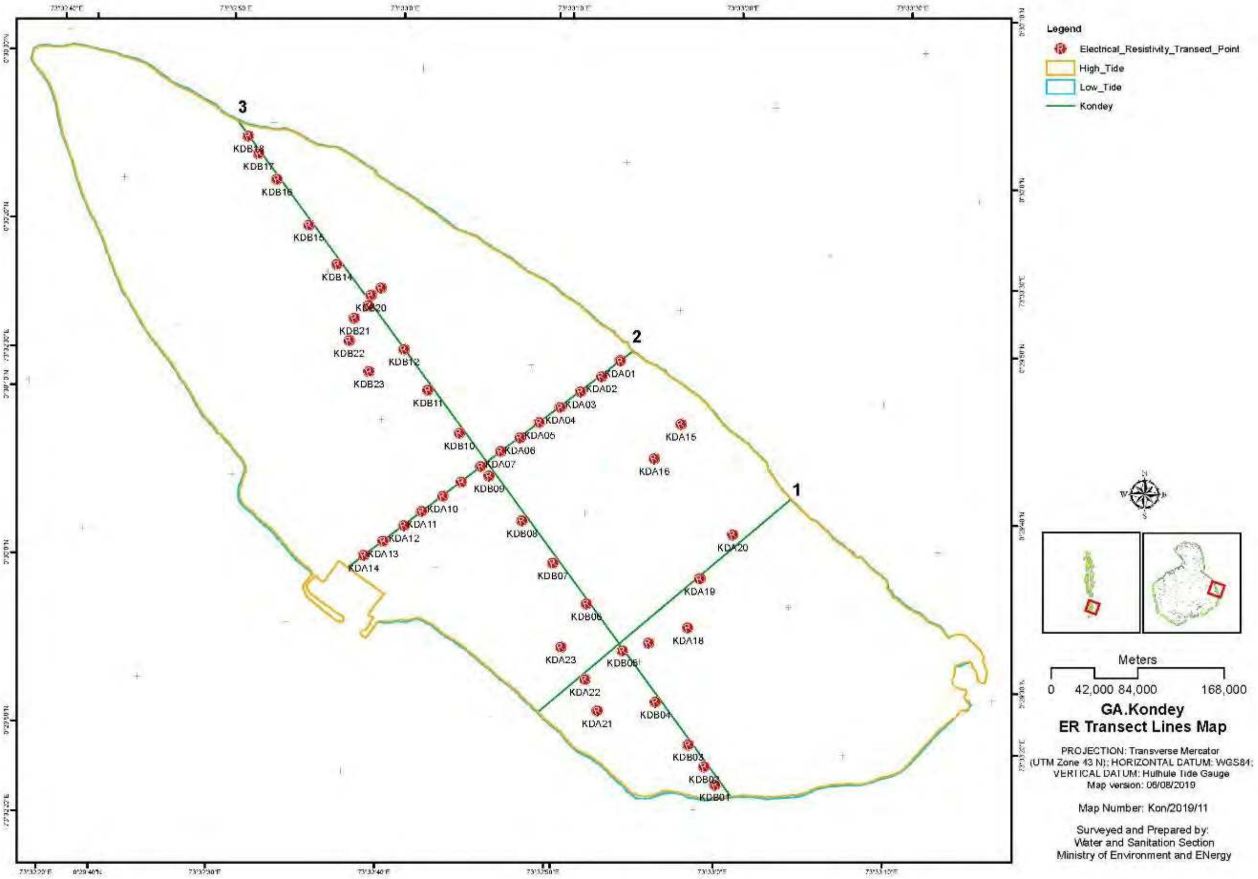
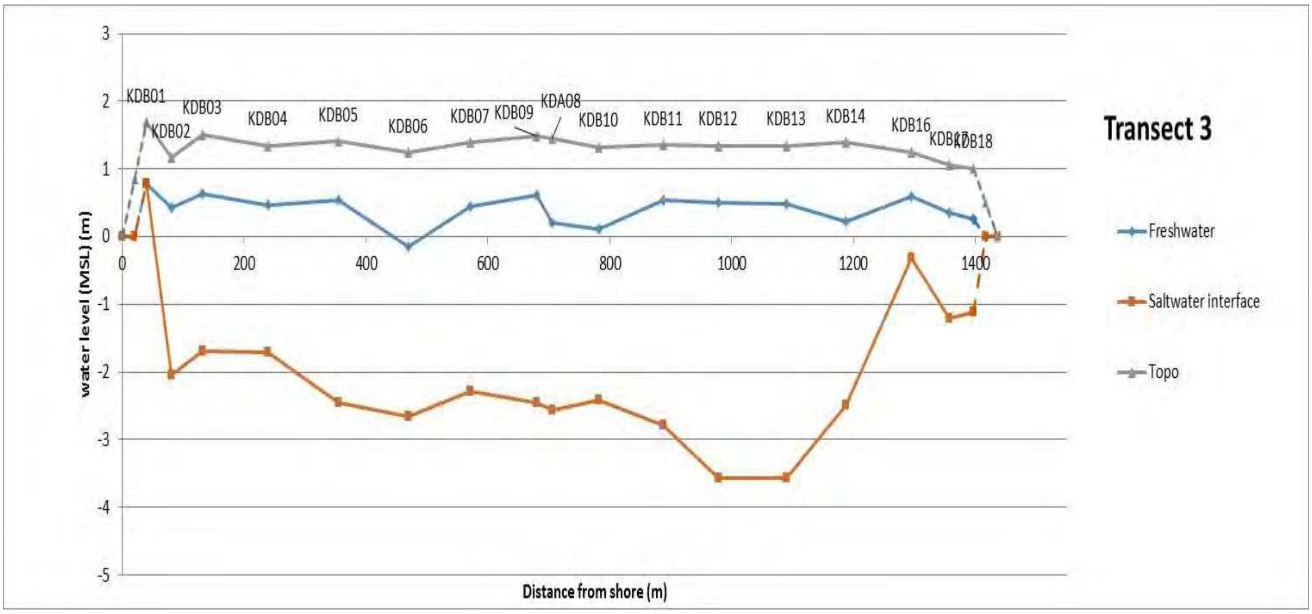


Figure 15.8: ER transect lines in Kondey Island



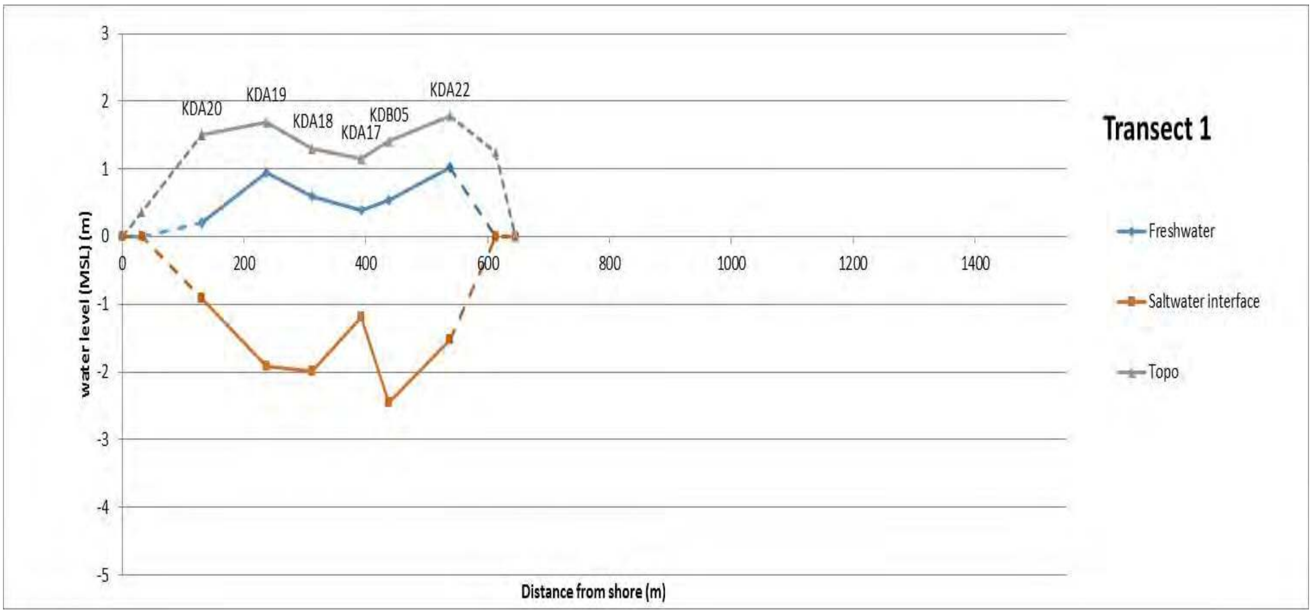
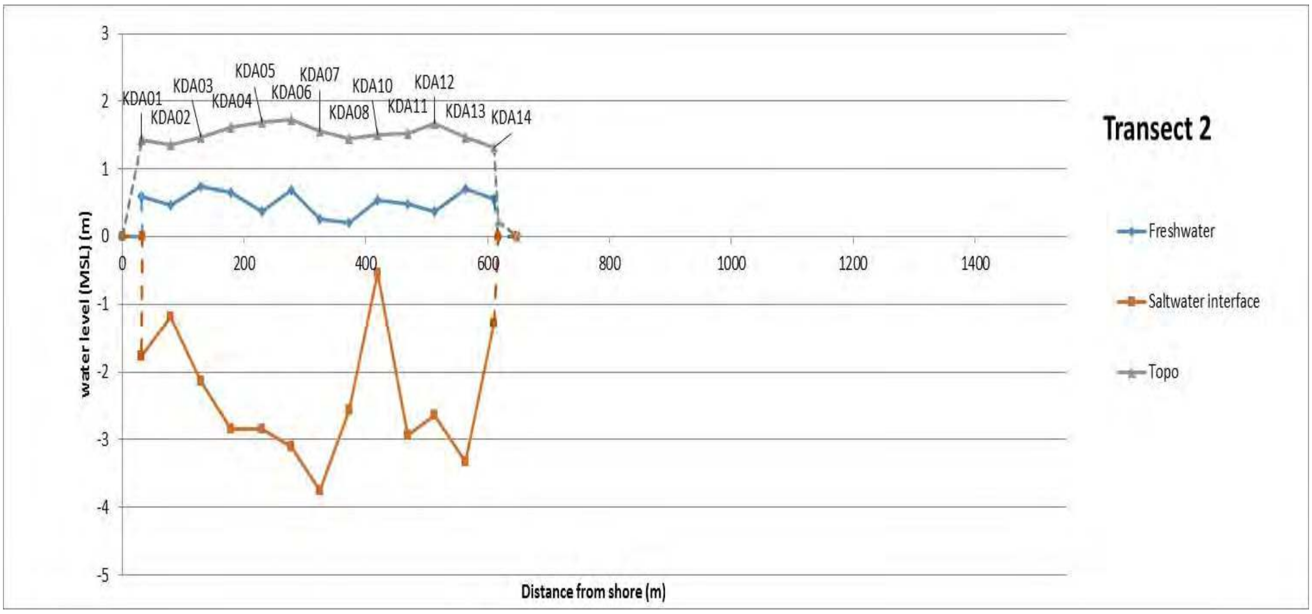


Figure 15.9: Cross-sections of transect lines in Kondey Island



The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented in the following pages.

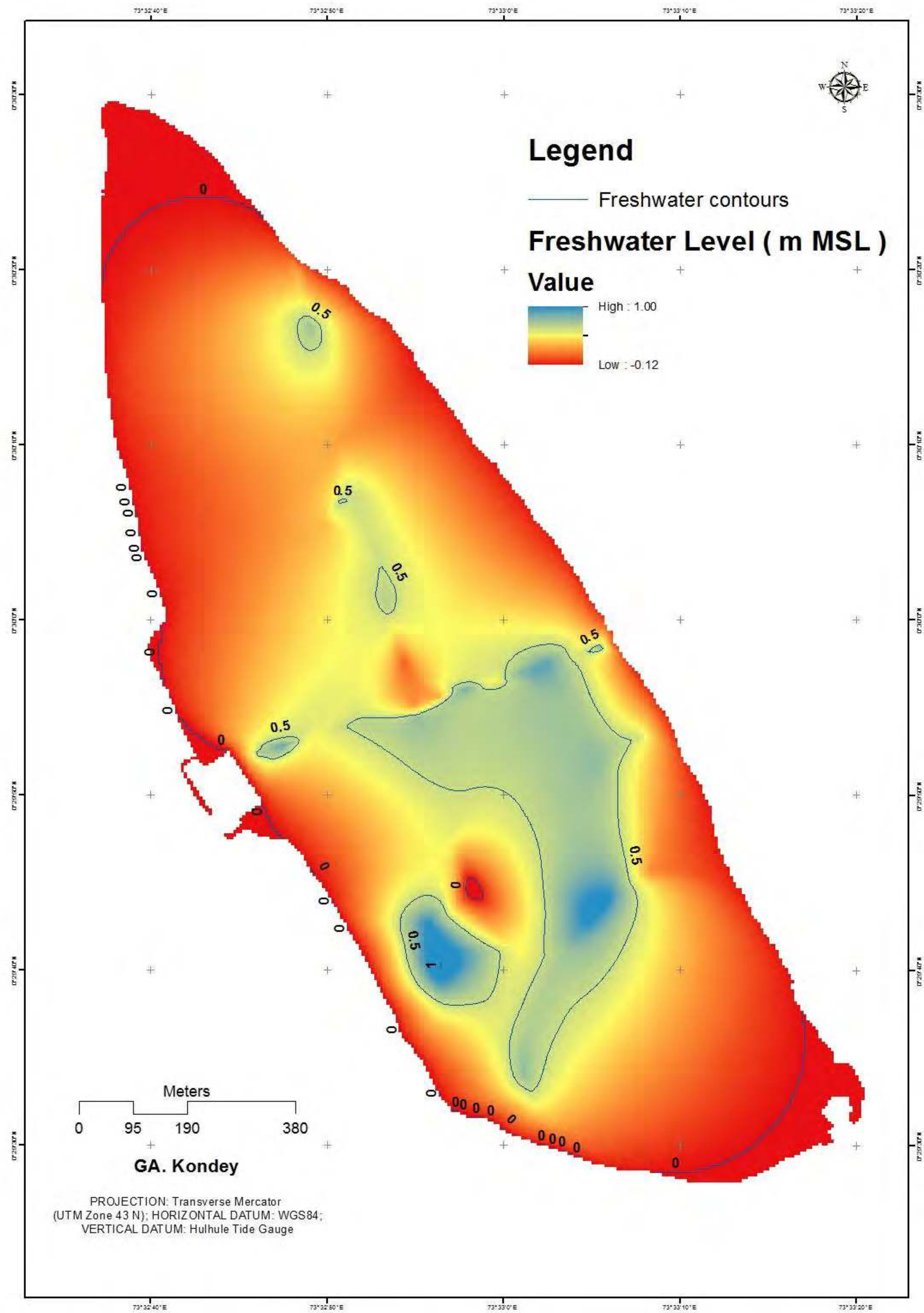


Figure 15.10: Freshwater Level in Kondey Island

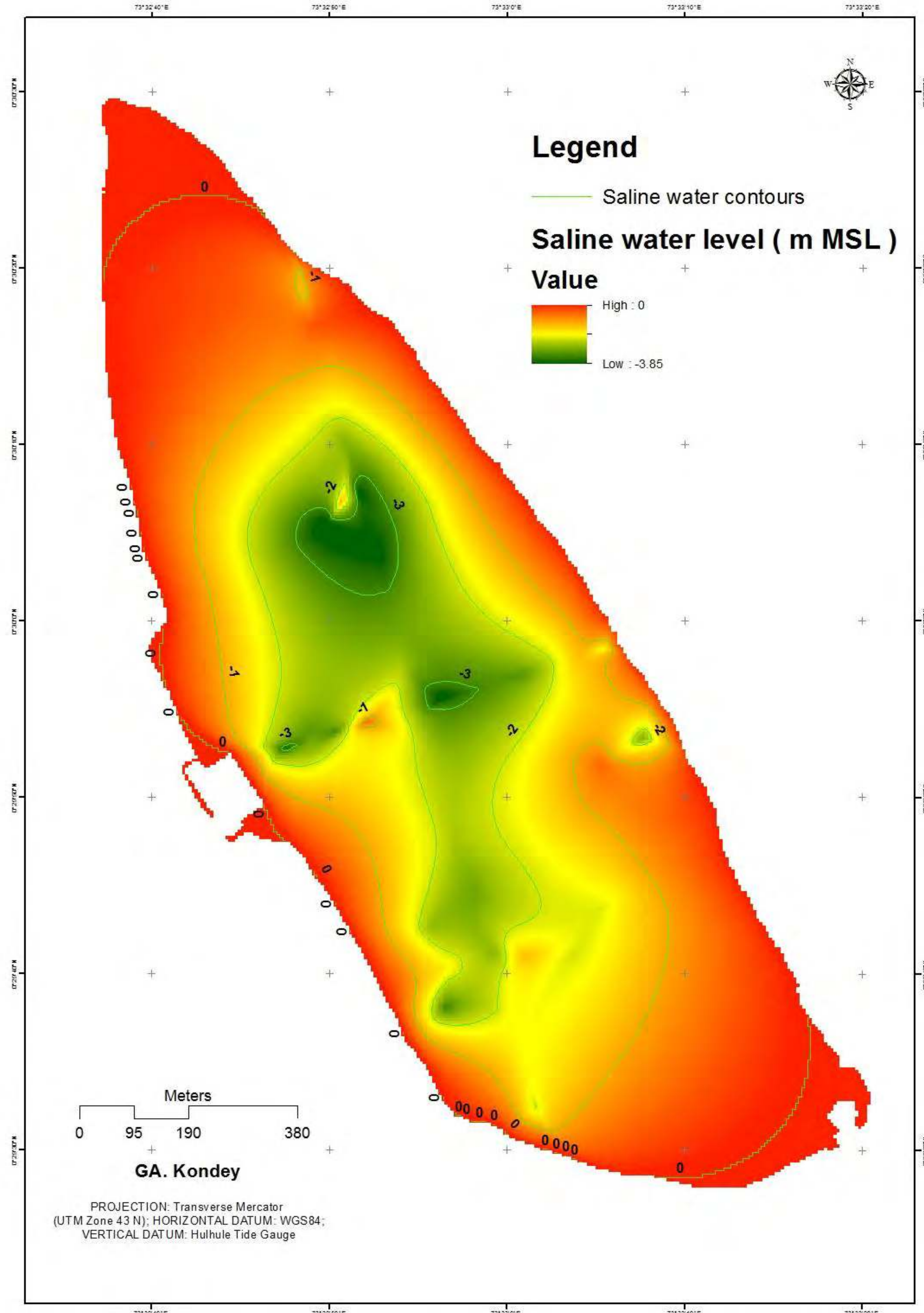


Figure 15.11: Saline water Level in Kondey Island

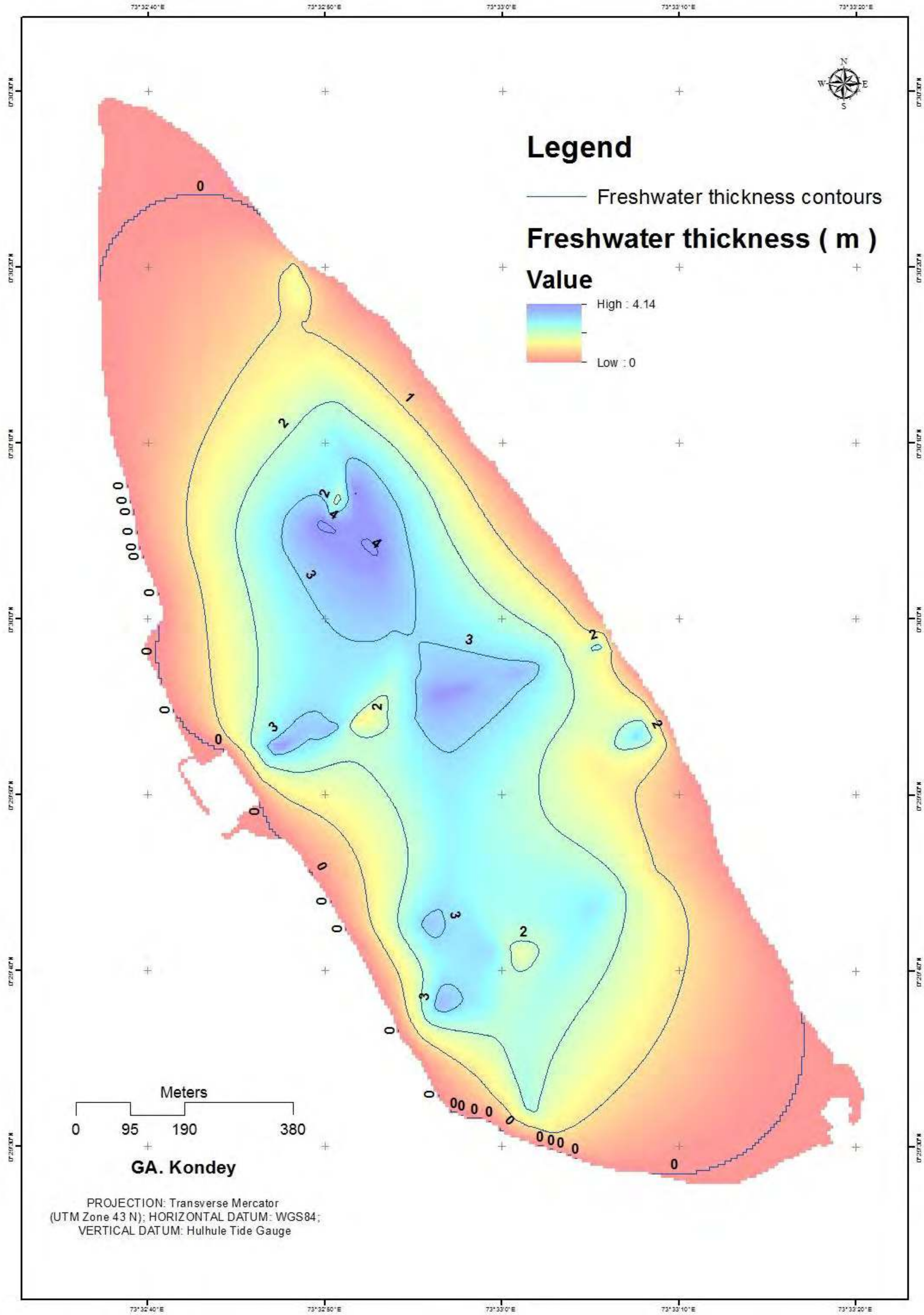


Figure 15.12: Freshwater thickness in Kondey Island

The maximum freshwater thickness of the island is 5.2 m. According to Falkland, 1994, the freshwater level thickness of the island is 9m. The relevant calculations are as follows;

Average Annual Rainfall = 2250 mm/yr

Width of the island = 649 m

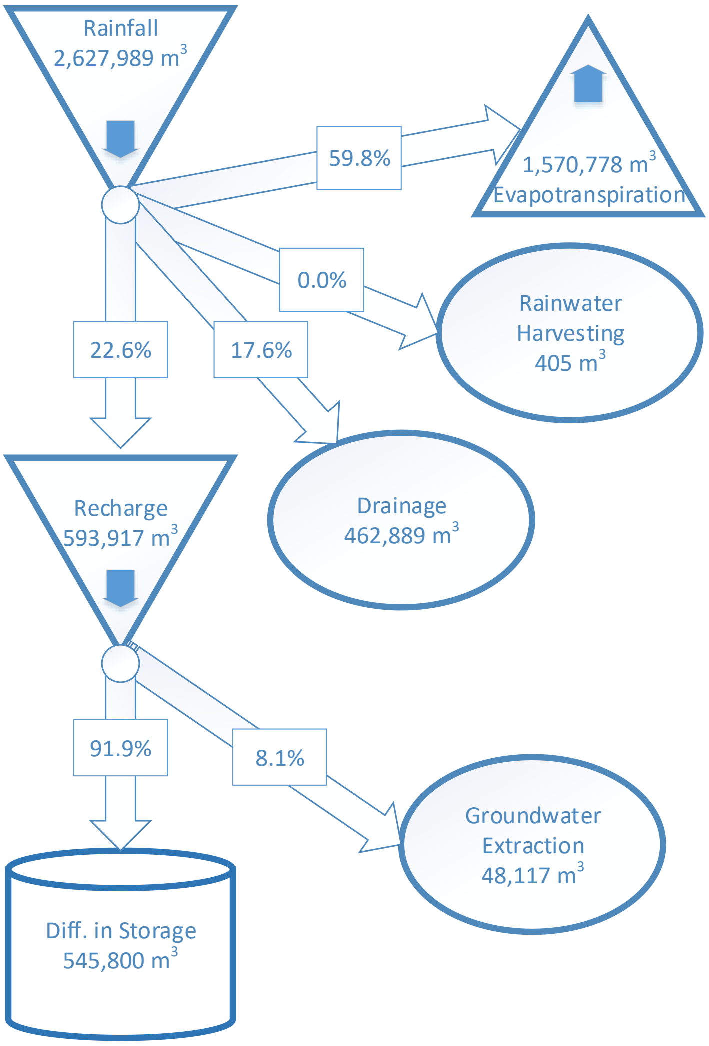
Length of the island = 1437 m

Freshwater lens Thickness (m)

= (6.94*log(width of the island)-14.38)*Average Annual Rainfall = 12 m

15.8.1 Water balance and recharge

An annual estimation is carried out based on water balance method. Rainwater harvesting is calculated using number of rainwater harvesting units in the island. According to the spatial mean annual rainfall of Maldives, the island is reported as 2250 mm/year. Evapotranspiration was estimated using crop water requirement for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. The groundwater extractions were estimated from amount of water usage in different sectors (residential, resorts, restaurants, agriculture and farming).The difference between recharge and groundwater extraction is taken to estimate different in storage.



