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Republic of Maldives



Assessing Groundwater Resources and Design of Aquifer Recharge Systems in Selected Islands of Maldives

BASELINE ASSESSMENT REPORT

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- Th Gaadhiffushi
- Th Omadhoo
- Th Vandhoo
- Th Kandoodhoo
- Th Dhiyamigili
- Sh Foakaidhoo

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List of abbreviations and acronyms

DNP	Department of National Planning
DTM	Digital Terrain Model
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EPA	Environment Protection Agency
FS	Feasibility Study
GCF	Global Climate Fund
LHI	Lanka Hydraulics Institute
ME	Ministry of Environment
NBS	National Bureau of Statistic
PMU	Project Management Unit
WS	Water Solutions Pvt. Ltd

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 the 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, Climate Change and Technology, Republic of Maldives presents the results of a study of baseline assessment to establish the current status and catchment characterization of individual islands with the main objective of undertaking an assessment of the existing groundwater quality and recharge rates and develop a groundwater resources management plan with clear recommendations to ensure improved aquifer recharging and protection. The target six (06) islands of the assignment are: Th Gaadhiffushi, Th Omadhoo, Th Vandhoo, Th Kandoodhoo, Sh Foakaidhoo, and Th. Dhiyamigili.

The study was conducted as per the conditions and tasks stipulated in the Terms of Reference (ToR) 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) characteristics and land-use investigations for 05 islands (geo-physical surveys were not conducted in Th. Dhiyamigili Island due to unexpected reasons beyond the control of the expert team).

The groundwater quality of the freshwater lens was studied based on physiochemical measurements (pH, Dissolved Oxygen, Electrical Conductivity, Turbidity, Temperature, Salinity, Ammonia, Nitrate, and Phosphate) and microbiological parameters (Total coliform and Faecal 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/officials 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 were estimated based on the geo-physical investigations using Electrical Resistivity (ER) method to establish depths to groundwater table and freshwater-saline water interphase, respectively. 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 selected six (06) islands under this package were located in two separate atolls where five (05) islands located on the Thaa atoll (Southern side of the Maldives) while one island is located in the Shaviyani atoll (Norther side of the Maldives). Therefore, the five (05) islands located on the southern side show some similar features when compared to groundwater parameters. All the six (06) islands are located nearly 200 – 240 km away from the main capital, Male.

Area extent of the islands varies from 14.63 Ha (Th. Gaadhiffushi) to 80.62 Ha (Th. Kandoodhoo) while the population range between 321 (Th. Vandhoo) and 1,882 (Sh. Foakaidhoo) as per the council records (Dec., 2021). Th. Kandoodhoo has the least population density of 9.20 per Ha while Th. Gaadhiffushi has the highest population density of 48.67 per Ha.

Land use distribution of each island has a significant difference based on each island’s vision and mission. Only Th. Kandoodhoo and Th. Vandhoo islands have farmlands where 35% of the total area extent of Th. Kandoodhoo has farmlands. Th. Vandhoo is covered with thick vegetation cover of 61%

of its total land extent. Since Th. Gaadhiffushi and Th. Dhiyamigili are densely populated, there is no thick vegetation in those islands.

More than 45% of each island have a positive perception of ‘use of groundwater for daily uses is safe’ while less than 45% have a negative perception. Furthermore, based on the interviews, more than 40% agreed that the ‘quality of the groundwater is good’ while less than 50% disagreed with that statement.

In all the islands, the sewer networks are under construction and they have no island-wide water supply networks. More than 84% of the households of these six (06) islands have rainwater harvesting tanks and more than 56% of them use rainwater for drinking purposes. More than 93% use rainwater for cooking. Groundwater is generally used for non-potable use in all the islands while 3% of the Th. Omadhoo uses groundwater for drinking purposes.

From these six (06) islands, Th. Vandhoo shows the highest average of Electrical Conductivity ($\mu\text{S}/\text{cm}$) of 1,039.46 $\mu\text{S}/\text{cm}$ which is still within the acceptable limit for potable water of 1,500 $\mu\text{S}/\text{cm}$. Th. Omadhoo and Th. Gaadhiffushi Islands had got EC values within the acceptable range for all the samples. Average Ammonia concentration of the tested samples remained within the acceptable limit of 1.5 mg/L.