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15.8.2 Sustainable yield of the lens

Sustainable yield of the water lens refers to the safe extraction potential of a given groundwater aquifer without significantly affecting its quality or quantity. This parameter is an important factor in the

sustainable development of islands as it allows planning and design of water and sanitation intervention in islands.

The island has a sustainable yield of 1495 m^3 per day which was calculated subtracting groundwater extraction from recharge volume derived from water balance (

Figure 8.13). According to Metai & Unit, n.d., based on geophysical investigations and drilling programme concluded that the safe sustainable yield was about 10% of mean annual rainfall. Such that the expected sustainable yield for the island should be 720 m^3 per day.

15.8.3 Permeability test

Permeability tests were carried out in the locations as outlined in Figure 15.14.

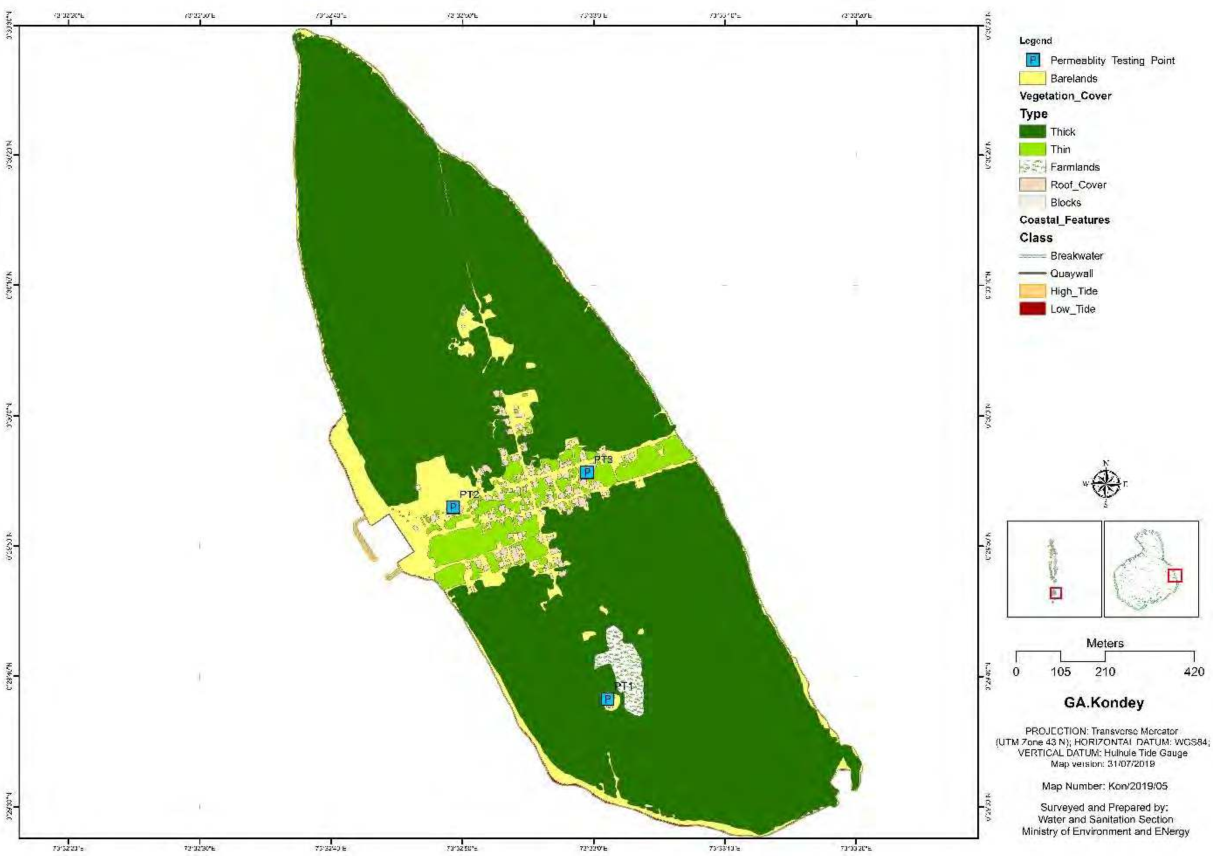

Figure 15.14: Locations of permeability tests in Kondey Island

The estimated permeability values for the above test locations are presented below.

Table 15.10: The estimated permeability Values

r_e	0.026
r1	0.0285

Point	H	Tu	Cs	H/re	Q	K (m/s)	K (m/day)		Q (l/min)	Q (m^3/s)
PT1	0.7	1	47	26.9	1.4E-04	2.07E-04	17.89		8.3	0.000138
PT2	0.7	1.5	47	26.9	6.7E-05	6.65E-05	5.75		4	6.67E-05
PT3	0.7	0.8	47	26.9	1.0E-04	1.89E-04	16.33		6.06	0.000101

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m^3/s), H = Height of water in well (m), l = length of perforated section (m), r_1 = outside radius of casing (radius of hole in consolidated material) (m), r_e = effective radius of well = r_1 (area of perforations) / (outside area of perforated section of casing) : $r_1 = r_e$ in consolidated material that will stand open and is not cast, C_u and C_s =Conductivity Coefficients, and T_u = distance from water level in casing to water table (m).

15.8.4 Groundwater availability

1) The selected Kondey island has dimensions of width = 700 m and length = 2205 m, with a total land area of 105.76 ha, a population of 272 persons, and a land use of built-up area 1.75 ha (1.5%), thick vegetation 96.51 ha (83.3%), light vegetation 5.19 ha (4.5%), barelands 1.02 (1.0%) and farmlands 1.30 ha (1.2%).

2) In order to recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of freshwater lens (FWL) and its associated recharge-discharge characteristics, 46 number of Electrical Resistivity (ER) location readings along 03 representatively selected transects were collected.

3) Soil overburden permeability tests (constant head) were carried out at 03 locations. In addition, groundwater level was also recorded at 20 locations where groundwater quality samples were tested.

4) Permeability tests were carried out at representatively selected 03 number of locations. The measured permeability (K m/day) values ranged from a minimum of 5.75 m/day to a maximum of 17.89 m/day, with an average of 13.32 ± 6.61 m/day (Mean ± 1 Standard Deviation).

5) The ground elevation values ranged from a minimum of 0.22 m MSL to a maximum of 2.44 m MSL, with an average of 1.34 ± 0.18 m MSL (Mean ± 1 Standard Deviation).

6) The upper boundary of the freshwater lens (FWL) varied from a minimum of -0.14 m MSL to a maximum of 1.65 m MSL, with an average of 0.61 ± 0.38 m MSL (Mean ± 1 Standard Deviation).

7) The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -3.90 m MSL to a maximum of 1.65 m MSL, with an average of -1.64 ± 1.53 m MSL (Mean ± 1 Standard Deviation).

8) Accordingly, the freshwater lens (FWL) thickness values ranged from a minimum of 0.00 m to a maximum of 4.18 m, with an average of 2.25 ± 1.29 m (Mean ± 1 Standard Deviation).

9) The groundwater profile in the island is characterised by a relatively Very Low (0.02%) Rainwater Harvesting, relatively Very Low (17.61%) Drainage, relatively Very Low (22.60%) Recharge, while the water use shows relatively Very Low (8.10%) Groundwater extraction, leading to relatively Very High (91.90%) Difference in Balance Storage.

10) The freshwater lens (FWL) volume calculated based on ER transect test data is 601,600 m^3 with a maximum FWL thickness of 4.18 m. The potential maximum FWL volume and thickness estimated based on Falkland (1994) method are 157,211 m^3 and 11.56 m.

15.8.5 Conclusive Comments and Recommendations

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 1,495 m^3 per day, while it is 720 m^3 per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 138 m^3 per day and this is about 19% of the allowable Safe Yield in the island with moderate up-coning and moderate drawdown in freshwater lens cross-sections. At present, there exists no island-wide sewerage network or water supply network. The water samples tested were found to be Slightly Odorous with 30.8% or 4/13 samples tested producing odour. The Hydrological condition of the freshwater lens aquifer can be categorised as Moderate based on above measurements and findings while Water quality aspects can be regarded as Contaminated with an Average Electrical Conductivity (EC) of 636.83 ± 119.45 µS/cm with measured values ranging from a minimum of 360.60 µS/cm to a maximum of 793.10 µS/cm, and an Average Ammonia Concentration of 0.99 ± 2.31 mg/L with measured values ranging from a minimum of 0.06 mg/L to a maximum of 8.62 mg/L.

The Availability of space for incorporating recharge measures and related infrastructure is High while therefore the Potential for Recharging is considered to be High. Overall recommendation for groundwater recharging would be to use recharging trenches and ponds.

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Annex I: List of islands selected for the study

1) AA. Bodufulhadhoo
2) ADh. Dhigurah
3) Dh. Meedhoo
4) Ga. Kon'dey
5) GDh. Fiyoari
6) Ha. Utheem
7) HDh. Nolhivaramfaru
8) M. Raiymandhoo
9) N. Hen'badhoo
10) Sh. Funadhoo
11) Th. Kin'bidhoo
12) B. Dharavandhoo
13) R. Maduvvari

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Annex II: Maps of the surveyed islands with recharge areas indicated

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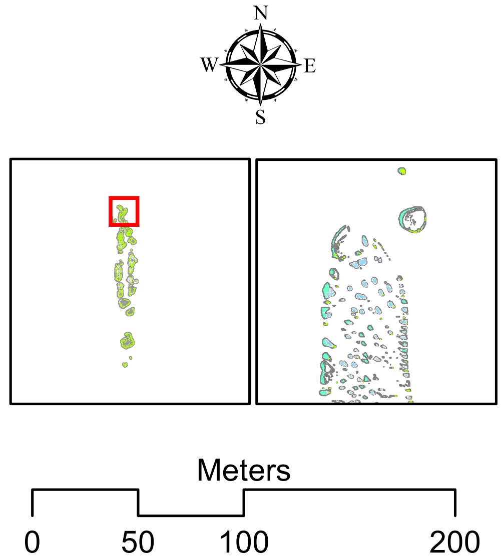
Recharging Potential

Entire land ares is suitable for Groundwater recharging. The most appropriate recharging structures are recharging trenches (in roads & forest area) and recharging pits (individual household and land blocks)

Legend

High Tide Line

Low Tide Line

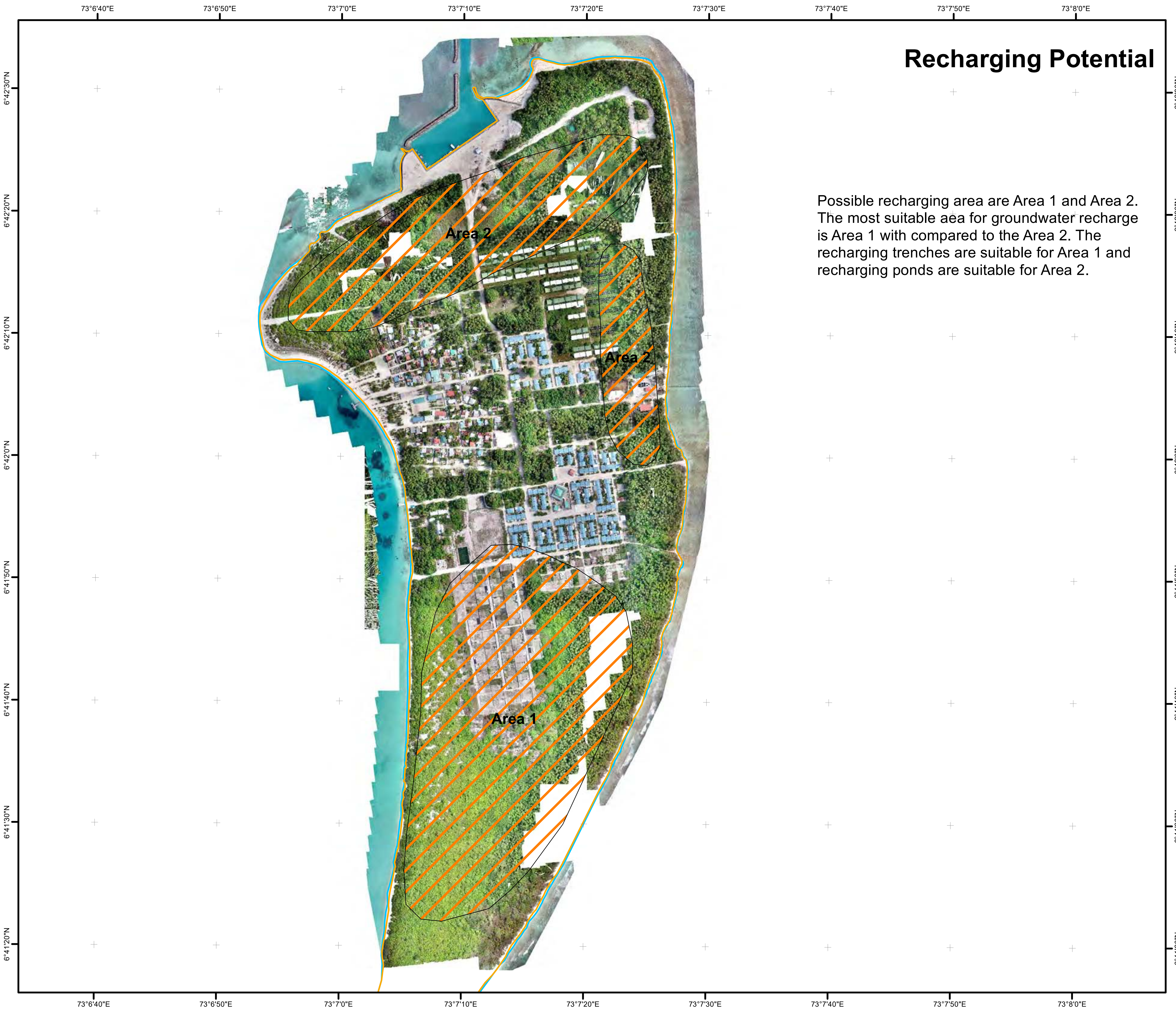


HA. Utheemu

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/18/2019

Map Number: Utheem/2019/08

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy



Legend

- Recharging areas
- High Tide Line
- Low Tide Line

Meters

0 130 260 520

HDh. Nolhivaranfaru

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/18/2019

Map Number: Nolhi/2019/08

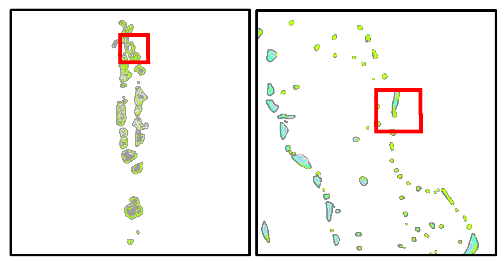
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

Recharging Potential

The recharging potential of the island is low. The area 1 is slightly suitable for the recharging. The recharging pits within individual land blocks (if space is available could be used).

Legend

- Recharging areas
- High Tide Line
- Low Tide Line



Meters

0 212.5 425 850

Sh.Funadhoo

PROJECTION: Transverse Mercator (UTM Zone 43 N); HORIZONTAL DATUM: WGS84; VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/18/2019

Map Number: FUNA-2019-08

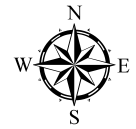
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

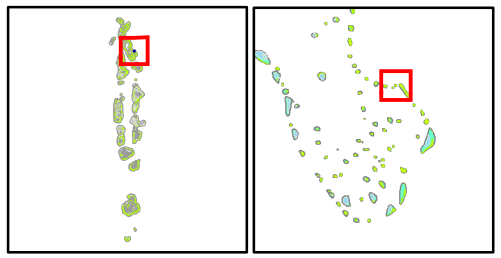
Recharging Potential

The recharging potential in the water bearing formation is available in the middle part of the island, however, limited. Bareland space is available. The trenches along the roads and recharging pit (space in the individual land block) are the most appropriate methods for groundwater recharging.

Legend

- High Tide Line
- Low Tide Line





Meters

0 30 60 120

N. Hen'badhoo

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/18/2019

Map Number: Henb/2019/09

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

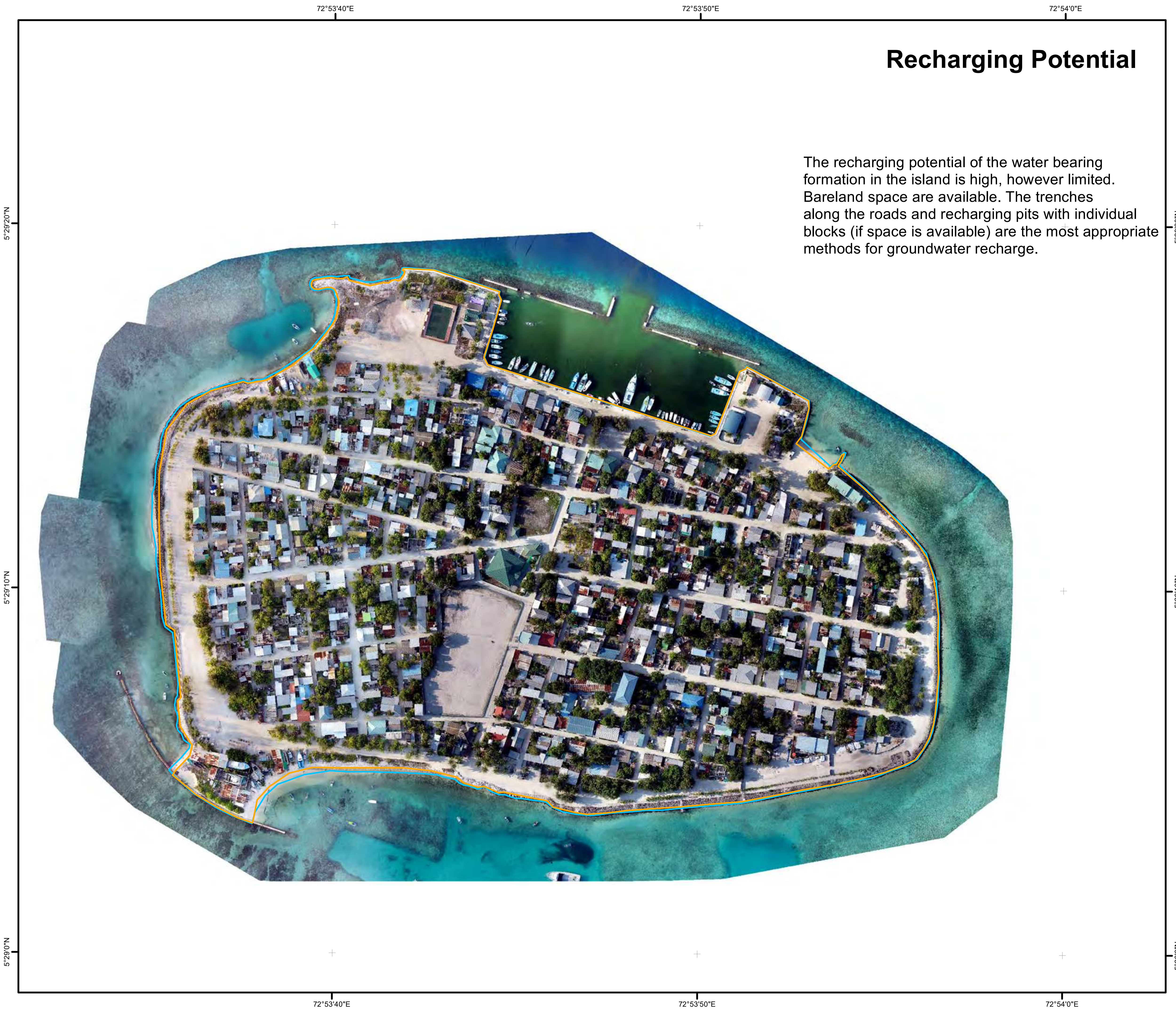
Recharging Potential

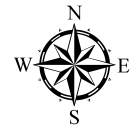
Legend

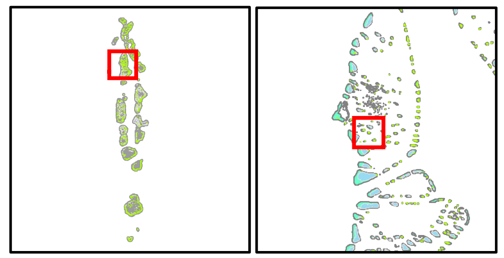
High Tide Line

Low Tide Line

The recharging potential of the water bearing formation in the island is high, however limited. Bareland space are available. The trenches along the roads and recharging pits with individual blocks (if space is available) are the most appropriate methods for groundwater recharge.







Meters

0 40 80 160

R. Maduvvari

PROJECTION: Transverse Mercator (UTM Zone 43 N); HORIZONTAL DATUM: WGS84; VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/18/2019

Map Number: Madu/2019/09

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

B.Dharavandhoo

Recharging Potential

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/18/2019

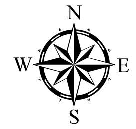
Map Number: Dh-2019-08

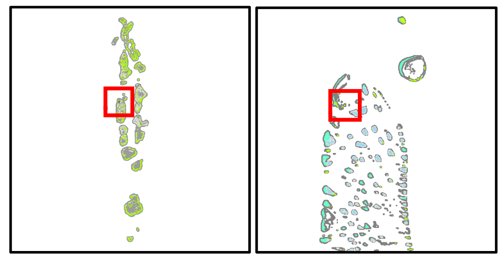
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

Recharging Potential

Legend

- High Tide Line
- Low Tide Line





Meters

0 37.5 75 150

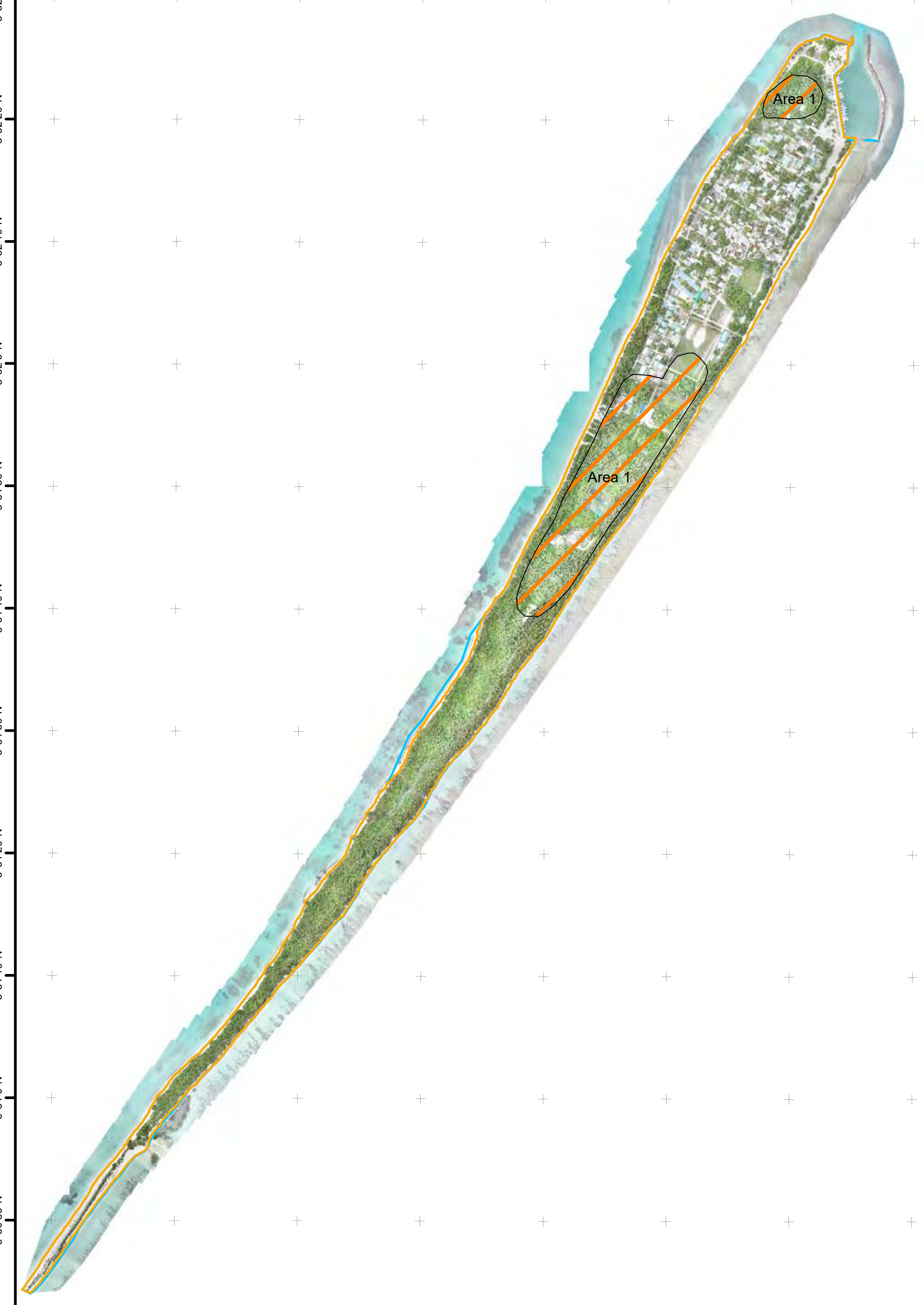
AA. Bodufulhadhoo

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/18/2019

Map Number: BF-2019-10

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

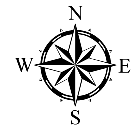
Recharging Potential

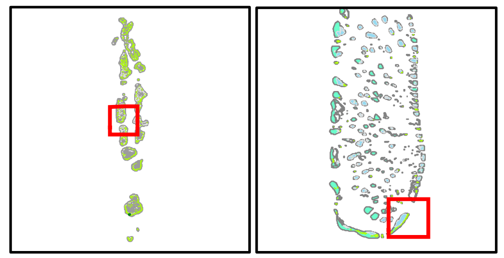


The highlighted Area 1 is suitable for the recharging exercises. Trenches and ponds are the most appropriate methods. The recharging pits within individual land blocks (if space is available) is suitable.