When comparing both water quality data sets collected during dry and wet periods, there were no significant variations of measured parameters of the tested samples within residential areas in Th. Kandoodhoo Island. But in other islands, there were some locations within residential areas where incremental values of EC and Ammonia were recorded which can be identified generally as due to sea water flooding, anthropogenic activities, and higher groundwater extraction. Agricultural areas in Sh. Foakaidhoo, Th. Vandhoo, and Th. Kandoodhoo islands were recorded with an increase of EC, Ammonia, and Nitrate, which could be due to higher extraction of groundwater, leaching of nitrate-based fertilizers, etc.

Freshwater level of each island varies from -0.996 m (below MSL) to 0.710 m (above MSL) and the depth to the top water level from the ground varies from 0.5 m ~ 1.4 m. The infiltration rate of the subsoils in the islands varies from the least average value of 2.96 ± 2.02 m/day in Th. Omadhoo to 10.56 ± 12.87 m/day in Th. Vandhoo.

All the five (05) islands lie in ‘Semi-pervious’ range of the relative hydraulic conductivity and shows ‘Low’ to ‘Moderate’ potential for groundwater recharge. All the (05) islands have ‘Poor’ to ‘Good’ present aquifer condition based on the estimated hydraulic conductivity and transmissivity.

Based on the developed water balance and recharge model, Gaadhiffushi, Omadhoo and Foakaidhoo shows the most stressed and overexploited freshwater aquifer conditions with the present groundwater extraction rates exceeding their safe yields by 514%, 380% and 271% respectively.

Th. Kandoodhoo: Island is famous for chilly cultivation and 35% of the land use can be identified as farm lands. Further, 29% of land use was thick vegetation showing good aquifer conditions. Based on the tested WQ samples, enrichments of parameters were identified only in agricultural areas which could be due to higher GW extraction, leaching Nitrate base fertilizers, and small distance to sea. Perception of people on “safeness of GW for daily uses” and “quality of GW” shows positive feedback scoring below 54% agreed percentage. This island is the largest island and shows the highest freshwater volume of the island set as 835,316 m^3 . The present groundwater extraction rate estimated based on survey data is 292 m^3 per day and this is about 55% of the allowable Safe Yield in the island. Relative hydraulic condition of the island lies in ‘Semi-pervious’ state while present aquifer condition remains at ‘Poor’ state. Moreover, general status based on transmissivity ranged ‘High’ to ‘Very High’ and potential for groundwater recharge remains ‘Low’ – ‘Moderate’ as per the estimations.

Th. Vandhoo: Is a small island where 65% of the land is covered with vegetation and there are farm lands lay in 3% of total land usage. Based on the tested WQ samples, enrichments of parameters were identified in residential, agricultural and other area (bare lands) which could be due to higher GW extraction, leaching Nitrate base fertilizers, and water logged areas with saline water due to sea water

flooding. Perception of people on “safeness of GW for daily uses” and “quality of GW” shows positive feedback scoring below 62% agreed percentage. The calculated freshwater volume of the island is 208,801 m³. The present groundwater extraction rate estimated based on survey data is 100 m³ per day and this is about 115% of the allowable Safe Yield in the island. Relative hydraulic condition of the island lies in ‘Semi-pervious’ state while present aquifer condition remains at ‘Poor’ – ‘Good’ state. Moreover, general status based on transmissivity ranged ‘High’ and potential for groundwater recharge remains ‘Low’ – ‘Moderate’ as per the estimations.

Th. Omadhoo: The island has a high population density and 50% of its land is covered with vegetation. Based on the tested WQ samples, enrichments of parameters were identified in residential, agricultural and other area (fish huts) which could be due to higher GW extraction and anthropogenic activities. Perception of people on “safeness of GW for daily uses” and “quality of GW” shows negative feedback scoring below 45% agreed percentage. The calculated freshwater volume of the island is 323,401 m³. The present groundwater extraction rate estimated based on survey data is 382 m³ per day and this is about 380% of the allowable Safe Yield in the island. Relative hydraulic condition of the island lies in ‘Semi-pervious’ state while present aquifer condition remains at ‘Poor’ state. Moreover, general status based on transmissivity ranged ‘High’ and potential for groundwater recharge remains ‘Low’ – ‘Moderate’ as per the estimations.

Th. Gaadhiffushi: The island has the highest population density of the lot and lack with thick vegetation cover. Based on the tested WQ samples, enrichments of parameters were identified in residential areas which could be due anthropogenic activities. Perception of people on “safeness of GW for daily uses” and “quality of GW” shows moderate feedback scoring nearly 51% agreed percentage. The calculated freshwater volume of the island is 68,000 m³. The present groundwater extraction rate estimated based on survey data is 206 m³ per day and this is about 514% of the allowable Safe Yield in the island. Relative hydraulic condition of the island lies in ‘Semi-pervious’ state while present aquifer condition remains at ‘Poor’ – ‘Good’ state. Moreover, general status based on transmissivity ranged ‘High’ and potential for groundwater recharge remains ‘Low’ – ‘Moderate’ as per the estimations.

Sh. Foakaidhoo: The island has a high population density and 44% of land is covered with thick vegetation. Based on the tested WQ samples, enrichments of parameters were identified in residential, agricultural and industrial areas which could be due anthropogenic activities, higher GW extraction and sea water mixing with water at water logged areas. Perception of people on “safeness of GW for daily uses” and “quality of GW” shows moderate feedback scoring below 61% agreed percentage. The calculated freshwater volume of the island is 517,753 m³. The present groundwater extraction rate estimated based on survey data is 511 m³ per day and this is about 271% of the allowable Safe Yield in the island. Relative hydraulic condition of the island lies in ‘Semi-pervious’ state while present aquifer condition remains at ‘Poor’ – ‘Good’ state. Moreover, general status based on transmissivity ranged ‘High’ and potential for groundwater recharge remains ‘Low’ – ‘Moderate’ as per the estimations.

Th. Dhiyamigili: The island has the highest population density of the lot and lack with thick vegetation cover. Perception of people on “safeness of GW for daily uses” and “quality of GW” shows moderate feedback scoring nearly 55% agree percentage. The present groundwater extraction rate estimated based on survey data is 240 m³ per day and this is about 113% of the allowable Safe Yield in the island.

Evaluation of Hydraulic Properties of Investigated Islands

Comparison of estimated hydraulic conductivity of the islands was carried out as per Bear (1972) and transmissivity of the formation was compared as per Krany (1993). The distribution of hydraulic conductivity and transmissivity of the islands are given below.

Hydraulic conductivity (cm/s)	10 ²	10	1	10 ⁻¹	10 ⁻²	10 ⁻³	10 ⁻⁴	10 ⁻⁵	10 ⁻⁶	10 ⁻⁷	10 ⁻⁸	10 ⁻⁹	10 ⁻¹⁰
Relative hydraulic conductivity	Pervious			Semi-Pervious				Impervious					
Aquifer condition	Good				Poor				None				
Islands													
Th. Omadhoo	0.00148-0.00681												
Th. Gaadhiffushi	0.0016-0.01742												
Sh. Foakaidhoo	0.000613-0.01491												
Th. Kandhoodoo	0.00321-0.0174												
Th. Vandhoo	0.00103-0.02891												

Therefore, All the five islands lie in the range of “Semi-previous” based on the Relative hydraulic conductivity while they show “Poor” to “Good” Aquifer conditions. Moreover, as shown below, the Transmissivity show “High” to “Very High” conditions.

Transmissivity(m ² /d)	>1000	1000-100	100-10	10-1	1-0.1	<0.1
General Status	Very High	High	Intermediate	Low	Very Low	Impermeable
Islands						
Th. Omadhoo		High (103-156)				
Th. Gaadhiffushi		High (648)				
Sh. Foakaidhoo		High (198-319)				
Th. Kandhoodoo	Very High to High (172-1123)					
Th. Vandhoo		High (138-216)				

The vertical hydraulic conductivity of surficial deposits and other strata in a recharge area of the aquifer determines the volume of recharged water capable of moving downward to the aquifer from the recharge pits, diverted or accumulated drainage paths and ponds, etc., and the transmissivity of the aquifer and potentiometric gradient determine how much water can move away from the recharge area. Therefore, the optimal conditions for recharge are produced when the hydraulic conductivity of the aquifer lies in the Good region and the transmissivity is limited to Intermediate to Low.

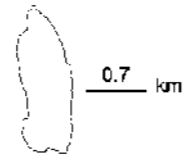
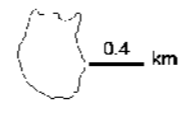

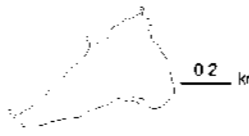
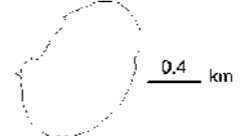

A complete summary of island characteristics and observed/measured geo-physical and hydraulic parameters are presented as below.