Legend

- Recharging areas
- High Tide Line
- Low Tide Line





Meters

0 195 390 780

ADh. Dhigurah

PROJECTION: Transverse Mercator (UTM Zone 43 N); HORIZONTAL DATUM: WGS84; VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/18/2019

Map Number: DG-2019-09

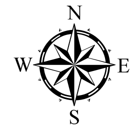
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

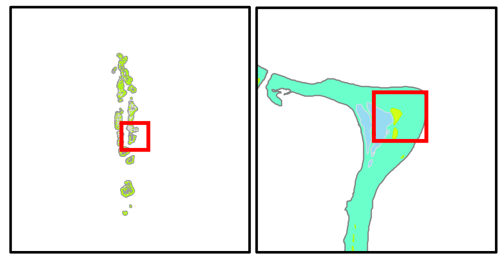
Recharging Potential

The selected areas (area 1) is suitable for groundwater recharging exceses. The appropriate recharging methods are trenches, ponds and recharging pits. Area 2 is suitable for recharging pits, for individual land blocks.

Legend

- Recharging areas
- High Tide Line
- Low Tide Line





Meters

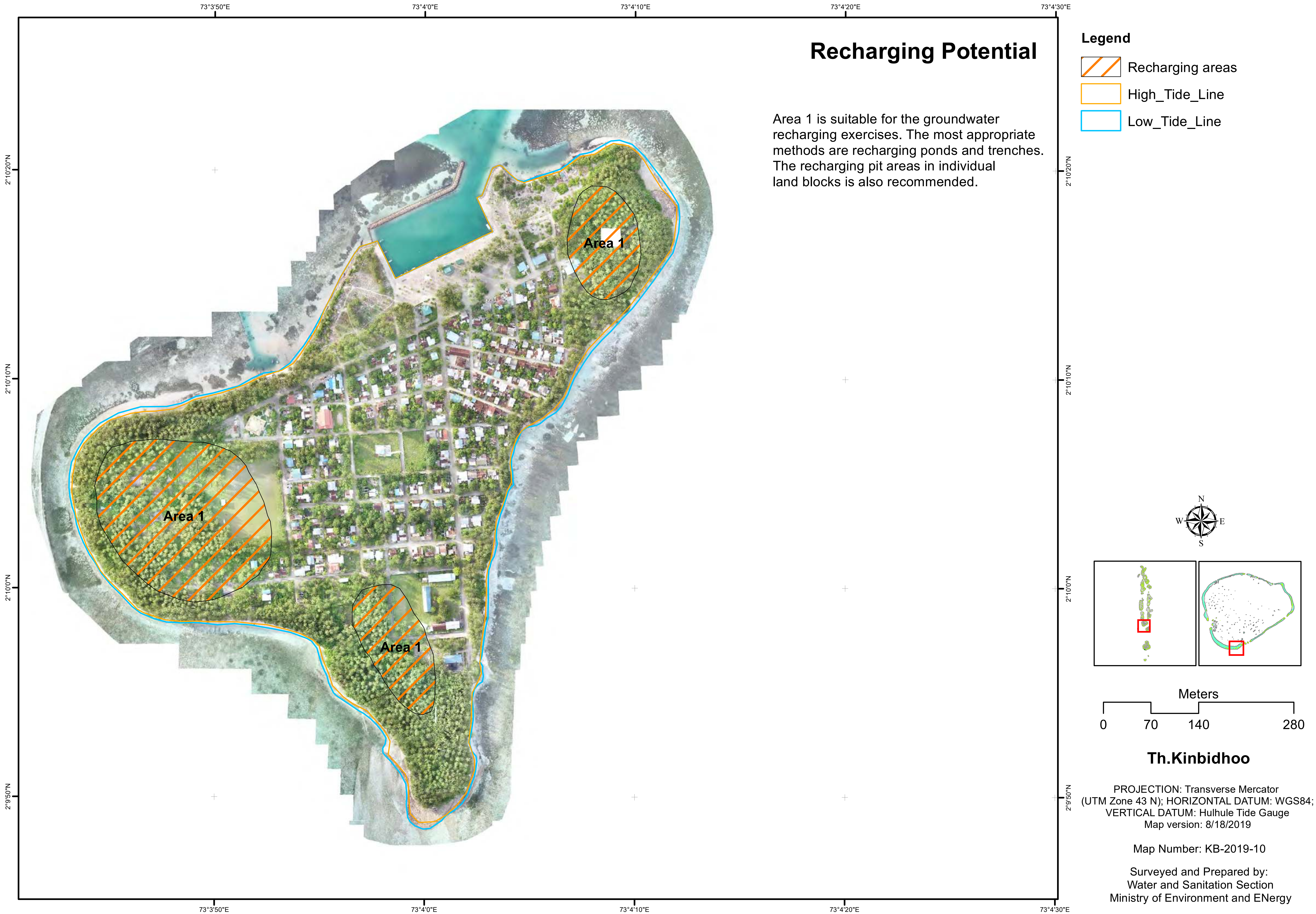
0 62.5 125 250

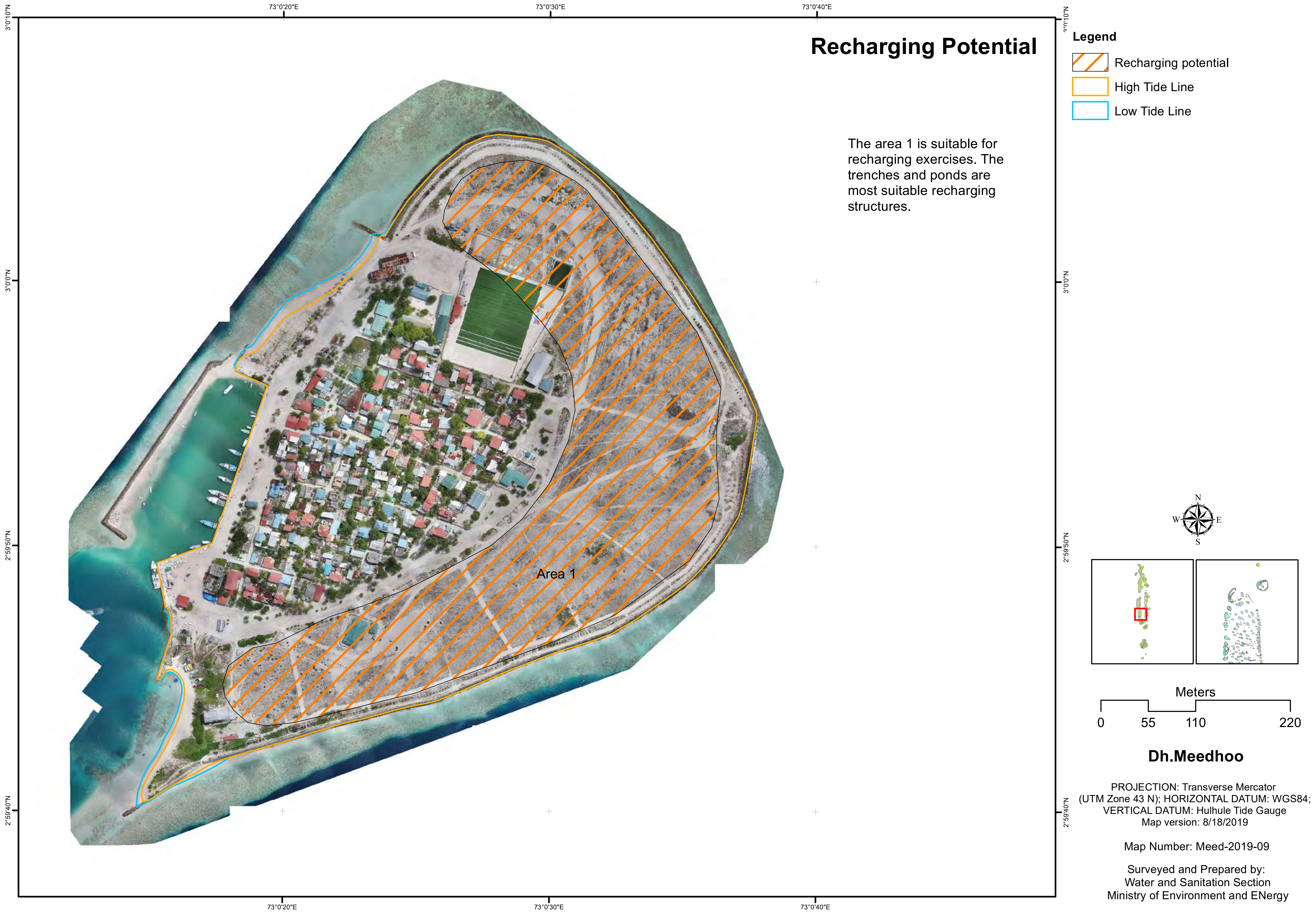
M. Raiymandhoo

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/18/2019

Map Number: Raiy/2019/10

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


Recharging Potential
Area 1 is suitable for the groundwater recharging exercises. The most appropriate methods are recharging ponds and trenches. The recharging pit areas in individual land blocks is also recommended.
Legend
Recharging areas
High_Tide_Line
Low_Tide_Line
Area 1
Area 1
Area 1
73°3'50"E
73°4'0"E
73°4'10"E
73°4'20"E
73°4'30"E
2°10'20"N
2°10'10"N
2°10'0"N
2°9'50"N
N
S
E
W
Meters
0
70
140
280
Th.Kinbidhoo
PROJECTION: Transverse Mercator (UTM Zone 43 N); HORIZONTAL DATUM: WGS84; VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/18/2019
Map Number: KB-2019-10
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


Recharging Potential
Legend
Recharging potential
High Tide Line
Low Tide Line
The area 1 is suitable for recharging exercises. The trenches and ponds are most suitable recharging structures.
Area 1
73°0'20"E
73°0'30"E
73°0'40"E
3°0'10"N
3°0'0"N
2°59'50"N
2°59'40"N
N
W
E
S
Meters
0
55
110
220
Dh.Meedhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/18/2019
Map Number: Meed-2019-09
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

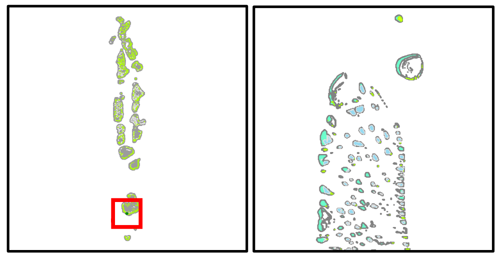
Recharging Potential

The Area 1 and Area 2 are suitable for the groundwater recharging excercises. Ponds, trenches, pits and latterals are appropriate methods for groundwater recharging in Area 1. Impoundary Earth dams are suitable for Area 2. In addition, recharging pits could be used for other individual households and land blocks.

Legend

- Recharging areas
- High Tide Line
- Low Tide Line

N
W E
S



Meters

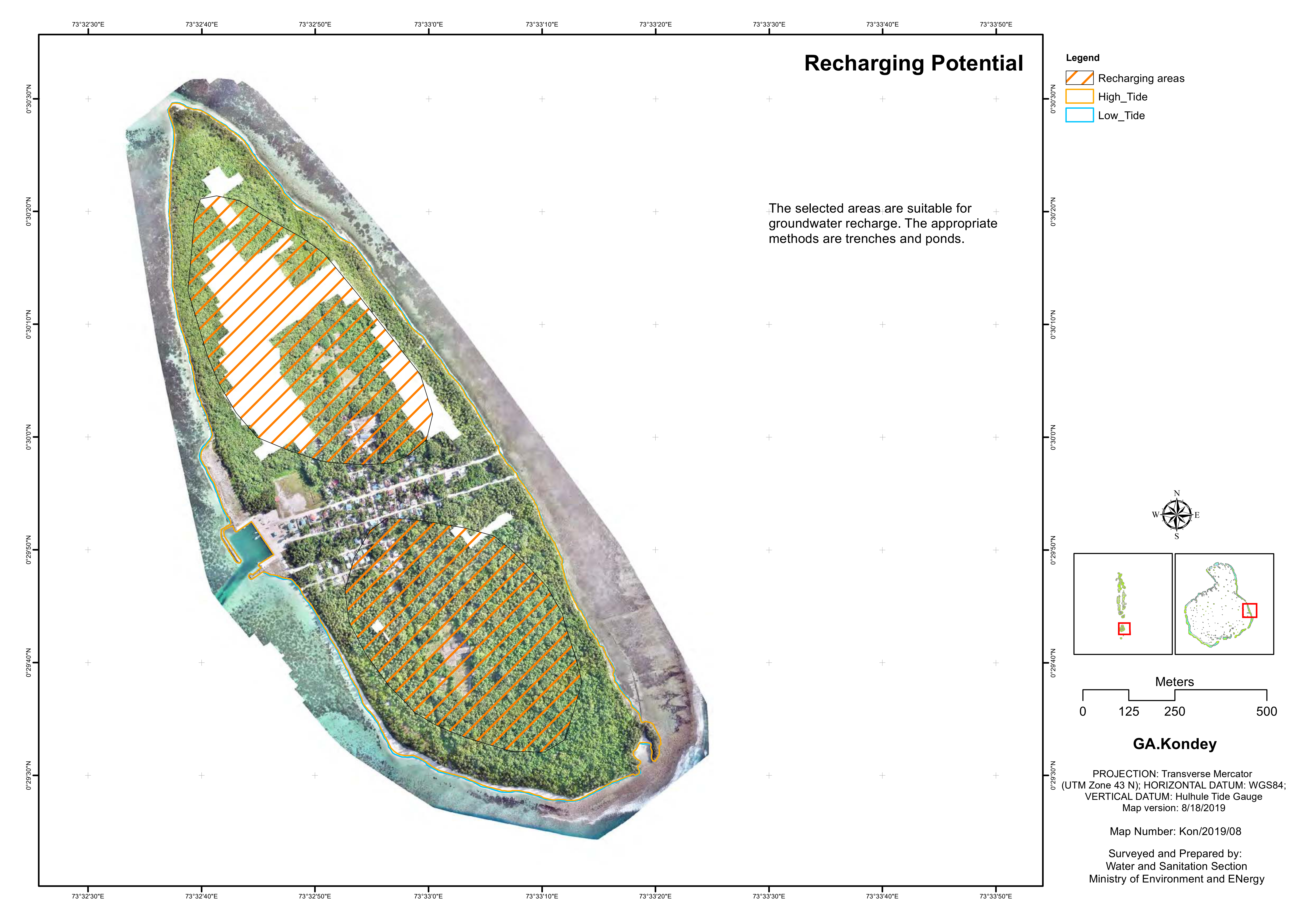
0 34,500 69,000 138,000

GDh. Fiyori

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/18/2019

Map Number: Fiyo/2019/10

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

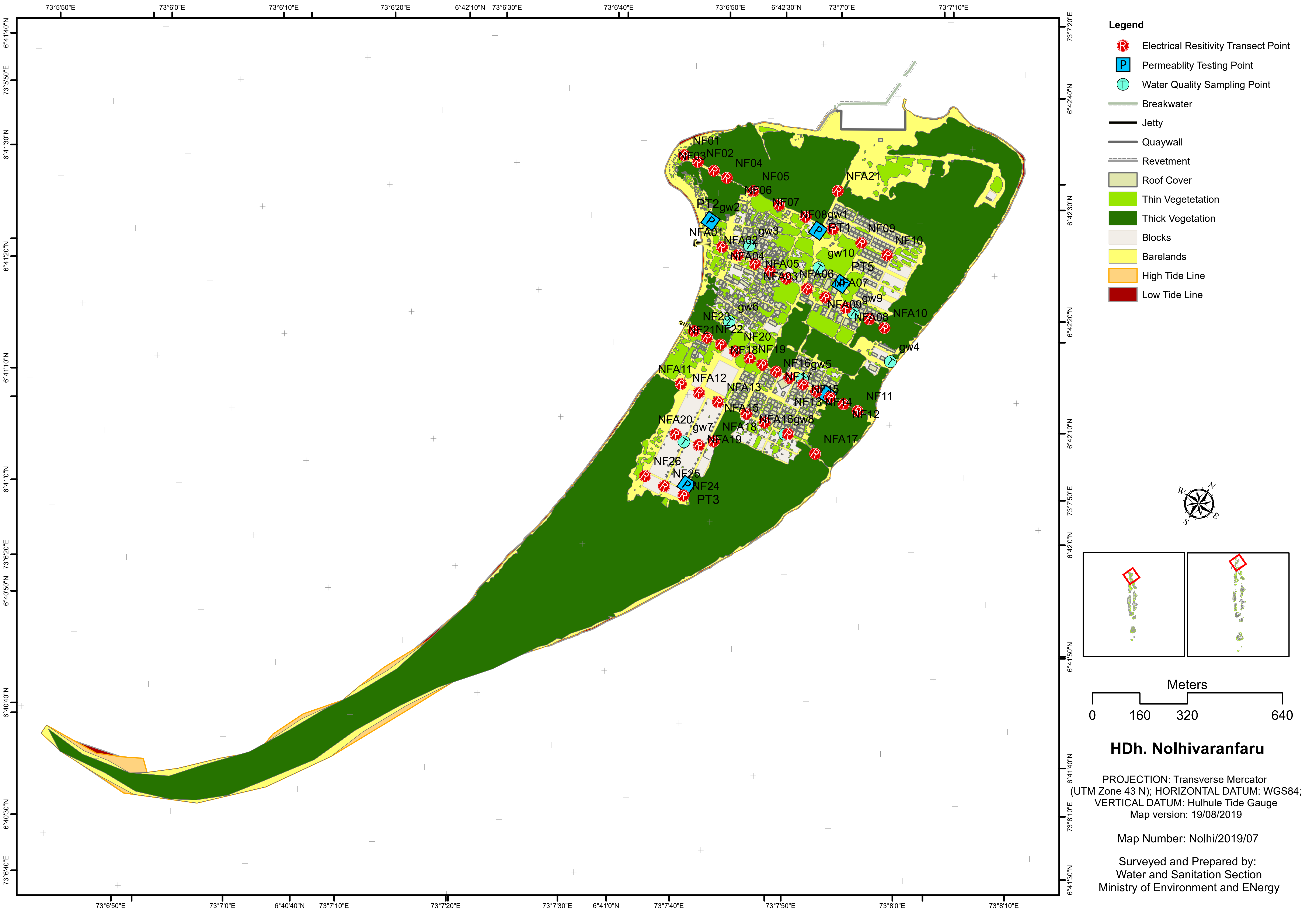


Recharging Potential
Legend
Recharging areas
High_Tide
Low_Tide
The selected areas are suitable for groundwater recharge. The appropriate methods are trenches and ponds.
73°32'30"E
73°32'40"E
73°32'50"E
73°33'0"E
73°33'10"E
73°33'20"E
73°33'30"E
73°33'40"E
73°33'50"E
0°30'30"N
0°30'20"N
0°30'10"N
0°30'0"N
0°29'50"N
0°29'40"N
0°29'30"N
N
S
E
W
Meters
0
125
250
500
GA.Kondey
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 8/18/2019
Map Number: Kon/2019/08
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

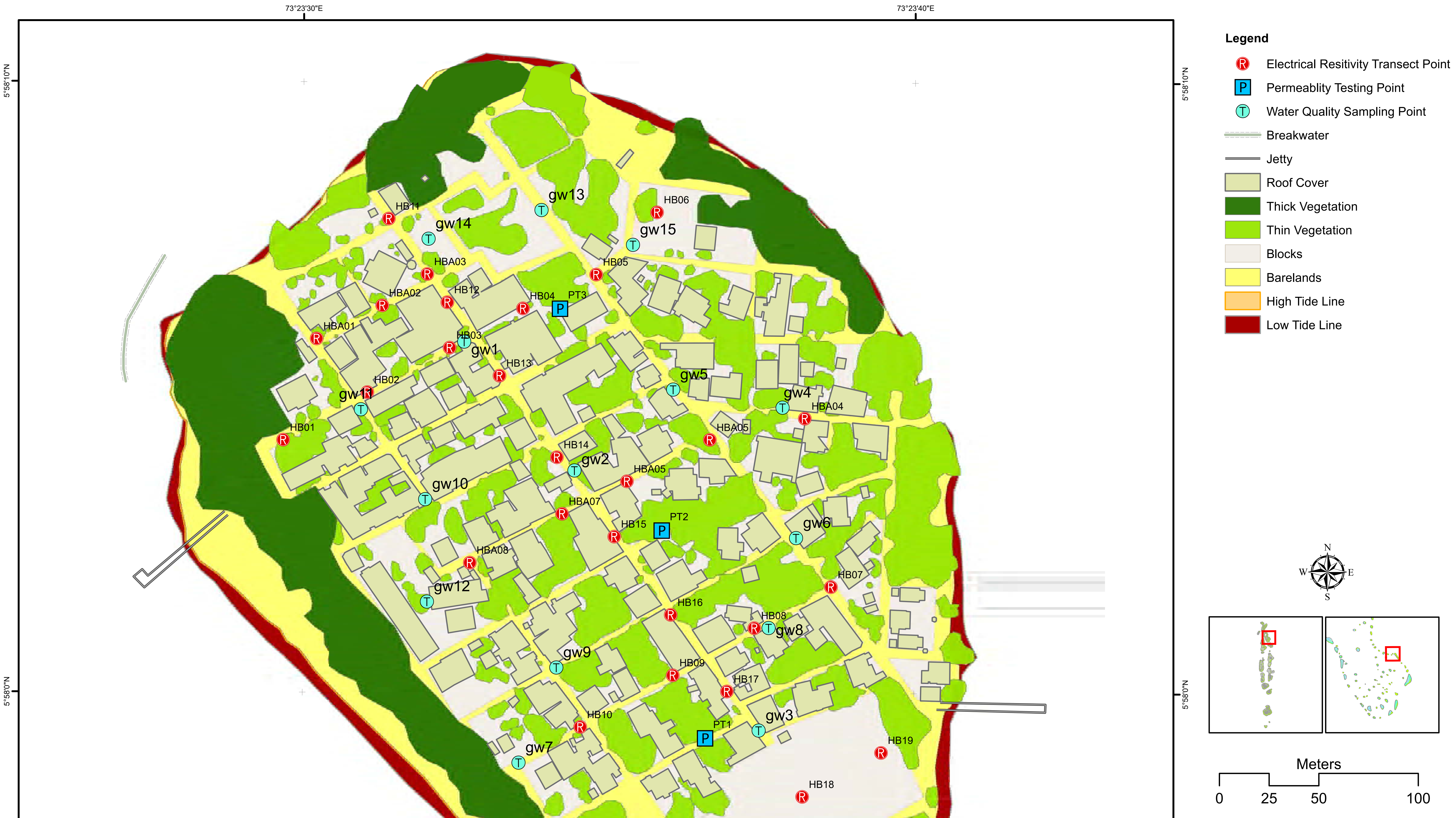
Annex III: Maps of the surveyed islands with surveyed points

BLANK PAGE


73°6'30"E
73°6'40"E
73°6'50"E
73°7'0"E
6°50'10"N
6°50'0"N
Legend
Electrical Resitivity Transect Point
Permeablity Testing Point
Water Quality Sampling Point
Break_Water
Quay_Wall
Revetment
Thin Vegetation
Thick Vegetation
Roof Cover
Blocks
Barelands
High Tide Line
Low Tide Line
N
E
S
W
Meters
0 45 90 180
HA. Utheemu
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 19/08/2019
Map Number: Utheem/2019/07
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy
Quay_Wall
Revetment
Break_Water
PT1
PT2
PT3
PT4
PT5
gw1
gw2
gw3
gw4
gw5
gw6
gw7
gw9
gw10
UM01
UM02
UM03
UM04
UM05
UM06
UM07
UM08
UM10
UM11
UM12
UM13
UM14
UM15
UM16
UM17
UM19
UM21
UM22
UM23
UM24
UM25
UM26
UMA01
UMA02
UMA03
UMA04
UMA05
UMA06
UMA07
UMA08
UMA09
UMA10
UMA11
UMA12
UMA13
UMA14
UMA15
UMA16
UMA17
UMA18
UMA19
UMA20


Legend
Electrical Resitivity Transect Point
Permeablity Testing Point
Water Quality Sampling Point
Breakwater
Jetty
Quaywall
Revetment
Roof Cover
Thin Vegetetation
Thick Vegetation
Blocks
Barelands
High Tide Line
Low Tide Line
Meters
0 160 320 640
HDh. Nolhivaranfaru
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 19/08/2019
Map Number: Nolhi/2019/07
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


Legend
Electrical Resitivity Transect Point
Permeablity Testing Point
Water Quality Sampling Point
Breakwater
Quaywall
Revetment
Barelands
Roof Cover
Thin Vegetation
Thick Vegetation
High Tide Line
Low Tide Line
Meters
0 90 180 360
Sh.Funadhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 18/08/2019
Map Number: FUNA-2019-07
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

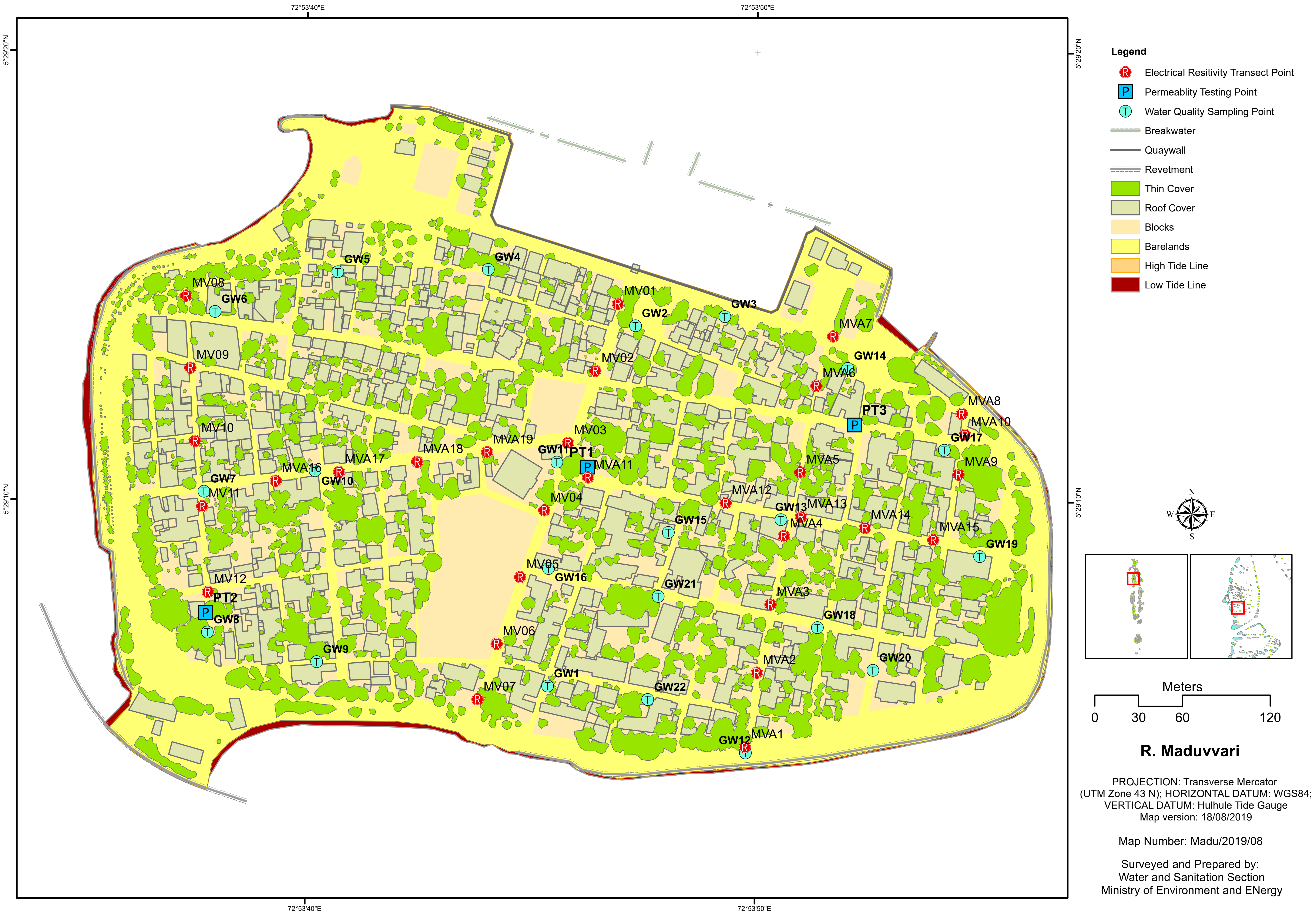


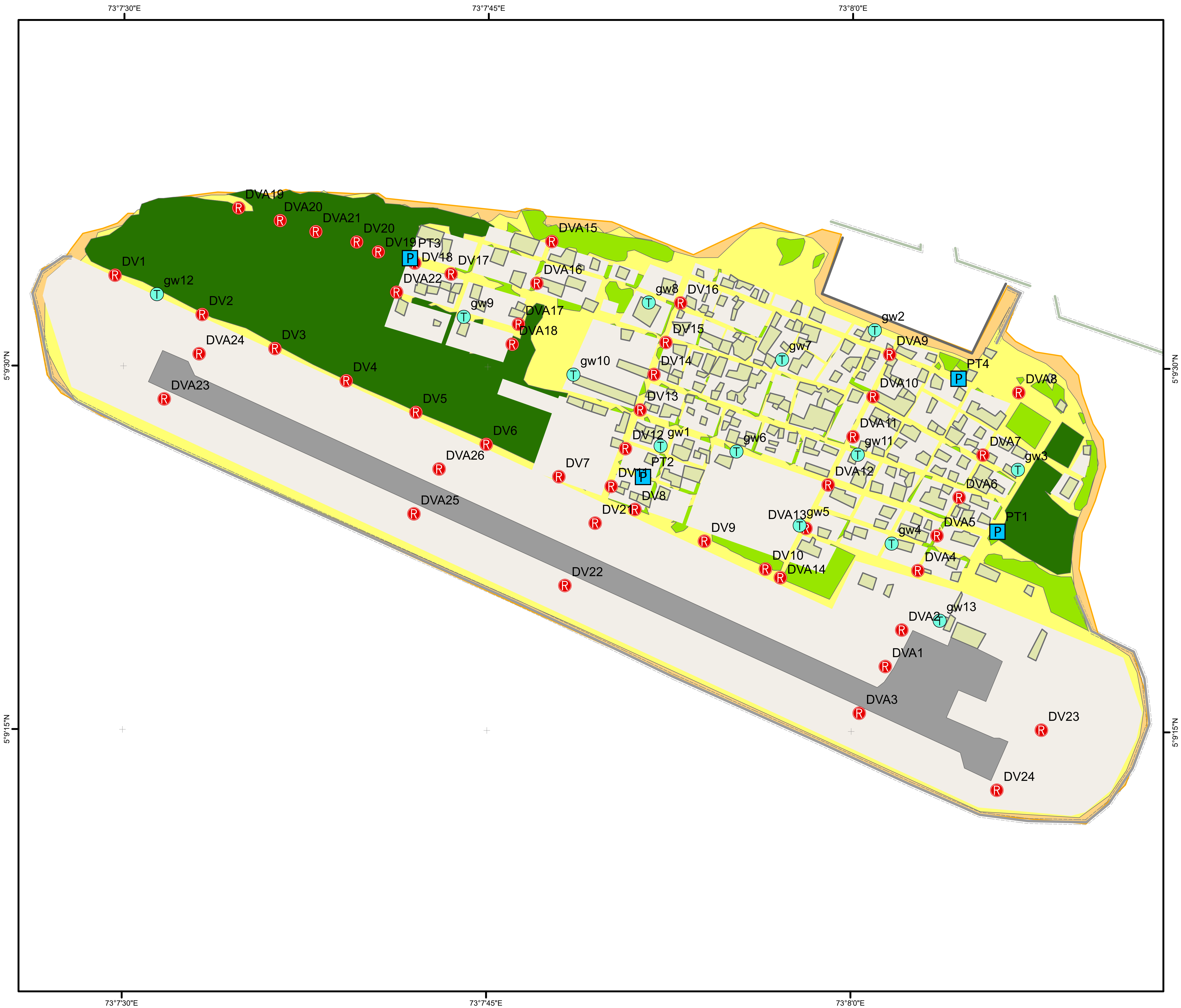
N. Hen'badhoo

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 18/08/2019

Map Number: Henb/2019/08

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


72°53'40"E
72°53'50"E
5°29'20"N
5°29'10"N
Legend
Electrical Resitivity Transect Point
Permeablity Testing Point
Water Quality Sampling Point
Breakwater
Quaywall
Revetment
Thin Cover
Roof Cover
Blocks
Barelands
High Tide Line
Low Tide Line
N
S
E
W
Meters
0
30
60
120
R. Maduvvari
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 18/08/2019
Map Number: Madu/2019/08
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy
GW1
GW2
GW3
GW4
GW5
GW6
GW7
GW8
GW9
GW10
GW11
GW12
GW13
GW14
GW15
GW16
GW17
GW18
GW19
GW20
GW21
GW22
PT1
PT2
PT3
MV01
MV02
MV03
MV04
MV05
MV06
MV07
MV08
MV09
MV10
MV11
MV12
MVA1
MVA2
MVA3
MVA4
MVA5
MVA6
MVA7
MVA8
MVA9
MVA10
MVA11
MVA12
MVA13
MVA14
MVA15
MVA16
MVA17
MVA18
MVA19



Legend

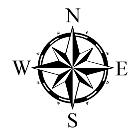
- Ground Water Sample Locations
- Permeability Testing Locations
- Electrical Resistivity Transect locations

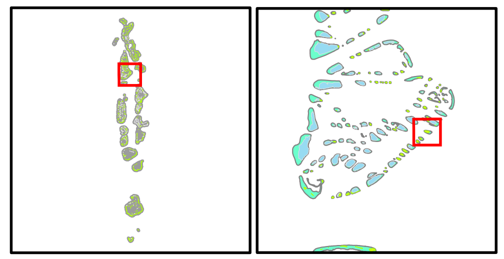
Coastal Features

- Breakwater
- Quaywall
- Revetment
- Runway
- Roof cover
- blocks

Vegeation Cover

- Thick
- Thin
- Bareland
- Vegetation line
- Shoreline





Meters

0 50 100 200

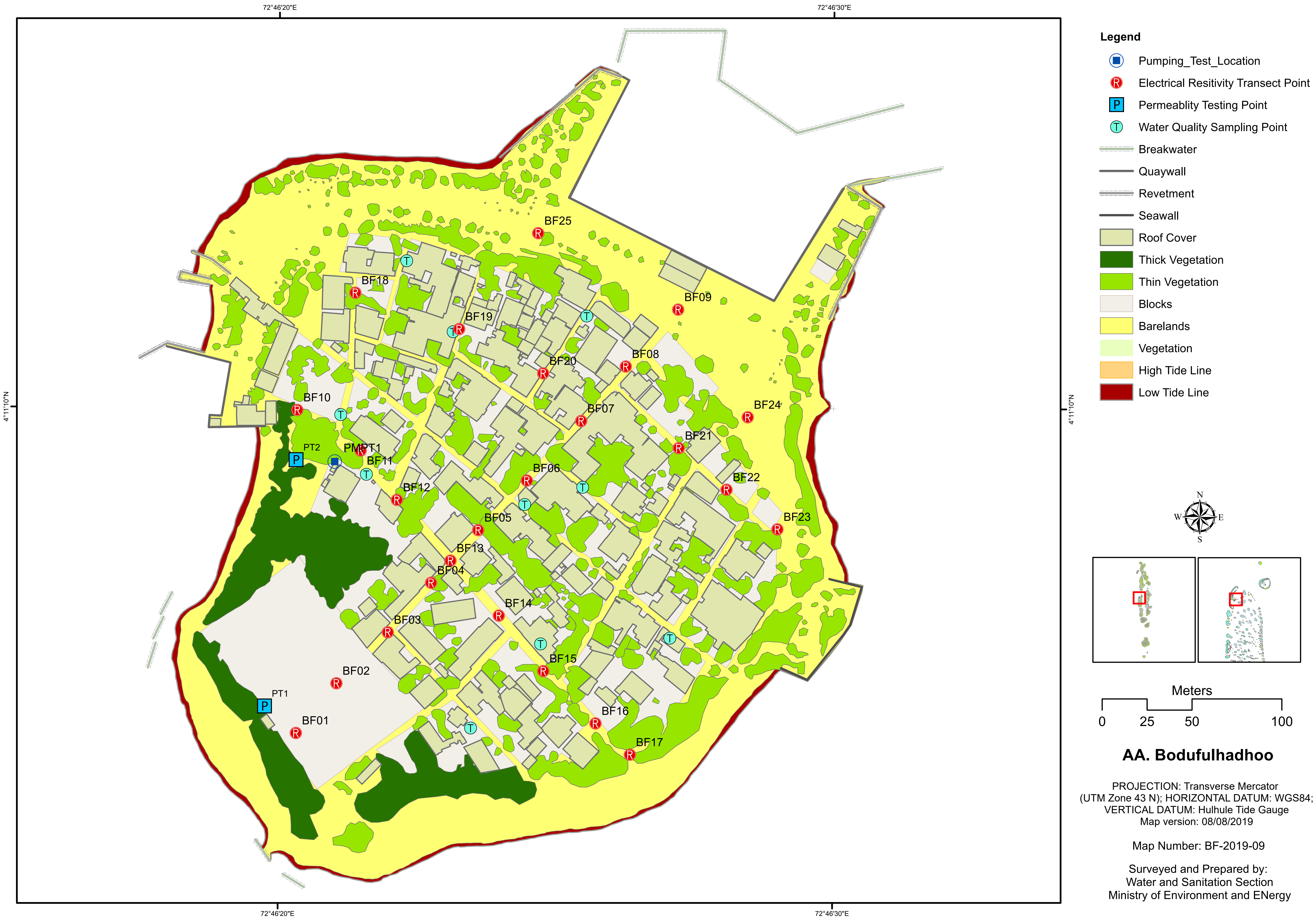
B.Dharavandhoo

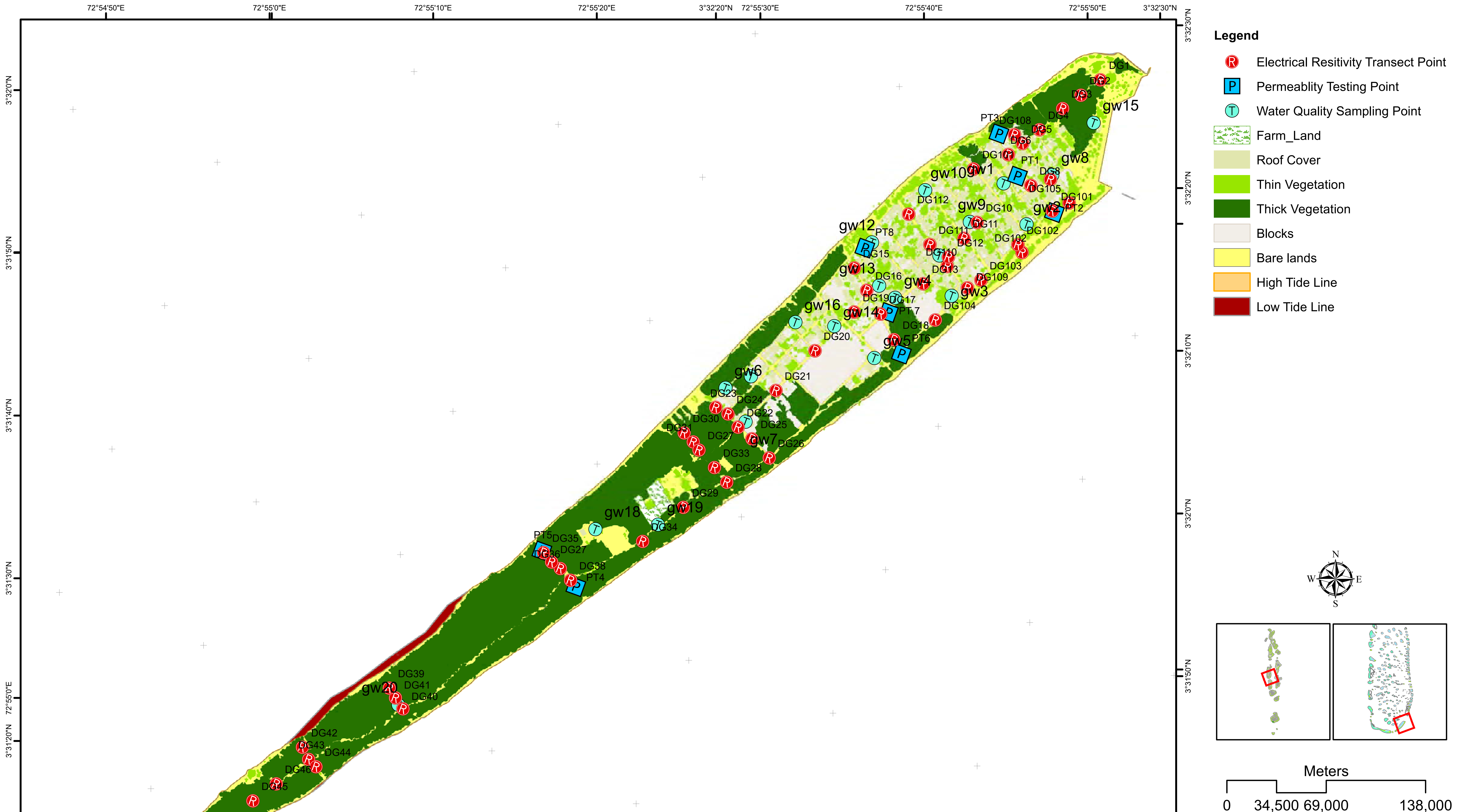
All test Locations

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 18/08/2019

Map Number: Dhara-2019-07

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


72°46'20"E
72°46'30"E
4°11'10"N
BF01
BF02
BF03
BF04
BF05
BF06
BF07
BF08
BF09
BF10
BF11
BF12
BF13
BF14
BF15
BF16
BF17
BF18
BF19
BF20
BF21
BF22
BF23
BF24
BF25
PT1
PT2
PMPT1
Legend
Pumping_Test_Location
Electrical Resitivity Transect Point
Permeablity Testing Point
Water Quality Sampling Point
Breakwater
Quaywall
Revetment
Seawall
Roof Cover
Thick Vegetation
Thin Vegetation
Blocks
Barelands
Vegetation
High Tide Line
Low Tide Line
N
S
E
W
Meters
0 25 50 100
AA. Bodufulhadhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 08/08/2019
Map Number: BF-2019-09
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

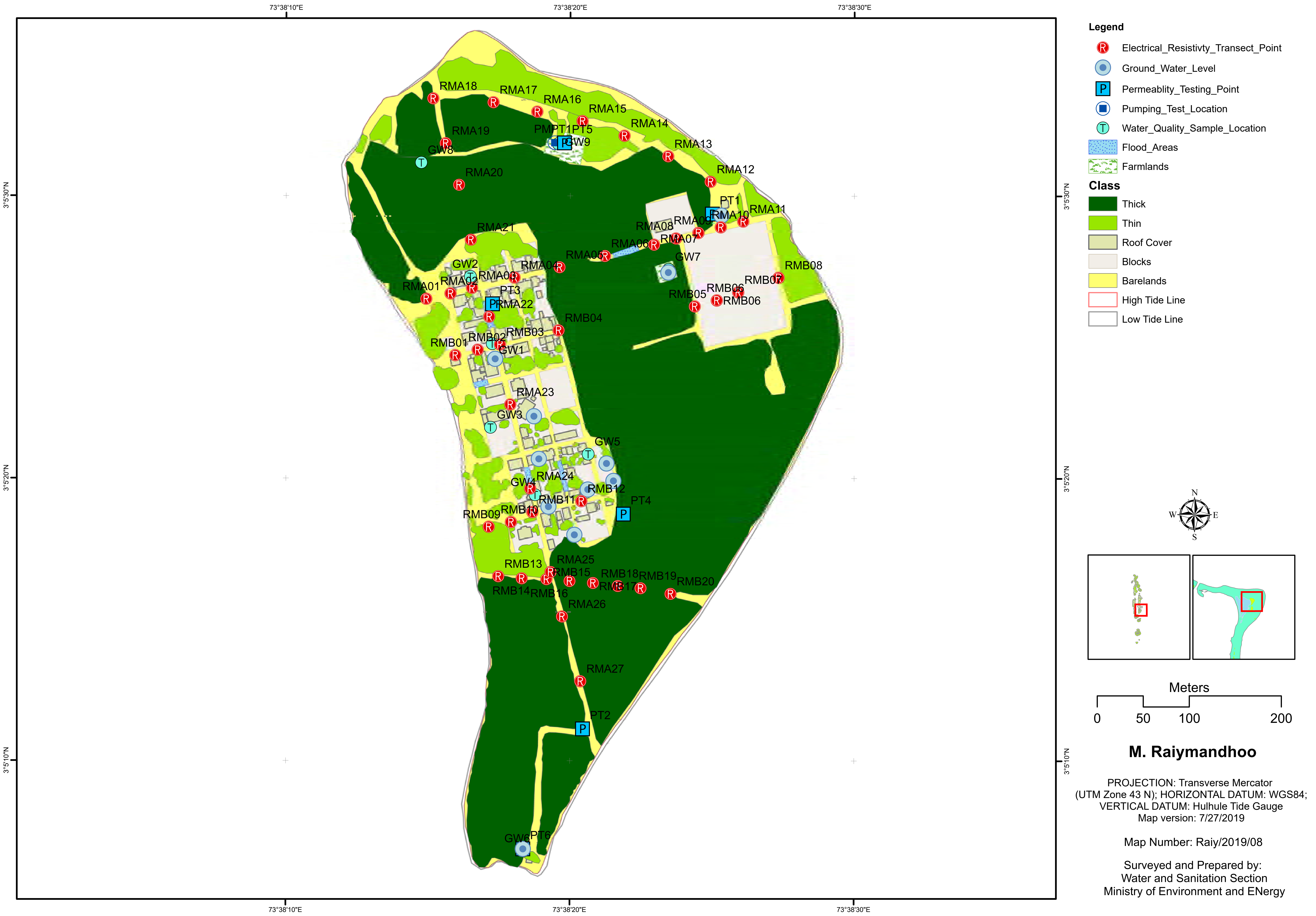


ADh. Dhigurah

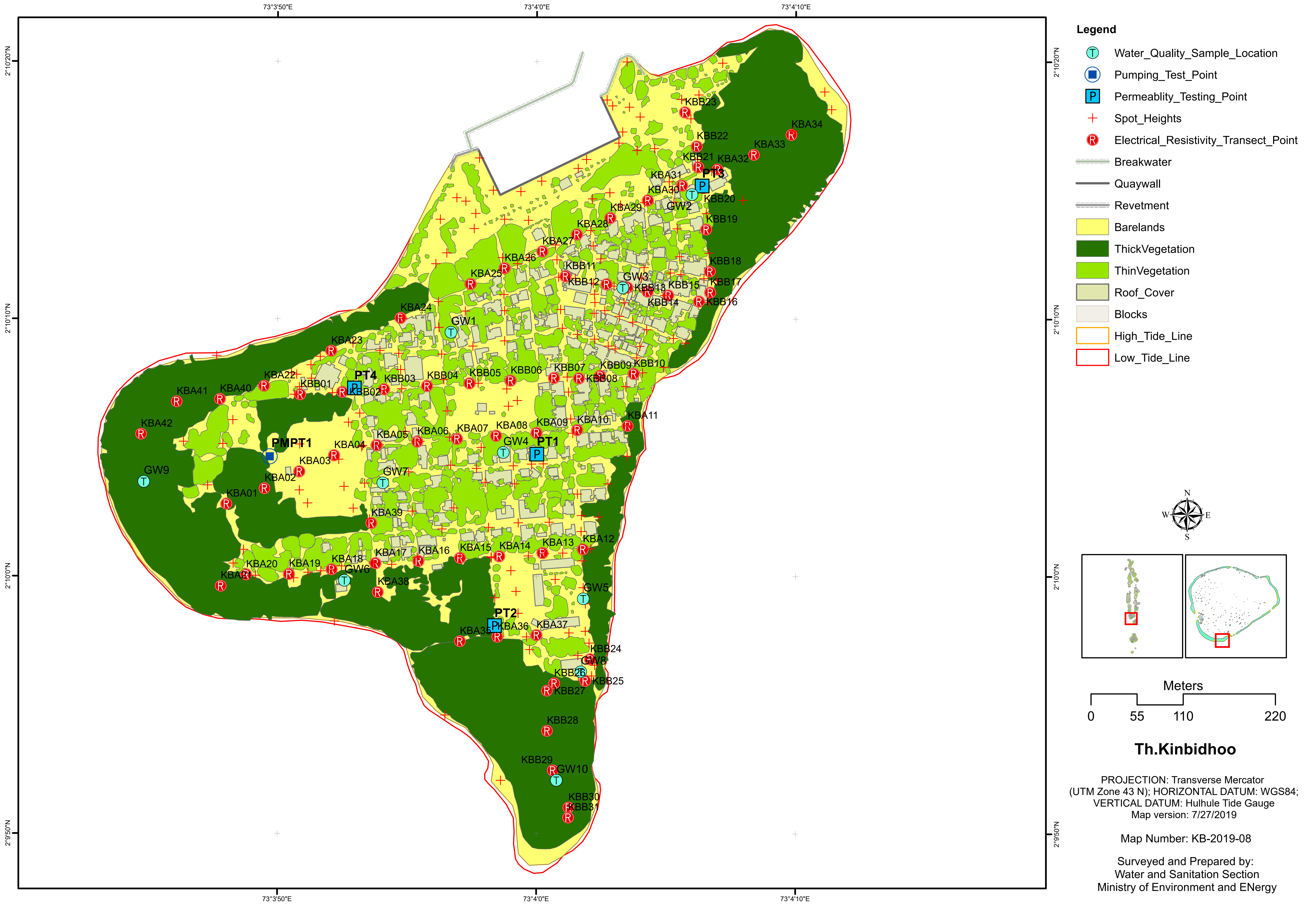
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 18/08/2019