Overall Conclusion

Six (06) islands selected under the study was situated in two separate atolls located in northern and southern part of Maldives islands. Each island shows individual characteristics compared to water quality parameters and hydraulic conductivity parameters as discussed above. Based on the variations identified on the groundwater quality parameters and observations made during the field visits, identified main reasons for the critical variation on EC, Ammonia, Nitrate and Phosphates are; higher extraction of groundwater, leaching on nitrate based fertilizers, coral stockpiling within the island area, sea water flooding, and contaminants from anthropogenic activities.

Groundwater extraction for daily activities (for domestic, farming, fisheries, industrial and institutional purposes) in selected islands differs from 36,492 ℓ /yr. in Th. Vandhoo to 186,558 ℓ /yr. in Sh. Foakaidhoo. Furthermore, the stress level of the aquifer differs from 'Not stressed' (55% of allowable safe yield of Th. Kandoodhoo) to "Very highly stressed" (514% of allowable safe yield of Th. Gaadhiffushi) which could be related to the land usage and population density. Therefore, immediate actions are warranted to avoid further degrading groundwater quantity and quality issues for the islands with 'Moderately stressed' to 'Very highly stressed'.

Summary of Island Characteristics and Observed/Measured Geo-physical and Hydraulic Parameters

Atoll	Thaa	Thaa	Thaa	Thaa	Shaviyani	Thaa
Island	Kandoodhoo	Vandhoo	Omadhoo	Gaadhiffushi	Foakaidhoo	Dhiyamigili
Shape of the Island						
Latitude	2°19'17"N	2°17'30"N	2°10'5"N	2°15'9"N	6°19'35"N	2°20'20"N
Longitude	72°55'E	72°56'30"E	73° 1'28"E	73°12'45"E	73° 8'55"E	73°20'12"E
General Overview of the Island and Demography						
Area (Ha)	80.62	25.13	40.05	14.63	66.01	29.62
Length (m)	1,200	670	1,080	700	1,152	1,120
Width (m)	470	500	730	400	780	410
Distance to Male (km)	215	218	228	215	241.2	204.15
Population	742	321	1157	712	1882	974
Pop. density (per /hectare)	9.20	12.77	28.89	48.67	28.51	32.88
Land Cover and Built up Area (As a percentage of total land area)						
Roof area (%)	3%	6%	6%	12%	9%	9%
Thick Vegetation (%)	29%	61%	41%	-	44%	-
Thin Vegetation (%)	3%	5%	12%	34%	8%	28%
Bare lands (%)	3%	23%	27%	33%	39%	62%
Farm lands (%)	35%	3%	-	-	-	-
Socio-economic Condition						
Overview	Several scattered farms (35% of land use)	Over 65% vegetation	Nearly 50% Vegetation high population density	Highest population density	High population density with fishing	High population density
Number of Households	130	67	115	73	280	121
Number of institutions	4	4	5	3	4	4
Number of restaurants	3	1	2	3	4	5
Perception on "use of GW for daily uses is safe"	69% - Agree 25% - Disagree	66% - Agree 20% - Disagree	45% - Agree 45% - Disagree	51% - Agree 43% - Disagree	61% - Agree 26% - Disagree	55% - Agree 31% - Disagree
Perception on "quality of GW for is good"	54% - Agree 34% - Disagree	62% - Agree 26% - Disagree	39% - Agree 51% - Disagree	42% - Agree 49% - Disagree	48% - Agree 35% - Disagree	42% - Agree 41% - Disagree
Present Sanitation and Water-use Characteristics						
Presence of Sewer Network	Under Construction	Under Construction	Under Construction	Under Construction	Under Construction	Under Construction
Presence of Water Supply	No	No	No	No	No	No
Households with RW tanks	87%	86%	84%	97%	95%	96%
Rainwater use for drinking	73%	84%	56%	77%	87%	95%
Rainwater use for cooking	96%	93%	97%	97%	98%	99%
Groundwater as a drinking source	0%	0%	3%	0%	0%	0%
Groundwater use for cooking	12%	4%	22%	3%	7%	3%
Groundwater use for non-potable use	91%	95%	93%	90%	77%	83%
Water Quality Aspects (Selected Parameters; please refer to respective chapters for other details and data)						
Elect. Conductivity (µS/cm)	790.85 ± 668.44	1,039.46 ± 799.55	524.15 ± 172.37	641.31 ± 294.19	895.68 ± 366.37	966.16 ± 722.70
Ammonia (mg/L)	0.06 ± 0.18	0.27 ± 0.42	0.41 ± 1.30	0.29 ± 0.85	0.23 ± 0.88	0.78 ± 1.24
Faecal Contamination	Yes	Yes	Yes	Yes	Yes	Yes
Groundwater Availability, Usage, Water Balance and Recharge Potential						
Freshwater Lens Volume (m ³) & Thickness (m)	835,316 1.19 ± 0.72	208,801 0.89 ± 0.77	251,915 1.50 ± 0.85	66,352 0.67 ± 0.21	517,753 0.87 ± 0.05	-
Rainwater Harvesting (m ³ /year)	918	503	857	630	2394	995
Groundwater Extraction (m ³ /year)	106,502	36,492	139,320	75,220	186,558	91,863
Available Overland Flow (m ³ /year)	478,659	146,279	251,131	115,774	345,425	180,647
Safe Yield M1 & M2 (m ³ /day)	528 & 479	87 & 150	100 & 242	40 & 88	188 & 320	222 & 179
Usage / Safe Yield (%)	55% & 61%	115% & 67%	380% & 157%	514% & 233%	271% & 160%	113% & 141%
Relative hydraulic conductivity	Semi-pervious	Semi-pervious	Semi-pervious	Semi-pervious	Semi-pervious	-
Present Aquifer Condition	Poor	Poor - Good	Poor	Poor - Good	Poor - Good	-
Potential for GW Recharge	Low - Moderate	Low - Moderate	Low - Moderate	Low - Moderate	Low - Moderate	-