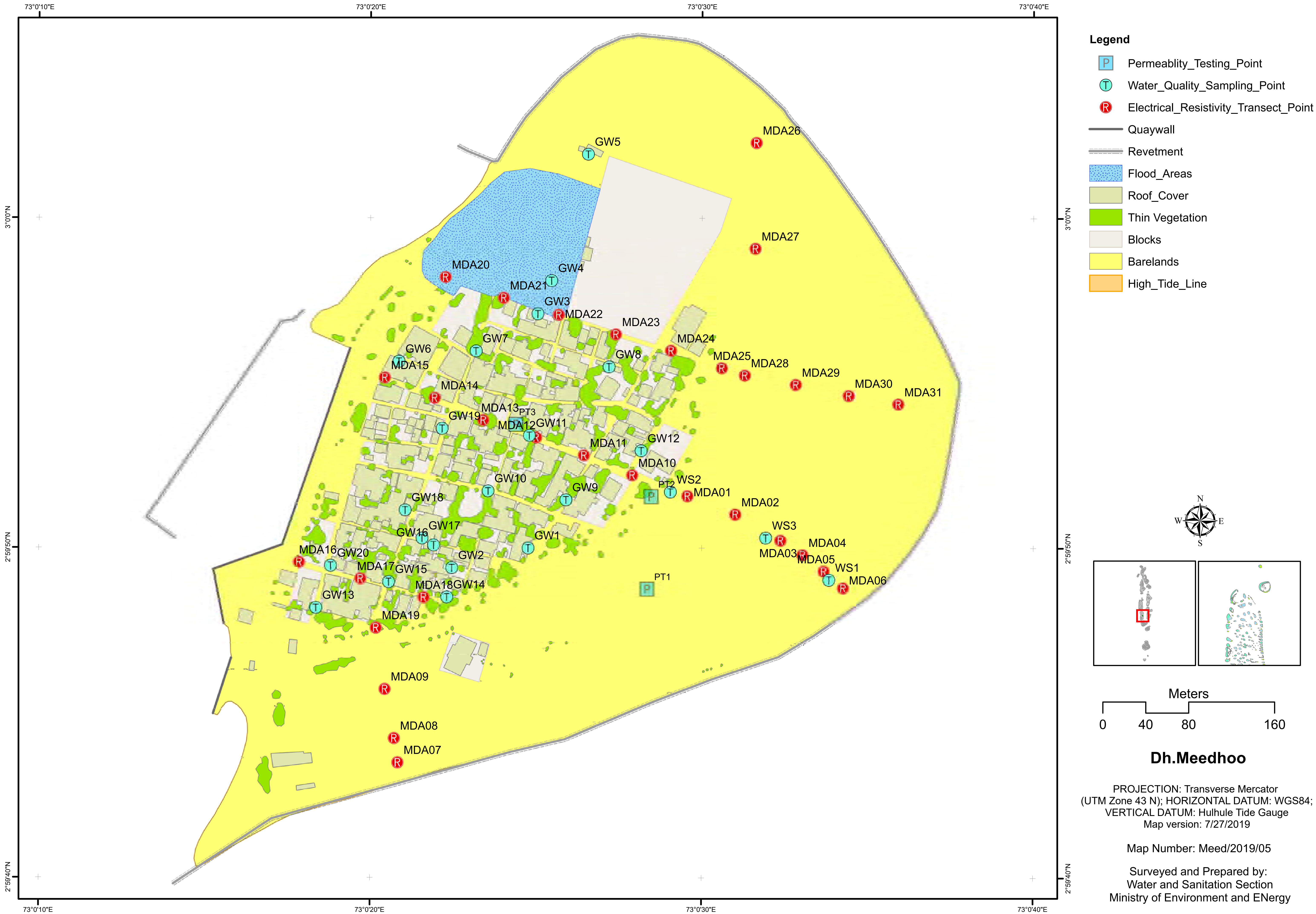
Map Number: DG-2019-08

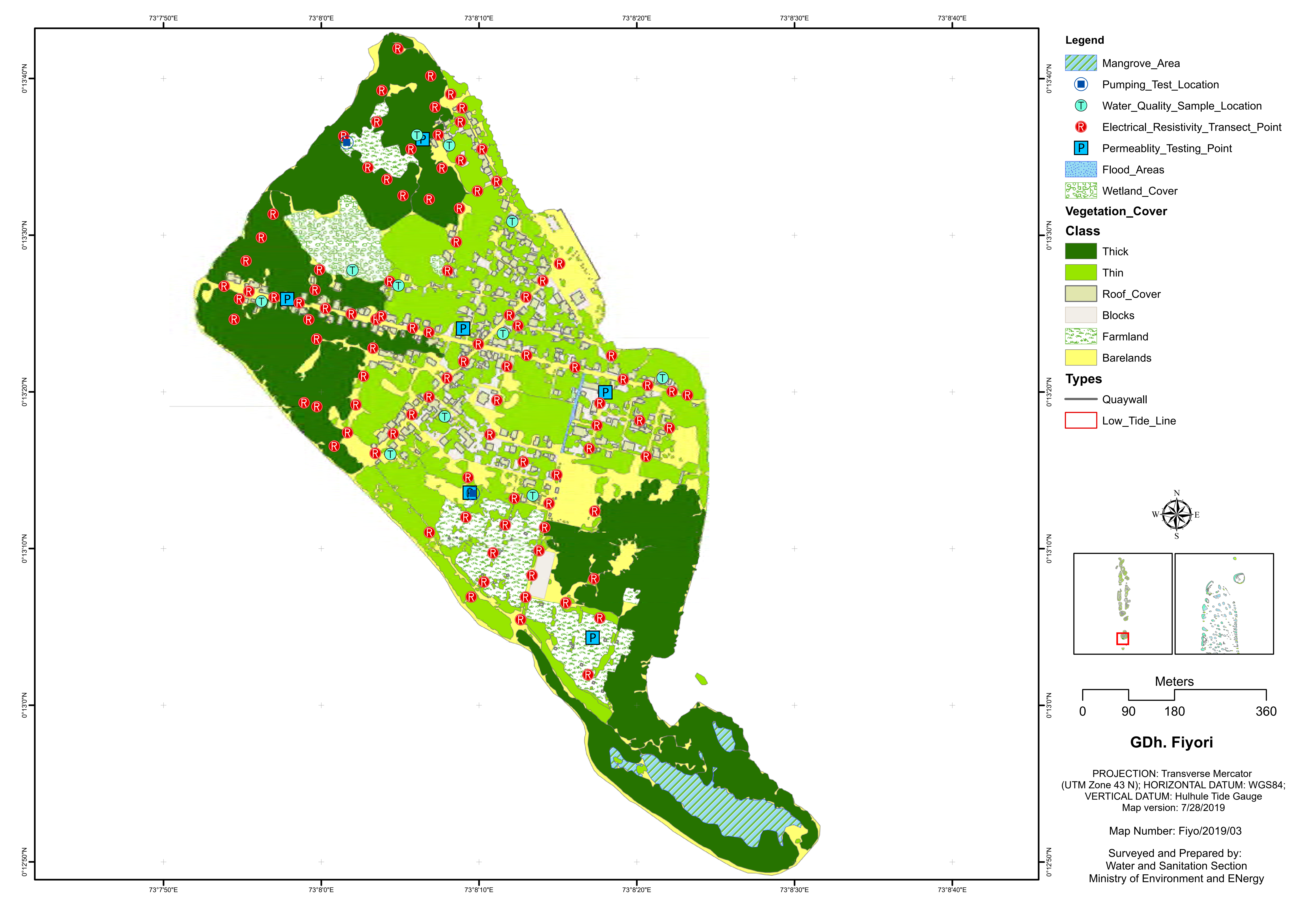
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

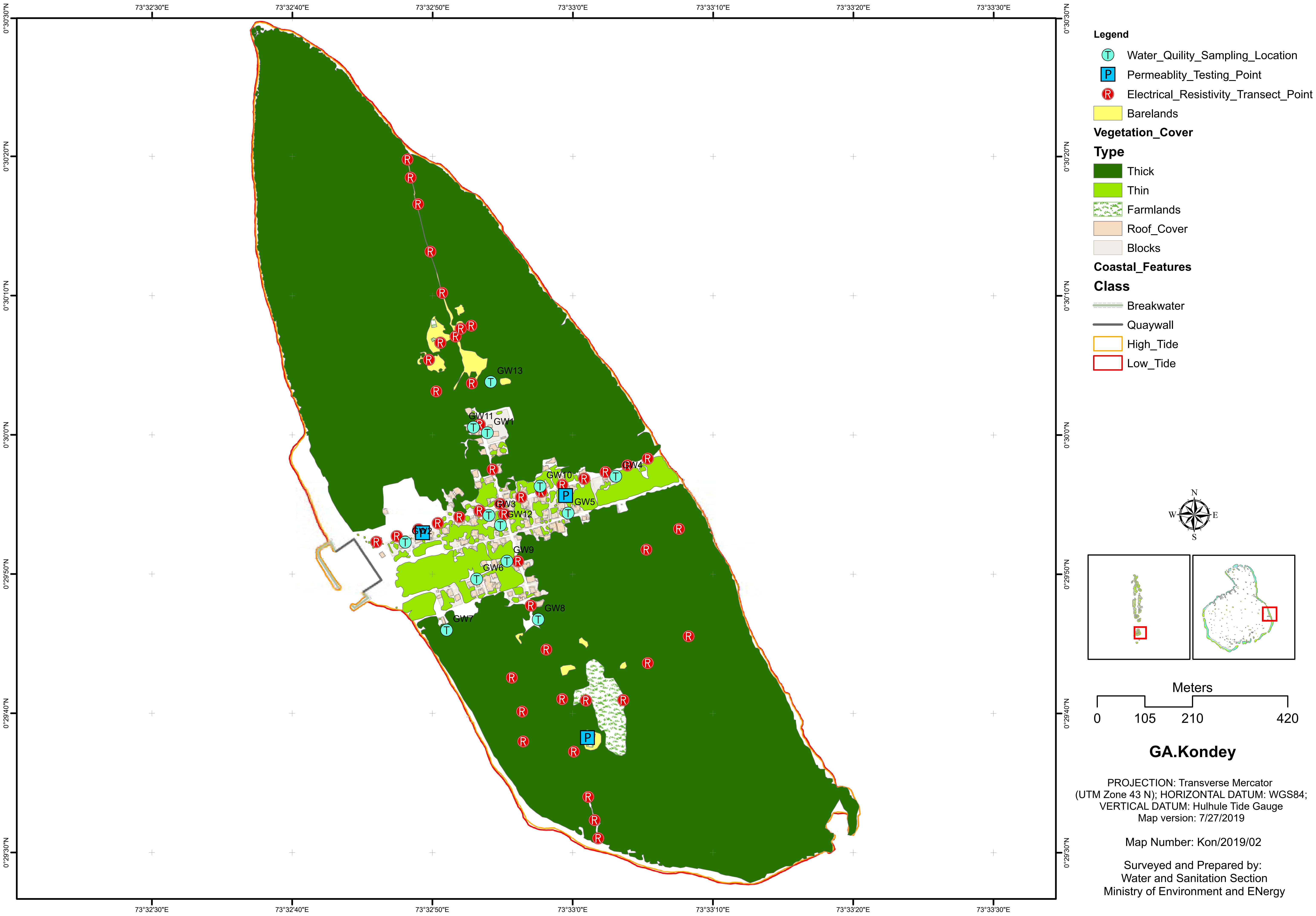


73°38'10"E
73°38'20"E
73°38'30"E
3°5'30"N
3°5'20"N
3°5'10"N
Legend
Electrical_Resistivty_Transect_Point
Ground_Water_Level
Permeablity_Testing_Point
Pumping_Test_Location
Water_Quality_Sample_Location
Flood_Areas
Farmlands
Class
Thick
Thin
Roof Cover
Blocks
Barelands
High Tide Line
Low Tide Line
RMA18
RMA17
RMA16
RMA15
RMA14
RMA13
RMA12
RMA11
RMA19
RMA20
RMA21
GW8
GW9
PT1
PT3
PT4
PT2
GW2
GW1
GW3
GW5
GW7
GW4
RMA01
RMA02
RMA03
RMA04
RMA05
RMA06
RMA07
RMA08
RMA22
RMA23
RMA24
RMA25
RMA26
RMA27
RMB01
RMB02
RMB03
RMB04
RMB05
RMB06
RMB07
RMB08
RMB09
RMB10
RMB11
RMB12
RMB13
RMB14
RMB15
RMB16
RMB18
RMB19
RMB20
GW6
PT6
N
W
E
S
Meters
0
50
100
200
M. Raiymandhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 7/27/2019
Map Number: Raiy/2019/08
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


73°3'50"E
73°4'0"E
73°4'10"E
2°10'20"N
2°10'10"N
2°10'0"N
2°9'50"N
Legend
Water_Quality_Sample_Location
Pumping_Test_Point
Permeablity_Testing_Point
Spot_Heights
Electrical_Resistivity_Transect_Point
Breakwater
Quaywall
Revetment
Barelands
ThickVegetation
ThinVegetation
Roof_Cover
Blocks
High_Tide_Line
Low_Tide_Line
N
S
E
W
Meters
0
55
110
220
Th.Kinbidhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 7/27/2019
Map Number: KB-2019-08
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


73°0'10"E
73°0'20"E
73°0'30"E
73°0'40"E
3°0'0"N
2°59'50"N
2°59'40"N
Legend
Permeablity_Testing_Point
Water_Quality_Sampling_Point
Electrical_Resistivity_Transect_Point
Quaywall
Revetment
Flood_Areas
Roof_Cover
Thin Vegetation
Blocks
Barelands
High_Tide_Line
GW1
GW2
GW3
GW4
GW5
GW6
GW7
GW8
GW9
GW10
GW11
GW12
GW13
GW14
GW15
GW16
GW17
GW18
GW19
GW20
WS1
WS2
WS3
PT1
PT2
PT3
MDA01
MDA02
MDA03
MDA04
MDA05
MDA06
MDA07
MDA08
MDA09
MDA10
MDA11
MDA12
MDA13
MDA14
MDA15
MDA16
MDA17
MDA18
MDA19
MDA20
MDA21
MDA22
MDA23
MDA24
MDA25
MDA26
MDA27
MDA28
MDA29
MDA30
MDA31
N
S
E
W
Meters
0
40
80
160
Dh.Meedhoo
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 7/27/2019
Map Number: Meed/2019/05
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


73°7'50"E
73°8'0"E
73°8'10"E
73°8'20"E
73°8'30"E
73°8'40"E
0°13'40"N
0°13'30"N
0°13'20"N
0°13'10"N
0°13'0"N
0°12'50"N
Legend
Mangrove_Area
Pumping_Test_Location
Water_Quality_Sample_Location
Electrical_Resistivity_Transect_Point
Permeablity_Testing_Point
Flood_Areas
Wetland_Cover
Vegetation_Cover
Class
Thick
Thin
Roof_Cover
Blocks
Farmland
Barelands
Types
Quaywall
Low_Tide_Line
N
S
E
W
Meters
0 90 180 360
GDh. Fiyori
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 7/28/2019
Map Number: Fiyo/2019/03
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


73°32'30"E
73°32'40"E
73°32'50"E
73°33'0"E
73°33'10"E
73°33'20"E
73°33'30"E
0°30'30"N
0°30'20"N
0°30'10"N
0°30'0"N
0°29'50"N
0°29'40"N
0°29'30"N
GW13
GW11
GW1
GW10
GW4
GW5
GW3
GW12
GW2
GW9
GW6
GW8
GW7
Legend
Water_Quility_Sampling_Location
Permeablity_Testing_Point
Electrical_Resistivity_Transect_Point
Barelands
Vegetation_Cover
Type
Thick
Thin
Farmlands
Roof_Cover
Blocks
Coastal_Features
Class
Breakwater
Quaywall
High_Tide
Low_Tide
N
S
E
W
Meters
0 105 210 420
GA.Kondey
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 7/27/2019
Map Number: Kon/2019/02
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

Annex IV: Maps of the surveyed islands with ER Transect Lines

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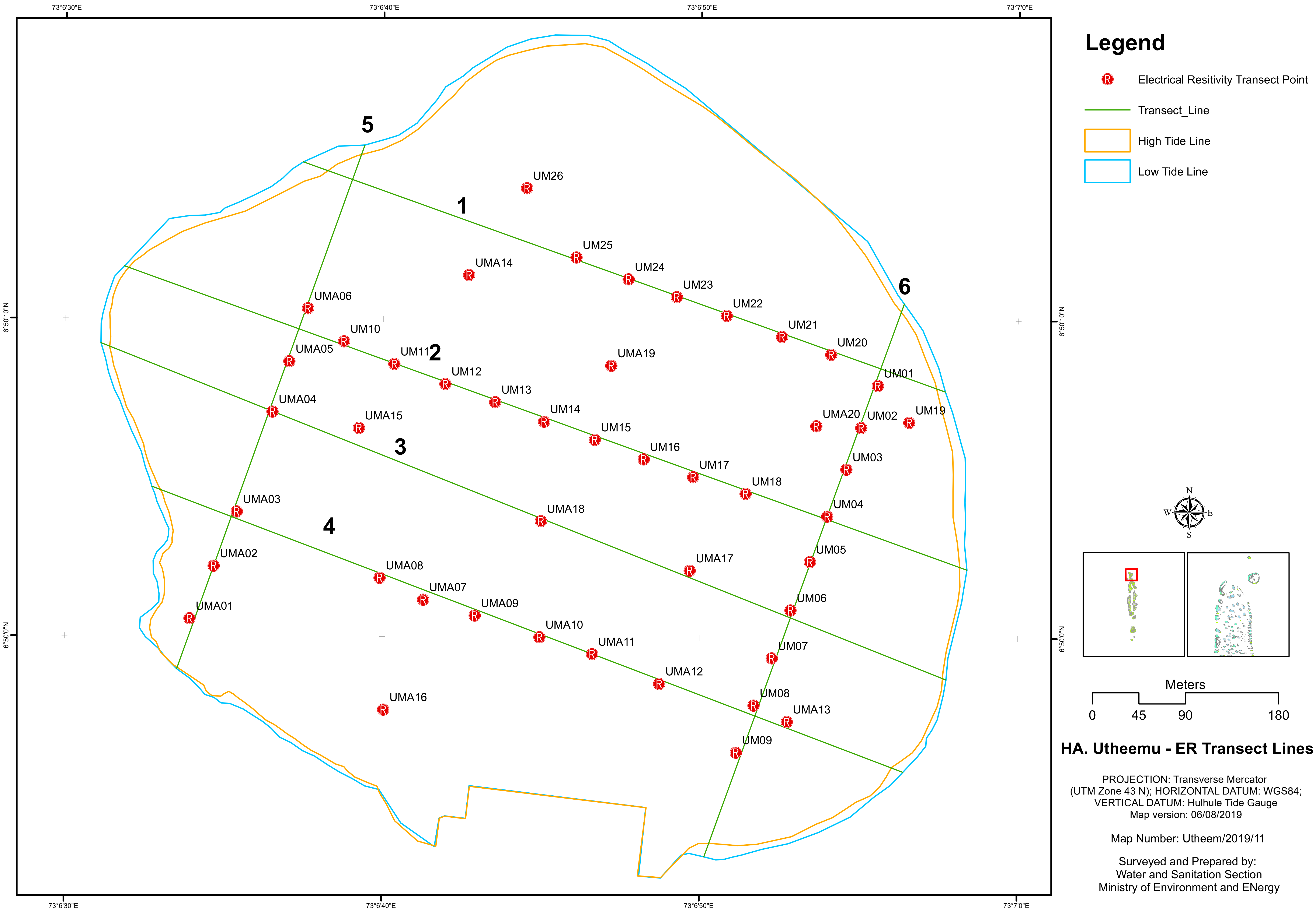

73°6'30"E
73°6'40"E
73°6'50"E
73°7'0"E
6°50'10"N
6°50'0"N
1
2
3
4
5
6
UM01
UM02
UM03
UM04
UM05
UM06
UM07
UM08
UM09
UM10
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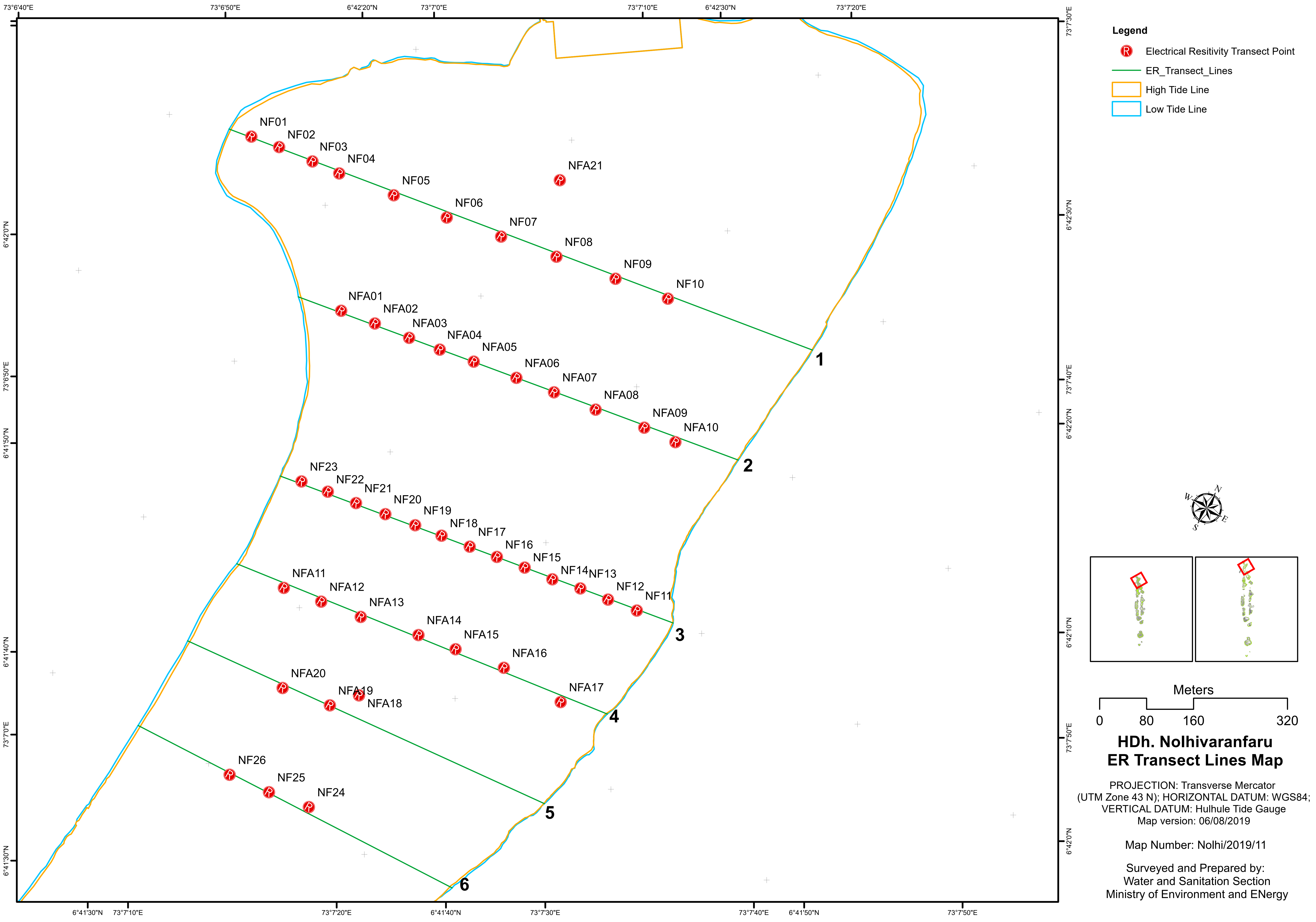
UMA10
UMA11
UMA12
UMA13
UMA14
UMA15
UMA16
UMA17
UMA18
UMA19
UMA20
Legend
Electrical Resitivity Transect Point
Transect_Line
High Tide Line
Low Tide Line
N
S
E
W
Meters
0 45 90 180
HA. Utheemu - ER Transect Lines
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 06/08/2019
Map Number: Utheem/2019/11
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


73°6'40"E
73°6'50"E
6°42'20"N
73°7'0"E
73°7'10"E
6°42'30"N
73°7'20"E
6°42'0"N
73°6'50"E
6°41'50"N
6°41'40"N
73°7'0"E
6°41'30"N
6°41'30"N
73°7'10"E
73°7'20"E
6°41'40"N
73°7'30"E
73°7'40"E
6°41'50"N
73°7'50"E
73°7'30"E
6°42'30"N
73°7'40"E
6°42'20"N
6°42'10"N
73°7'50"E
6°42'0"N
NF01
NF02
NF03
NF04
NF05
NF06
NF07
NF08
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NF10
NFA21
NFA01
NFA02
NFA03
NFA04
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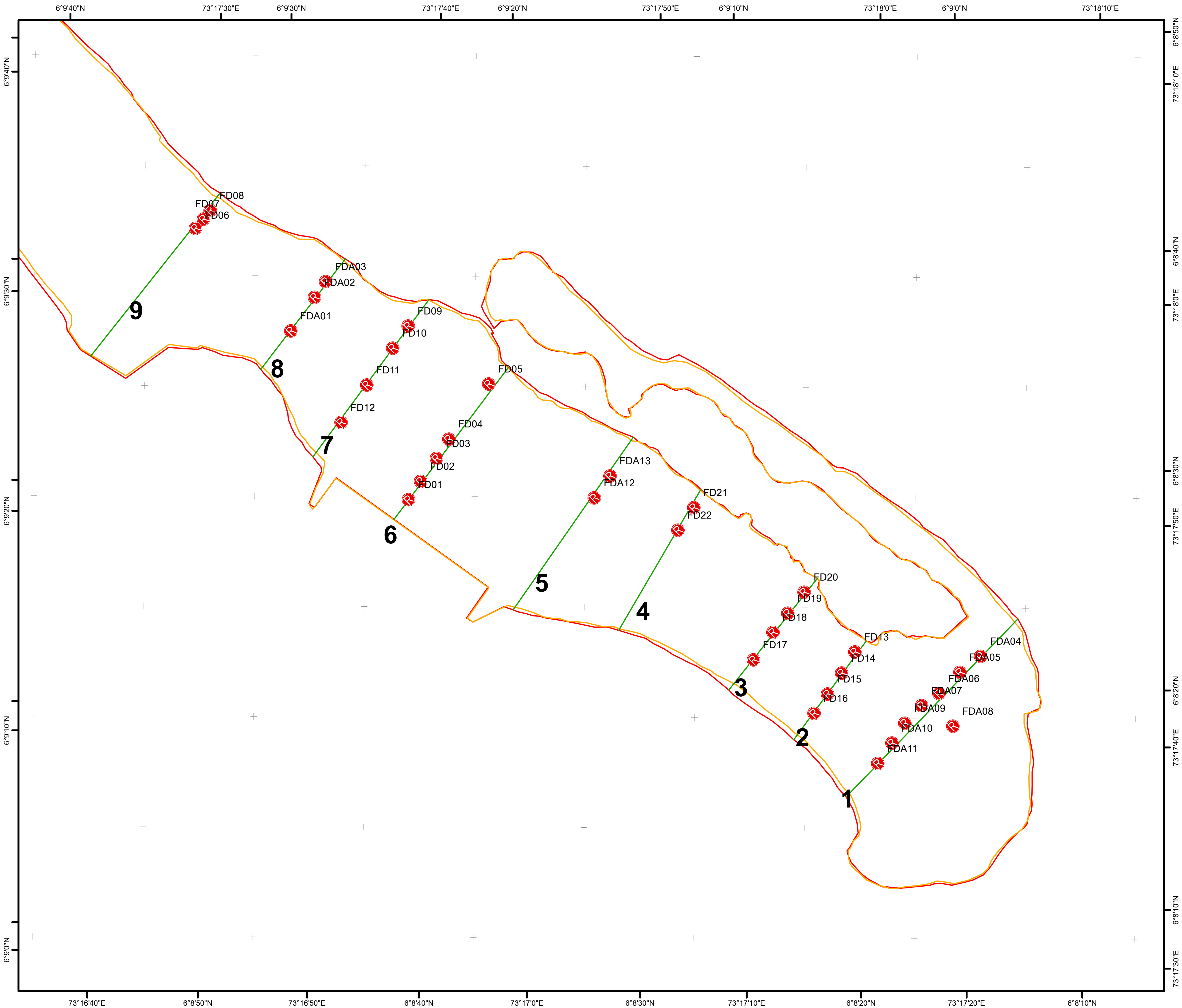
NFA14
NFA15
NFA16
NFA17
NFA20
NFA19
NFA18
NF26
NF25
NF24
1
2
3
4
5
6
Legend
Electrical Resitivity Transect Point
ER_Transect_Lines
High Tide Line
Low Tide Line
N
W
E
S
Meters
0
80
160
320
HDh. Nolhivaranfaru
ER Transect Lines Map
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 06/08/2019
Map Number: Nolhi/2019/11
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy



Legend

- Electrical Resitivity Transect Point
- ER Transect Line
- High Tide Line
- Low Tide Line

Meters

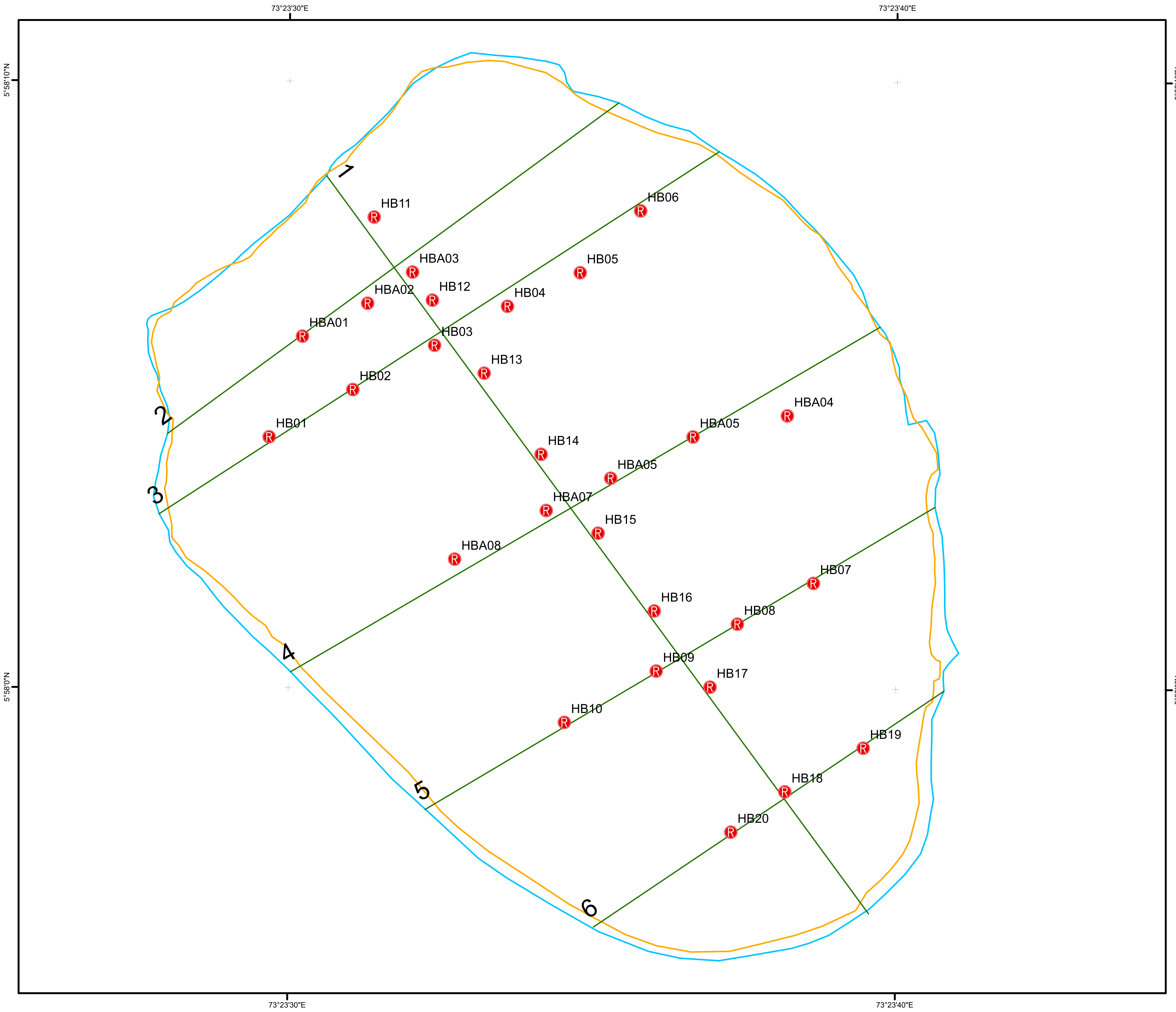
0 105 210 420

Sh.Funadhoo
ER Transect Lines Map

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 06/08/2019

Map Number: FUNA-2019-11

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

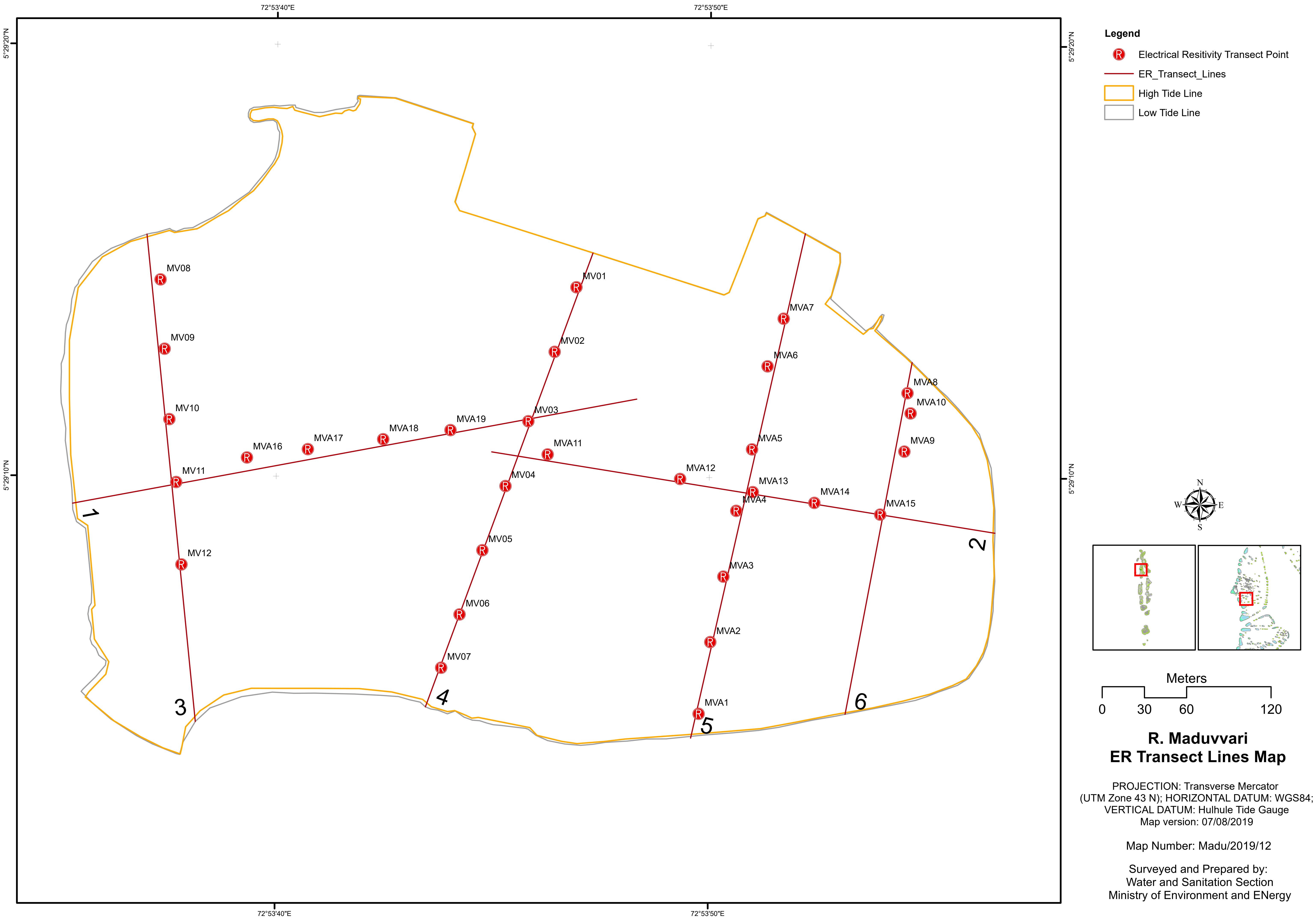


N. Hen'badhoo

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 07/08/2019

Map Number: Henb/2019/12

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

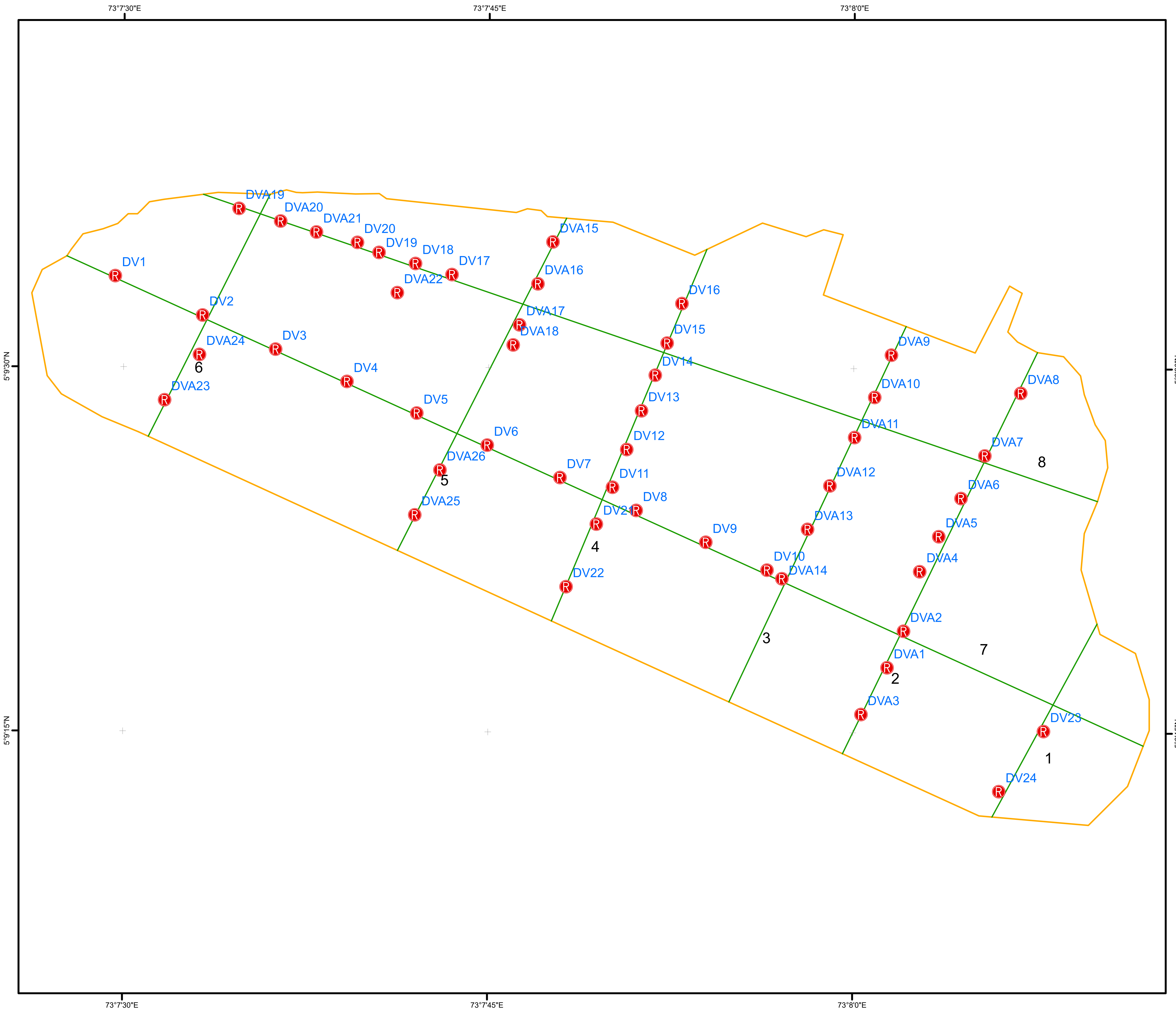


R. Maduvvari
ER Transect Lines Map

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 07/08/2019

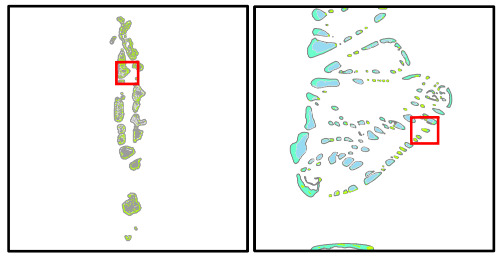
Map Number: Madu/2019/12

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy



Legend

- ER_locations
- Transect Lines
- Shoreline



Meters

0 50 100 200

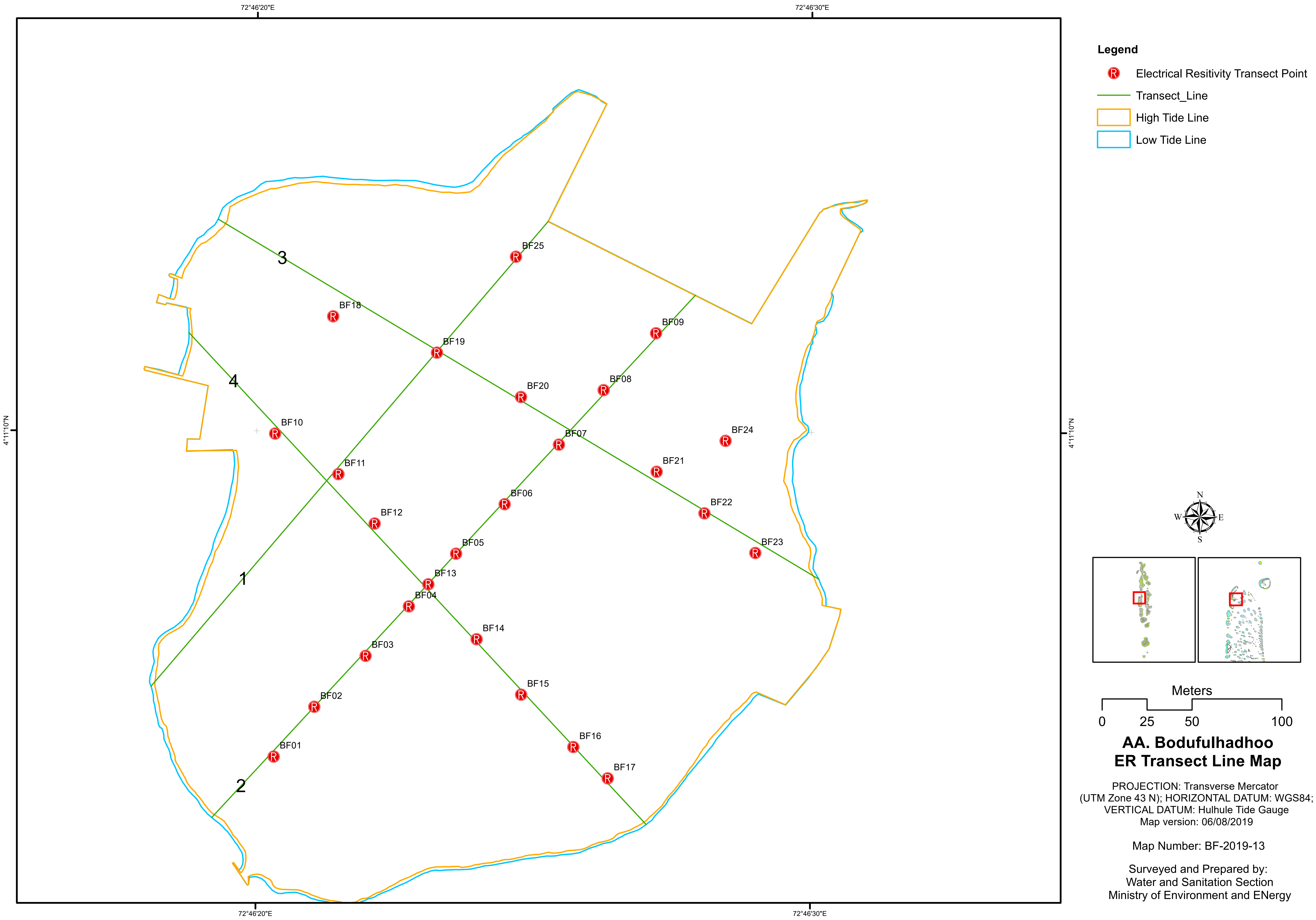
B.Dharavandhoo

ER Transect Lines

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 06/08/2019

Map Number: Dhara-2019-11

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

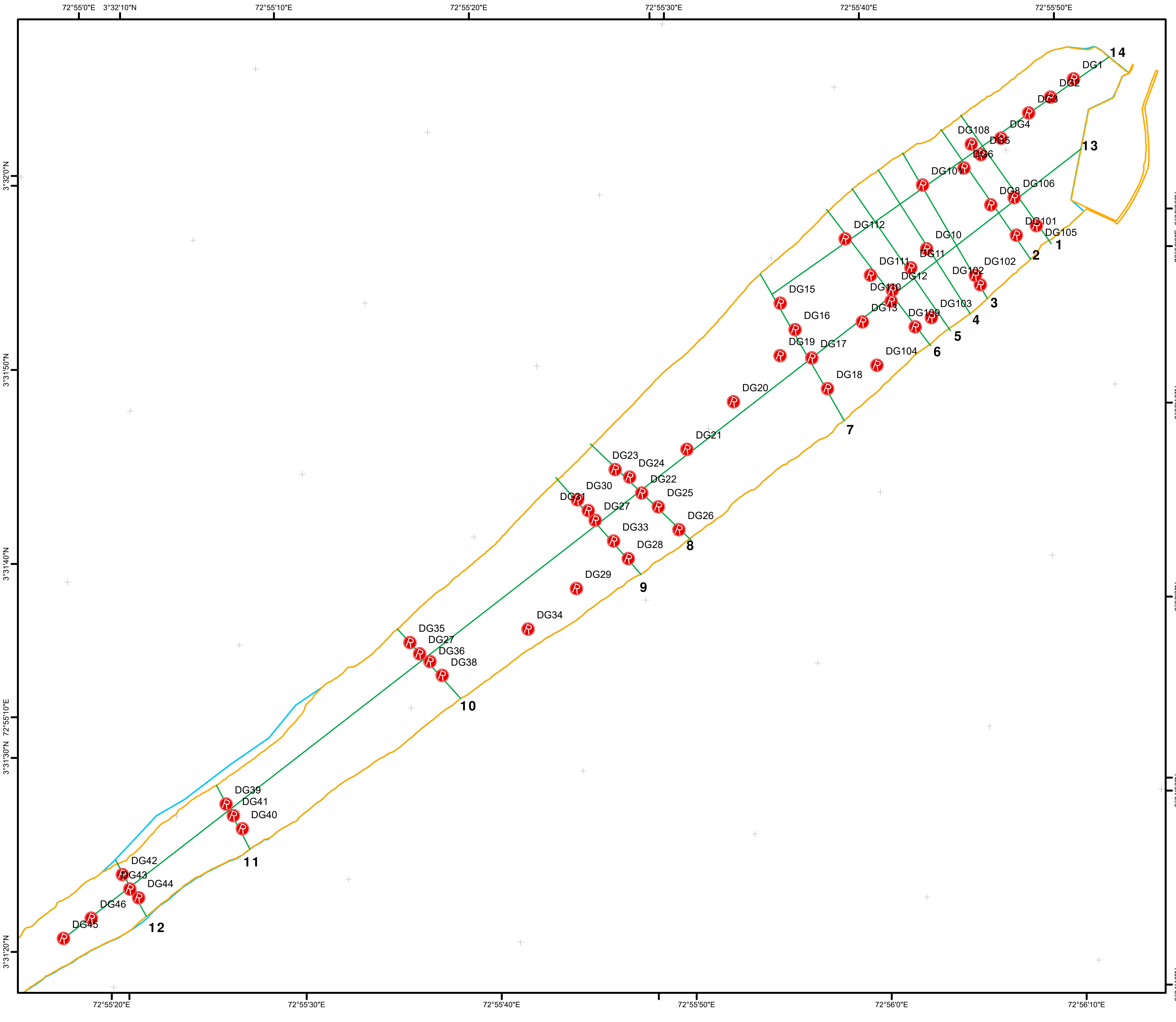


AA. Bodufulhadhoo
ER Transect Line Map

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 06/08/2019

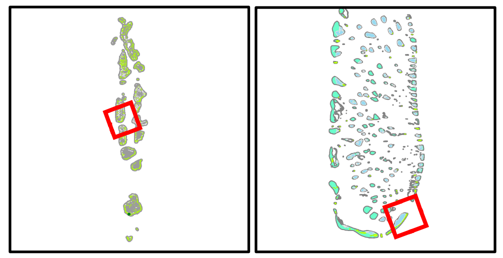
Map Number: BF-2019-13

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy



Legend

- Electrical Resitivity Transect Point
- Transect_Line
- High Tide Line
- Low Tide Line



Meters

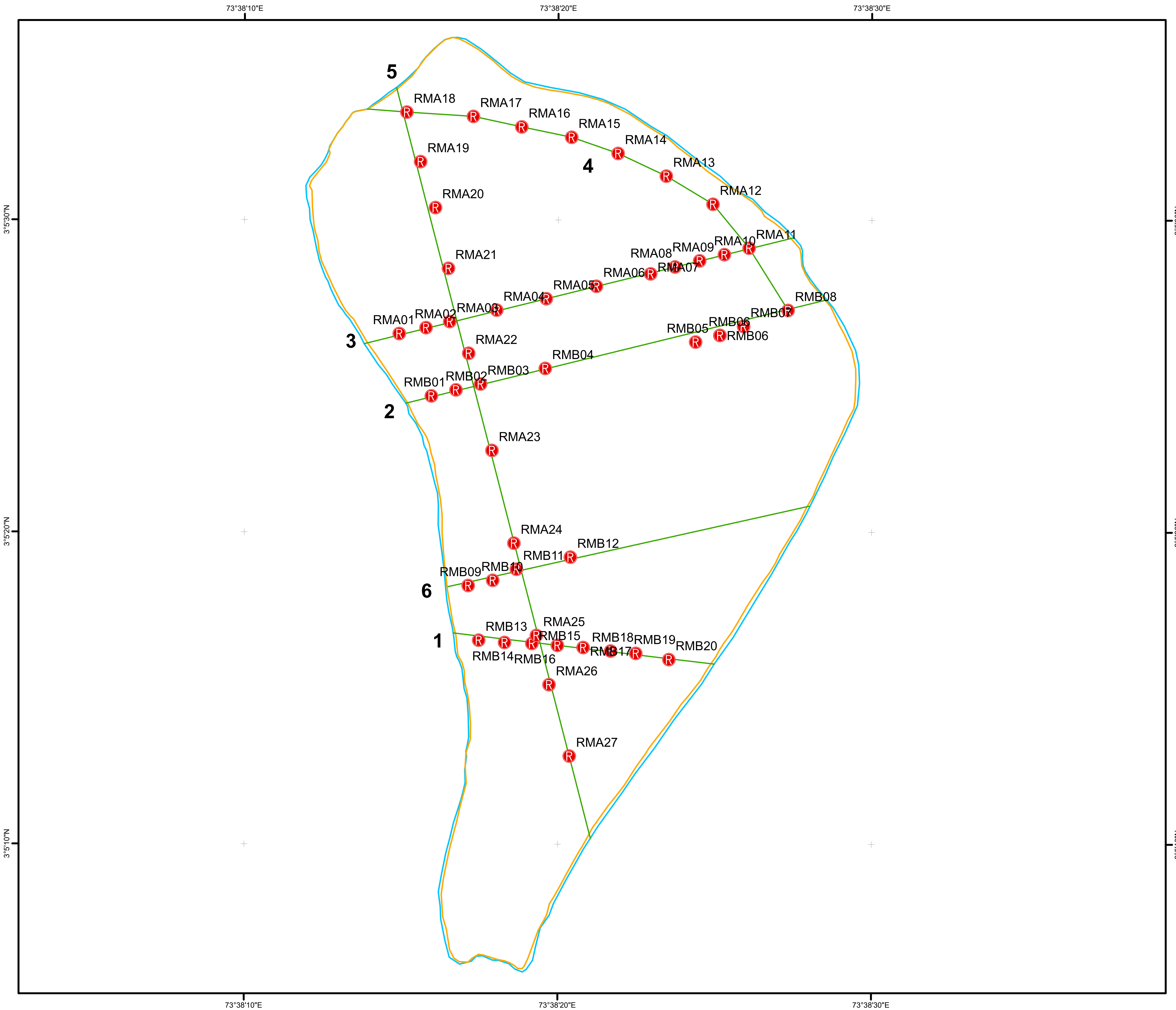
0 90 180 360

ADh. Dhigurah
ER Transect Lines

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 06/08/2019

Map Number: DG-2019-12

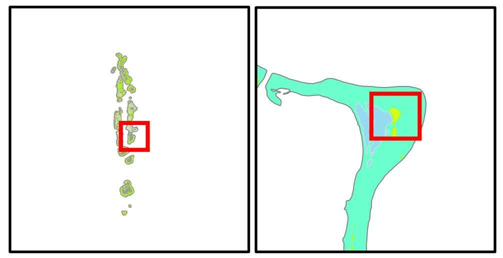
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy



Legend

- Electrical_Resistivity_Transect_Point
- ER_Transect_Lines
- High Tide Line
- Low Tide Line

N
W E
S



Meters

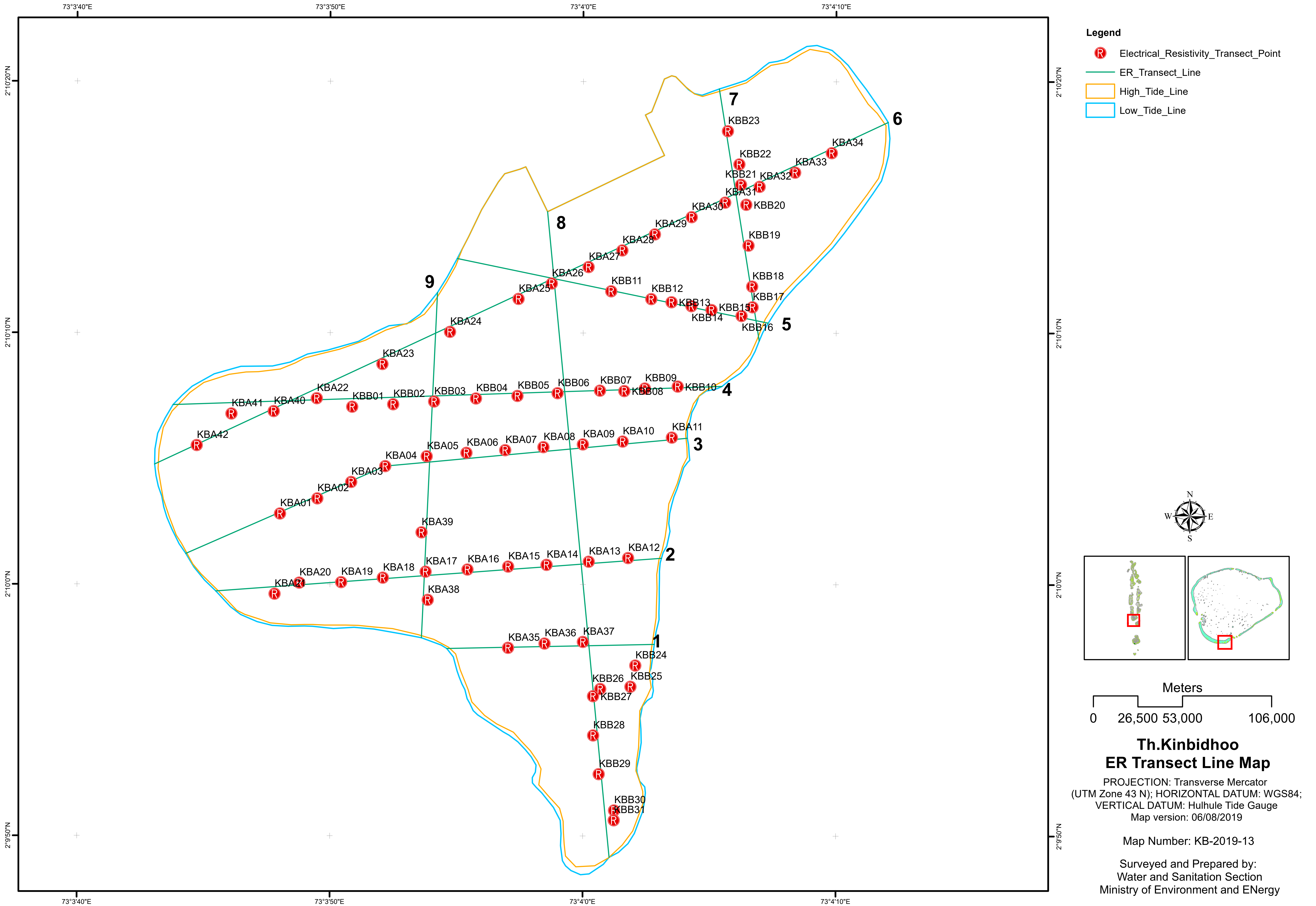
0 50 100 200

M. Raiymandhoo
ER Transect Lines Map

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 06/08/2019

Map Number: Raiy/2019/13

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

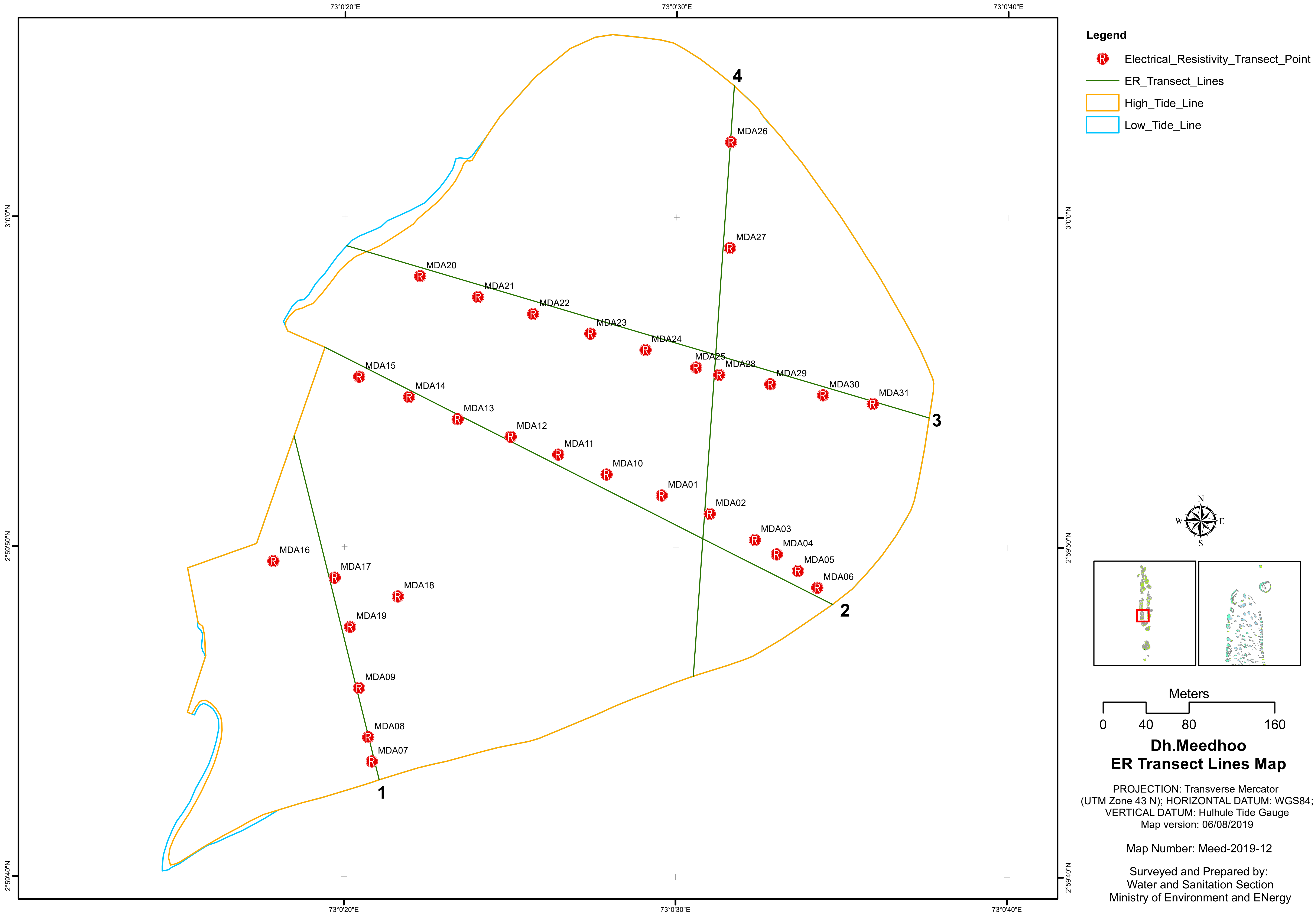


Th.Kinbidhoo
ER Transect Line Map

PROJECTION: Transverse Mercator (UTM Zone 43 N); HORIZONTAL DATUM: WGS84; VERTICAL DATUM: Hulhule Tide Gauge
Map version: 06/08/2019

Map Number: KB-2019-13

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

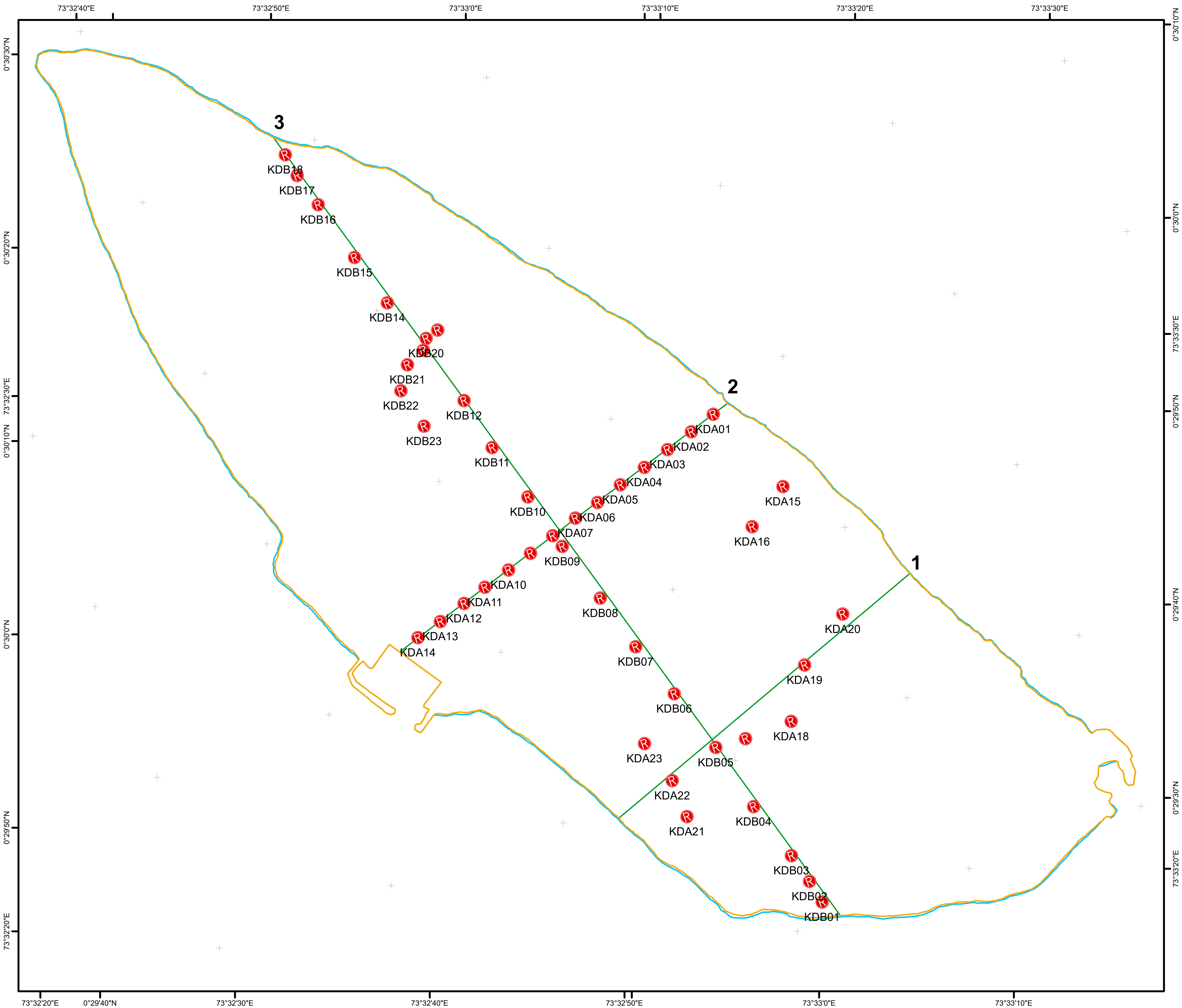


Dh.Meedhoo
ER Transect Lines Map

PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 06/08/2019

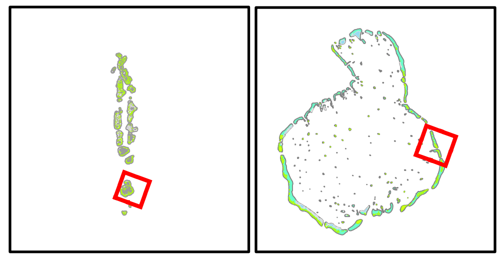
Map Number: Meed-2019-12

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy



Legend

- Electrical_Resistivity_Transect_Point
- High_Tide
- Low_Tide
- Kondey



Meters

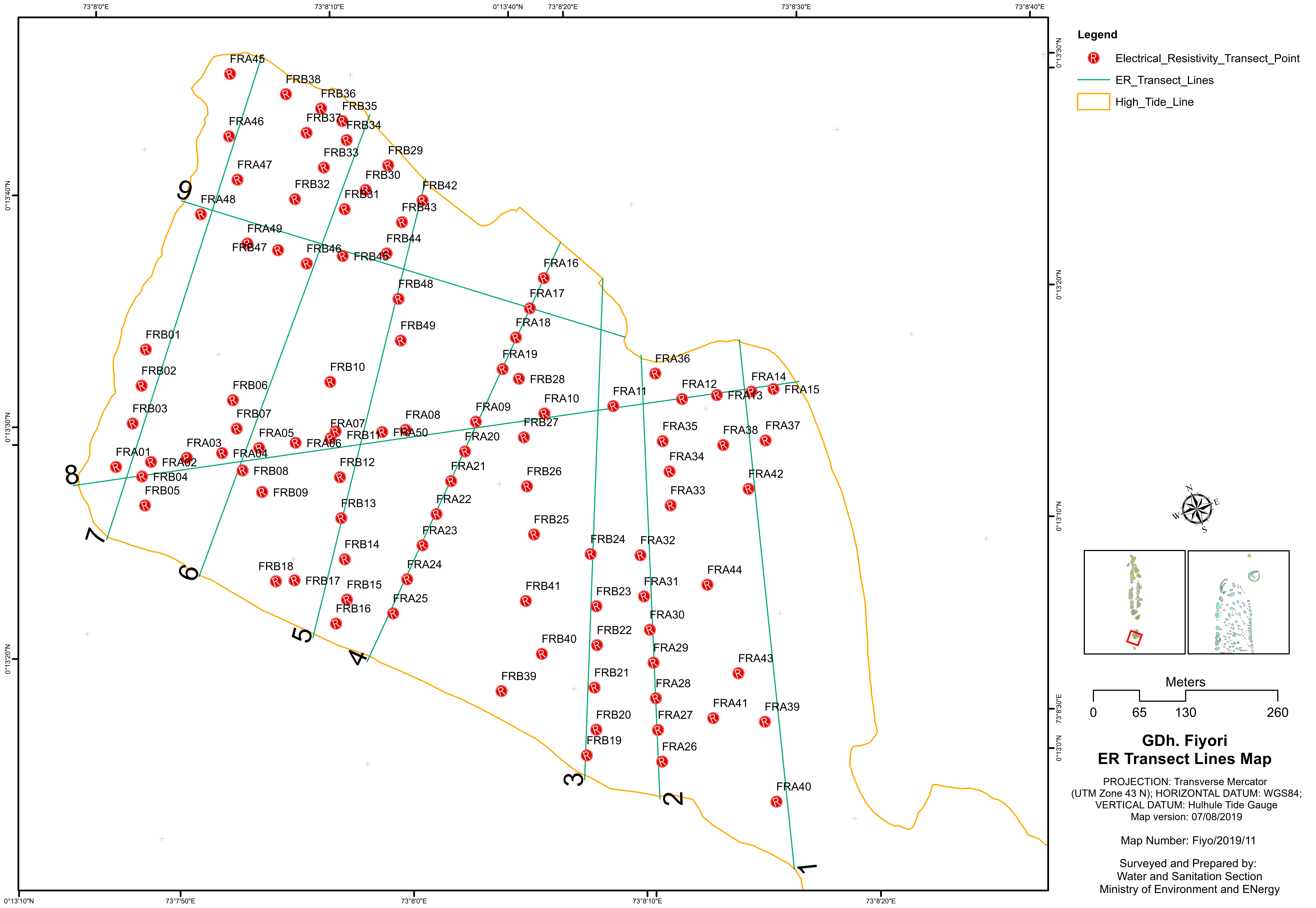
0 42,000 84,000 168,000

GA.Kondey
ER Transect Lines Map

PROJECTION: Transverse Mercator (UTM Zone 43 N); HORIZONTAL DATUM: WGS84; VERTICAL DATUM: Hulhule Tide Gauge
Map version: 06/08/2019

Map Number: Kon/2019/11

Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy


Legend
Electrical_Resistivity_Transect_Point
ER_Transect_Lines
High_Tide_Line
Meters
0 65 130 260
GDh. Fiyori
ER Transect Lines Map
PROJECTION: Transverse Mercator
(UTM Zone 43 N); HORIZONTAL DATUM: WGS84;
VERTICAL DATUM: Hulhule Tide Gauge
Map version: 07/08/2019
Map Number: Fiyo/2019/11
Surveyed and Prepared by:
Water and Sanitation Section
Ministry of Environment and ENergy

Annex V: Survey Questionnaire

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Demographic Information

This Survey will be used to determine the water consumption and future demand for the "Ground water and Aquifer management" project under GCF Funding.
Result of this survey will be published only in Anonymous Summary form.

* Required

1. **Island name** *

Mark only one oval.

- ( ) AA. Bodufulhadhoo
- ( ) ADh. Dhigurah
- ( ) Dh. Meedhoo
- ( ) Ga. Kon'dey
- ( ) GDh. Fiyoari
- ( ) Ha. Utheem
- ( ) HDh. Nolhivaramfaru
- ( ) M. Raiymandhoo
- ( ) N. Hen'badhoo
- ( ) Sh. Funadhoo
- ( ) Th. Kin'bidhoo
- ( ) B. Dharavandhoo
- ( ) R. Maduvvari

2. **Household name**

____

3. **Number of occupants**

____

4. **Number of adult males**

____

5. **Number of adult females**

____

6. **Number of children (Below 18 years)**

____

Drinking water

7. **What is the main source of Drinking water in the Household:**
Mark only one oval.

- ( ) Rain water
- ( ) Bottled water
- ( ) Ground Water

8. **If Other, Please specify.**

____

9. **What is your main source for cooking?**
Mark only one oval.

- ( ) Rain water
- ( ) Bottled water
- ( ) Well water (ground wells)

10. **If Other, Please specify.**

____

11. **If Bottled water is used, how many bottles do you by per week? 1.5 liter bottle, 12 bottles in a case.**

____

12. **If Bottled water is used, how many bottles do you by per week? 5 liter bottle, 4 bottles in a case**

____

13. **Do you have a rainwater tank in your household premises?**
Mark only one oval.

- ( ) Yes
- ( ) No

14. **How many rainwater tank are there?**

____

15. **What is the total capacity of the tanks in liters**

____

16. **Do you face rainwater shortage at your household?**
Mark only one oval.

- ( ) Yes
- ( ) No

17. **If yes, How often do you run out of rainwater at the household?**
Mark only one oval.

- Every 6 months
- Once a year
- Less than once a year
- More than twice a year

18. **If Other, Please specify**

____

19. **What alternative sources of water are used during water shortages (Cooking):**
Check all that apply.

- [ ] Community rainwater tank
- [ ] Mosque well
- [ ] Well water from household
- [ ] Rain water from other houses

20. **If other, Please specify**

____

21. **How do you deal with over-flow rainwater storage tanks or the roofs?**
Mark only one oval.

- Drained to the ground
- Drained to well through pipe

22. **If Other, Please specify**

____

Ground water

23. **What are the main uses of ground water at your household?**
Check all that apply.

- [ ] Drinking
- [ ] Cooking
- [ ] Laundry
- [ ] Gardening/Farming
- [ ] Toilet flushing
- [ ] Household cleaning
- [ ] Other: _______________________

24. **Do you use a pump to extract ground water?**
Mark only one oval.

- Yes
- No

25. **If yes, how many pumps?**

26. **How many taps are connected to ground water source?**

27. **How many toilets do you have at the household?**

28. **How many times do you use the toilet per day?**

29. **How many time do you shower per day?**

30. **How long do you spend in the shower? (in minutes)**

31. **How many loads laundry does your house hold do every week?**

32. **What kind of washing machine is used?**
Mark only one oval.

- Front load
- Top load

33. **If other or comments, please specify**

34. **Do you do gardening at the household?**
Mark only one oval.

- Yes
- No

35. **If you use watering cans to water the garden, what is the capacity of the watering can (in litres)?**

36. **How many cans of water do you use per day?**

37. **If you use water hose, how long does is take to water the whole garden? (total time for a day in minutes)**

38. **How many buckets of water is used to mop the floors per week.**

39. **What is the capacity of said bucket?**

40. **Do you notice changes in water quality during tidal or seasonal changes. If so, elaborate.**

Sanitation facilities

41. **Type of sanitation facility for the household:**
Mark only one oval.

- ( ) Connected to the island sewerage network
- ( ) Connected to a local outfall pipe
- ( ) Septic tanks

42. **If Other , Please specify**

43. **If Septic tanks are used, how is the solid septic waste disposed off during the cleaning process?**

44. **How many toilets do you have at the household?**

45. **What kind of flushtank is used at the household?**
Mark only one oval.

- ( ) Ecoflush
- ( ) Standard flushtank

46. **What is the approximate size of the flushtanks?**
Check all that apply.

- [ ] Small
- [ ] Normal
- [ ] Large

47. **How many "small" flushtanks?**

____

48. **How many "normal" flushtanks?**

____

49. **How many "large" flushtanks?**

____

50. **What is the approximate distance between septic tank and nearest well**

____

Agriculture

This Survey will be used to determine the water consumption and future demand for the "Ground water and Aquifer management" project under GCF Funding.
Result of this survey will be published only in Anonymous Summary form.

* Required

1. **Island name** *
   Mark only one oval.
   - ( ) AA. Bodufulhadhoo
   - ( ) ADh. Dhigurah
   - ( ) Dh. Meedhoo
   - ( ) Ga. Kon'dey
   - ( ) GDh. Fiyoari
   - ( ) Ha. Utheem
   - ( ) HDh. Nolhivaramfaru
   - ( ) M. Raiymandhoo
   - ( ) N. Hen'badhoo
   - ( ) Sh. Funadhoo
   - ( ) Th. Kin'bidhoo
   - ( ) B. Dharavandhoo
   - ( ) R. Maduvvari

2. **What is the approximate size of your plantation area?**

   ____

3. **If other, please specify.**

   ____

4. **What type of plants are grown in your farm?**

   ____

5. **How do you water your farm?**
   Check all that apply.
   - [ ] Automatic sprinkler system
   - [ ] Water pump and hose
   - [ ] Manual watering using watering cans

6. **If other, please specify.**

   ____

7. **What type of water is being used for watering the plants?**
Check all that apply.

- [ ] Ground water from water well withing the farm
- [ ] Rainwater from storage tank
- [ ] Desalinated water from the island water network

8. **If other, please specify**

____

9. **How often do you water the plants**
Mark only one oval.

- ( ) once a day
- ( ) twice a day
- ( ) more than twice a day
- ( ) Other: _______________________________

10. **How long does is take to water the whole farm (in minutes)?**

____

Fish processing

11. **How many people working on the fishing vessel?**

____

12. **Do you have a water tank (filled with ground water) in the fishing vessel? for basic needs such as cooking, drinking, cleaning, etc?**
Mark only one oval.

- ( ) Yes
- ( ) No

13. **IF YES, what is the capacity of the water tank? (liters)**

____

14. **How often do you fill the water tank (how many times a year)?**

____

15. **For which purposes do you use the ground water in the vessel?**
Check all that apply.

- [ ] Cooking
- [ ] Dishwashing
- [ ] Cleaning
- [ ] Shower

16. **If other, please specify**

____

17. **Do you carryout fish processing activities?**
Check all that apply.

- [ ] Cutting and cleaning
- [ ] Cooking and smoking
- [ ] Rihaakuru production

18. **If other, please specify**

____

19. **What kind of water is being used for fish processing activities at the household?**
Check all that apply.

- [ ] Rainwater
- [ ] Well water
- [ ] Desalinated water
- [ ] Ground water

20. **What is the size of the cookware used for fish processing? Diameter and height**

____

21. **How many taps are there in the fish cleaning area and how long do you normally keep the tap running during fish cutting and cleaning?**

____

Commercial

This Survey will be used to determine the water consumption and future demand for the "Ground water and Aquifer management" project under GCF Funding.
Result of this survey will be published only in Annonymous Summary form.

* Required

1. *Mark only one oval.*

- Option 1

2. **Island name**

Mark only one oval.

- AA. Bodufulhadhoo
- ADh. Dhigurah
- Dh. Meedhoo
- Ga. Kon'dey
- GDh. Fiyoari
- Ha. Utheem
- HDh. Nolhivaramfaru
- M. Raiymandhoo
- N. Hen'badhoo
- Sh. Funadhoo
- Th. Kin'bidhoo
- B. Dharavandhoo
- R. Maduvvari

3. **What kind of establishment?**

Mark only one oval.

- Cafe'
- Restaurant
- Guesthouse

4. **Name of the Guest house?**

5. **What is the capacity of the guest house (no. of rooms?**

6. **What is the occupancy of the guest house, (average percentage for the year)**

7. **If other, please specify**

____

8. **Is there an existing water network**
Mark only one oval.

- ( ) Yes
- ( ) No

9. **IF YES, is the guesthouse connected to island water network?**
Mark only one oval.

- ( ) Yes
- ( ) No

10. **IF YES, What is the monthly water consumption for the past month? liters (Please obtain water bill for the past month)**

____

11. **IF YES, What is the total number of occupants during the past month?**

____

12. **Do you use ground water for any of the purposes below:** *
Check all that apply.

- [ ] Cooking
- [ ] Drinking
- [ ] Toilet flushing
- [ ] Dishwashing
- [ ] Shower
- [ ] Laundry
- [ ] Other: ________________________

13. **If other, please specify**

____

14. **What is the main source of water for cooking and Drinking?** *
Check all that apply.

- [ ] Bottled water
- [ ] Desalinated Water from the island water network
- [ ] Rainwater
- [ ] RO plant from guest house
- [ ] Other: ________________________

15. **If other, Please specify**

____

16. **Do you have bath tubs?**
Mark only one oval.

- ( ) Yes
- ( ) No

17. **If yes, how many bath tubs do you have?**

____

18. **Do you have a swimming pool**
Mark only one oval.

- ( ) Yes
- ( ) No

19. **IF YES, What is the estimated volume (in liters)?**

____

20. **IF YES, what is the source of water for your pool?**
Mark only one oval.

- ( ) Desalinated water from the water network in the island or a water plant elsewhere
- ( ) RO plant at the guesthouse
- ( ) Salt water from sea
- ( ) Groundwater
- ( ) Other: _______________________

21. **If other, please specify**

____

22. **How many loads of laundry do you do per week?**

____

23. **What kind of washing machine do you use?**
Mark only one oval.

- ( ) Top load
- ( ) Front load

24. **Does the ground water have any signs of contamination?** *
Check all that apply.

- [ ] Smell
- [ ] Salty taste
- [ ] Milky / cloudy clour
- [ ] No

25. **Is the an oxygen pump connected to the well?**
Mark only one oval.

- ( ) Yes
- ( ) No

26. **Do you do gardening?**
Mark only one oval.

- ( ) Yes
- ( ) No

27. **If you use a watering can, what is the capacity of the watering can (in liters)?**

28. **How many watering can do you use per day?**

29. **If you use a hose, how long does it take, per day (in minutes)?**

30. **On average, how many people use the restaurant (number of people)?**

31. **How many buckets of water is used for mopping the floors per day?**

32. **What is the capacity of the bucket?**

Restaurants and Cafe's

33. **Name of restaurant/cafe':**

34. **What type of water is being used for food preparation at the food outlet?**
Mark only one oval.

- ( ) Rain water
- ( ) Well water
- ( ) Desalinated water

35. **If other please specify**

36. **On average how many customers get services from your food outlet per day?**

37. **Does your food outlet have a dishwasher? If YES, how many dishwashers are there?**
Mark only one oval.

- yes
- No

38. **IF YES, how many times do you use the dishwasher per day?**

39. **If you have a toilet, approximately how many times is the toilet used per day?**

40. **Does the food outlet use ground water for any purpose**
Check all that apply.

- Floor and table cleaning
- dishwashing
- laundry
- toilet flushing

41. **If other please specify**

42. **How much time is spent on washing dishes?**

43. **How any buckets of water is used to mop the floors per week?**

44. **What is the capacity of said bucket?**

General

This Survey will be used to determine the water consumption and future demand for the "Ground water and Aquifer management" project under GCF Funding.
Result of this survey will be published only in Annonymous Summary form.

* Required

1. **Island name** *
   Mark only one oval.
   - AA. Bodufulhadhoo
   - ADh. Dhigurah
   - Dh. Meedhoo
   - Ga. Kon'dey
   - GDh. Fiyoari
   - Ha. Utheem
   - HDh. Nolhivaramfaru
   - M. Raiymandhoo
   - N. Hen'badhoo
   - Sh. Funadhoo
   - Th. Kin'bidhoo
   - B. Dharavandhoo
   - R. Maduvvari

2. **What kind of an institution?**
   Mark only one oval.
   - School
   - Health Center
   - Office

3. **How many toilets are there?**

   ____

4. **What is the approximate size of the flush tanks? (lxbxh)**

   ____

5. **What kind of flush tanks are used at the institute?**
   Check all that apply.
   - [ ] Ecoflush
   - [ ] Standard flush
   - [ ] Other: ____________________

6. **Do you use ground water for any of the purposes?**
Check all that apply.

- [ ] floor cleaning
- [ ] laundry
- [ ] shower
- [ ] toilet flushing
- [ ] dish washing
- [ ] Other: ____________________

7. **Do you have a water network in the island'**
Mark only one oval.

( ) Yes
( ) No

8. **IF YES, is the facility connected to a water network?**
Mark only one oval.

( ) Yes
( ) No
( ) Other: ____________________

9. **IF YES, What is the monthly water consumption for the past month? liters (Please obtain water bill for the past month)**

____

10. **Do you have rain water storage tanks?**
Mark only one oval.

( ) Yes
( ) No

11. **IF YES, how many?**

____

12. **How do you deal with rain water over flow from the tanks and the roofs?**
Check all that apply.

- [ ] Connected to the well via pipe
- [ ] connected to the ground via pipe
- [ ] Other: ____________________

13. **How many buckets of water is used for mopping the floors?**

____

14. **What is the capacity of the mop bucket (in liter)?**
Mark only one oval.

- ◯ Option 1

15. **How many loads of laundry do you do per week?**

____

16. **What kind of washing machine do you have?**
Mark only one oval.

- ◯ Top load
- ◯ Front load

17. **If other, please specify.**

____

18. **Do you have a garden within the office courtyard?**
Mark only one oval.

- ◯ Yes
- ◯ No

19. **If you use a watering can, how many cans do you use per day?**

____

20. **What is the capacity of watering can (in litres)?**

____

21. **If you use a water hose, how long does it take to water the whole garden?**

____

Hospitals/Health centers

22. **How many staffs are there in the institute?**

____

23. **How many staffs work per duty shift?**

____

24. **How many people use the shower facility?**

____

25. **Do you have a pantry at office?**
Mark only one oval.
- ( ) Yes
- ( ) No

26. **On average how many people use the pantry per day? (If someone uses it multiple time please count as multiple people)**

Schools

27. **How many students are enrolled in the school?**

28. **What is the total number of staffs (Teachers, Management staffs, Administrative staffs and others)**

29. **How many toilets are there?**

30. **How many buckets of water do you use to mop the floors per day?**

31. **If you use a watering can, how many cans of water do you use per day?**

Offices

32. **How many staff members are working in your office?**

33. **What are the working hours?**

34. **How many toilets are there?**

35. **Do you have a pantry in your office?**
Mark only one oval.

- ( ) Yes
- ( ) No

36. **Do you have a garden within the office courtyard?**
Mark only one oval.

- ( ) Yes
- ( ) No

37. **How often do you water this garden?**

____

38. **If you use a watering can, how many cans of water do you use per day?**

____

39. **If you use a water hose, how long does it take to water the whole garden?**

____

40. **Are there future plans for construction in these area?**

____

Annex VI: Pumping Test Data

Pumping test were conducted in four existing wells in three islands (Raimandhoo (1), Kinbidhoo (1), and Fiyori (2)) in order to estimate the aquifer properties of the unconfined water bearing formation. However, only two wells located in Raimandhoo and Kinbidhoo were selected for the estimation of the aquifer properties based on the conditions of well construction. The transmisivity of the water bearing formation was estimated by using Muskat's Method.

$$T = \frac{C'A}{2\pi t'} \ln(\frac{S_1}{S_2})$$

Where $C' = \ln \frac{r_0}{r_w}$

T	=	Transmissivity
A	=	Cross Sectional Area
r_0	=	Distance of which drawdown is negligible at the end of pumping
r_w	=	Radius of the well
S_1	=	Drawdown at the time pumping stops
S_2	=	Residual Drawdown at time of t' after pumping stops

The details of the two wells are given in Table 1.

Table 1: Details of the tested dug well in Raimandhoo and Kinbidhoo islands

Parameter	Raimandhoo	Kinbidhoo
Coordinates	348737.286/341880.35	284670.968/239763.502
Depth of the well(m)-bgl	1.43	2.3
Depth to static water level(m)-bgl	0.85	0.69
Internal diameter of the well(m)	1.1	1.2
Bottom of well	unlined	unlined
Water bearing formation	Unconsolidated fine sand	Unconsolidated fine sand
Approximate distance from coast line(m)	60	100

1.1. Raimandhoo Island

The existing well was pumped at a rate of 90 liters per minute for period of 70 minute and steady condition was reached after 25 minute of pumping. After termination of the pumping recovery was measured and more than 94% recovery was reached within 15 minute. The water level behavior of the tested well during the pumping and recovery phases is given in figure (1).

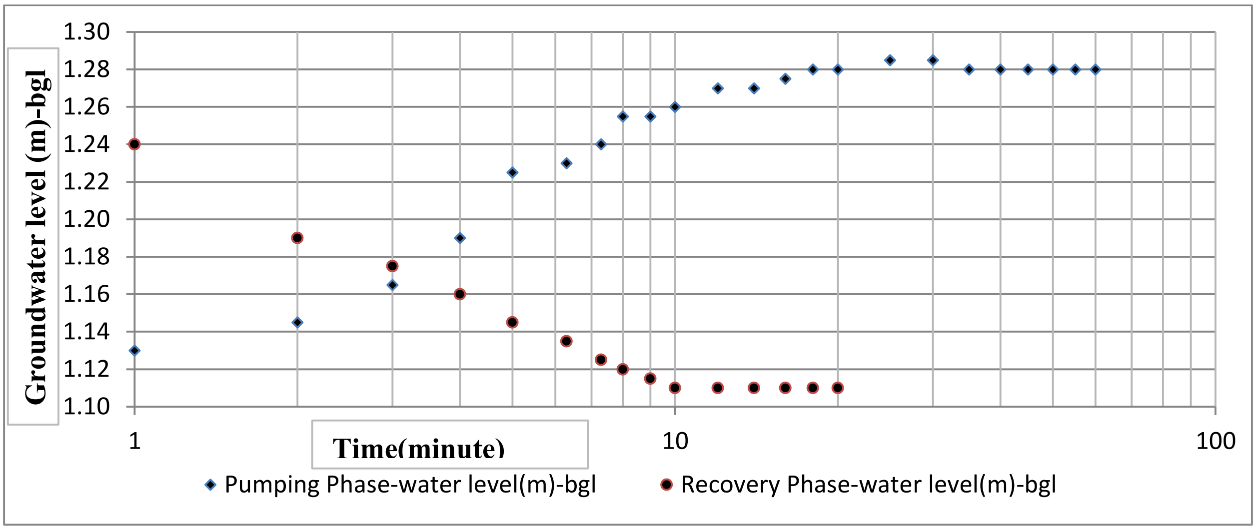

Figure 1: Groundwater level behavior of the tested well during pumping and recovery phase in Raimandhoo

1.2. Kinbidhoo Island

The existing well was pumped at a rate of 70 liters per minute for period of 80 minute and steady condition was reached after 55 minute of pumping. After termination of the pumping recovery was measured and about 97% recovery was reached within 30 minute. The water level behavior of the tested well during the pumping and recovery phases is given in figure (2).

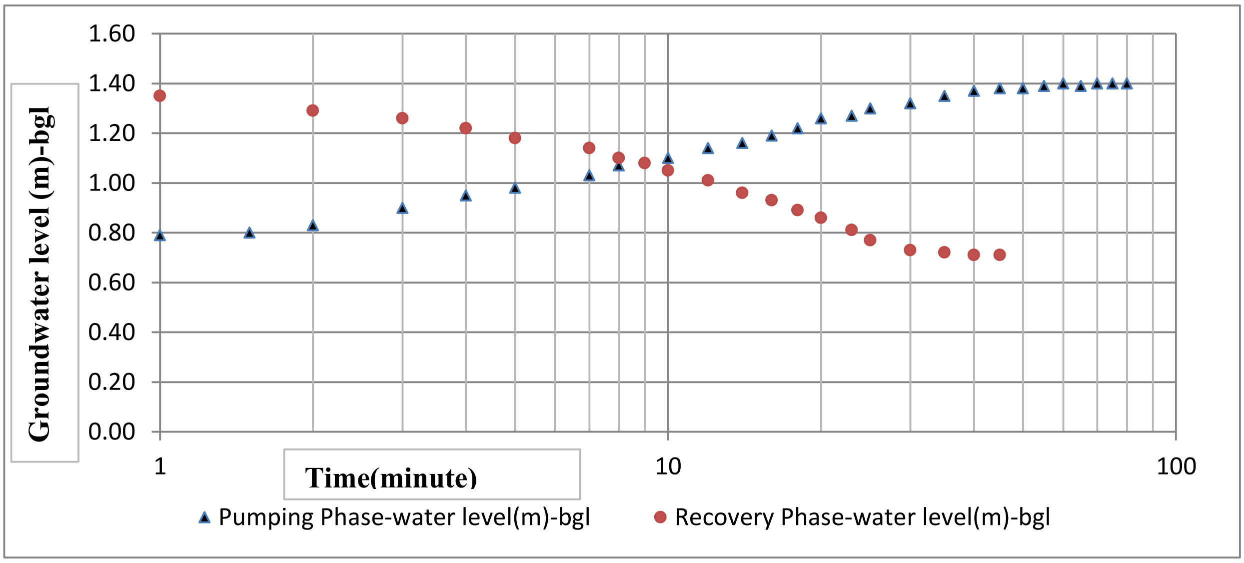

Figure 2: Groundwater level behavior of the tested well during pumping and recovery phase in Kinbidhoo

1.3. Results of the Pumping Tests

Transmissivity of the water bearing formation and electrical conductivity of the water are given in following tables (Table 2 and 3).

Table 2: Electrical conductivity variation in groundwater during the testing period of two islands

Name of Island	**Electrical conductivity of the groundwater in tested wells(µs/cm)**				
	Before the pumping	**During the pumping(after 30 minute)**	**End of the pumping phase**	**Middle of recovery phase**	**End of recovery phase**
Raimandhoo	3491(33.2°C)	3597(32.7°C)	4016(32.8°C)	3769(32.7°C)	3760(32.5°C)
Kinbidhoo	703(34.4°C)	653(34.7°C)	639(34.6°C)	Not measured	626(34.8°C)

Table 3: Transmissivity of the water bearing formation in two islands

C'	**A** (m^2)	t'**(s)**	**ln** $(\frac{S_1}{S_2})$	**T** (m^2/s)
Raimandhoo				
4.69	2	900	2.89	4.77×10^{-3}
Kinbidhoo				
5.11	6.07	1800	3.57	9.80×10^{-3}

Annex VII: General Geology of Kondey Island

The Kondey Island is located at the eastern side of the atoll and surrounded by fairly wider coral reef. The island is elongated and oriented into nearly NNW-SSE direction. Sothern side of the island has very narrow coral reef while eastern and western sides have 350 m to 500 m wide coral reef, and it is more widening to east and the north wards. However, the southern and northern ends of the island is getting very narrow and middle part of the island is only section getting wider and it is about 650 m. The length of the island is about 2 km along maximum length. Though the average width of the coral reef is same along the rim of the atoll where the island is located, the shape of the island is getting very narrow and elongated due to action of ocean waves / currents and the geological characteristics of coral bed.

The geological cross section developed using surface observations and resistivity profiles shows that the island has similar subsurface geological condition throughout the Island. Simplified geological profile of the island shows that 3 m to 4 m bellow, there is a moderate to hard coral bed which is located on the volcanic basement rock as usual condition of an atoll. The coral bed is overlain by average 2 m to 3 m thick medium to coarse calcareous sand and partially clayey sand bed which has 15% to 20% porosity and average permeability coefficient of 6.12 l/min. This layer acts as the main water bearing aquifer and considered as the water bearing layer. Top exposed layer of the profile is completely weathered with little humus bearing top soil layer which is always less than 0.5 m and in some places totally absent.

The geological condition in Kendey Island is therefore distinctly different than the single layered overburden soil characteristics to most other islands and this was taken into consideration while estimating the freshwater lens thickness and volume.

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