1 INTRODUCTION

1.1 Background

The Republic of Maldives is a low lying atoll in the Indian Ocean situated about 670 km southwest of Sri Lanka. The 1,196 coral islets of this archipelagic state which are administratively grouped into 26 atolls spread over an area of 90,000 km² stretching over 760 km in length (from north to south) / approximately 120 km in width (from west to east) with their land area occupying a mere 298 km². With a predicted mid-year total resident population of 557,426 (Statistical Yearbook 2018), the Maldives is one of the world's most geographically dispersed sovereign states (FAO, 2011) as well as the smallest Asian country by land area and the 2nd least populous country in Asia (UNDP, 2019).

The World Bank (WB) classifies the Maldives as having an upper-middle income economy (World Bank, 2015). Fishing has historically been the dominant economic activity, and remains the largest sector by far, followed by the rapidly growing tourism industry and these together contribute nearly 80% of the country's Gross Domestic Product (GDP). The country has an average elevation of 1.5 m above mean sea level (AMSL) and with global warming and the shrinking of the polar ice caps, climate studies have found that the Maldives is directly threatened, as none of its islands rises more than 1.8 m AMSL (World Bank, 2014; BBC, 2018).

According to the Ministry of Environment, Climate Change & Technology, 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. It has been noted that the Maldivian 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' was launched by the Government of Maldives in the year 2015. The accredited entity for the project is the United Nations Development Programme (UNDP) and the implementer is the Ministry of Environment, Climate Change and Technology. The project has the objective to deliver safe and secure freshwater to 105,000 people in the islands of the Maldives in the face of climate change risks. This will be achieved by delivering the following undertakings (Project RFP, Ministry of Environment, 2020):

- 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 the first phase of the project Groundwater Resource Management and Aquifer Protection in the Maldives, the compilation of the Baseline Assessment Report of aquifer groundwater conditions was undertaken for 13 islands in 2019 (MoEnv., 2020).

As an integral component of the ongoing project, the Maldivian Government intends to apply part of the proceeds towards procuring the services of Riyan Private Limited (Riyan, Maldives) and Master Hellie's Engineering Consultants Private Limited (MHEC, Sri Lanka) for the Consultancy Services to Assessing Groundwater Resources and Design of Aquifer Recharge Systems in Selected Islands of Maldives (GCF Project) with the following specific objectives.

1.2 Specific Objectives

The scope of work of this consultancy service is broadly categorized into three (03) areas with specific objectives as outlined below.

- a. Undertake baseline assessment to establish the current status and catchment characterization of each island.
- b. Feasibility study and concept design of Managed Aquifer Recharge (MAR) systems for the islands with a specific emphasis on floodwater management
- c. Detail design of MAR systems

This report outlines the results of the baseline assessment surveys undertaken in the following six (06) islands. The 6th island, Th. Dhiyamigili was covered only partially due to accessibility issues.

- | | |
|--------------------|--------------------|
| 1. Th Gaadhiffushi | 4. Th Kandoodhoo |
| 2. Th Omadhoo | 5. Sh Foakaidhoo |
| 3. Th Vandhoo | 6. Th. Dhiyamigili |

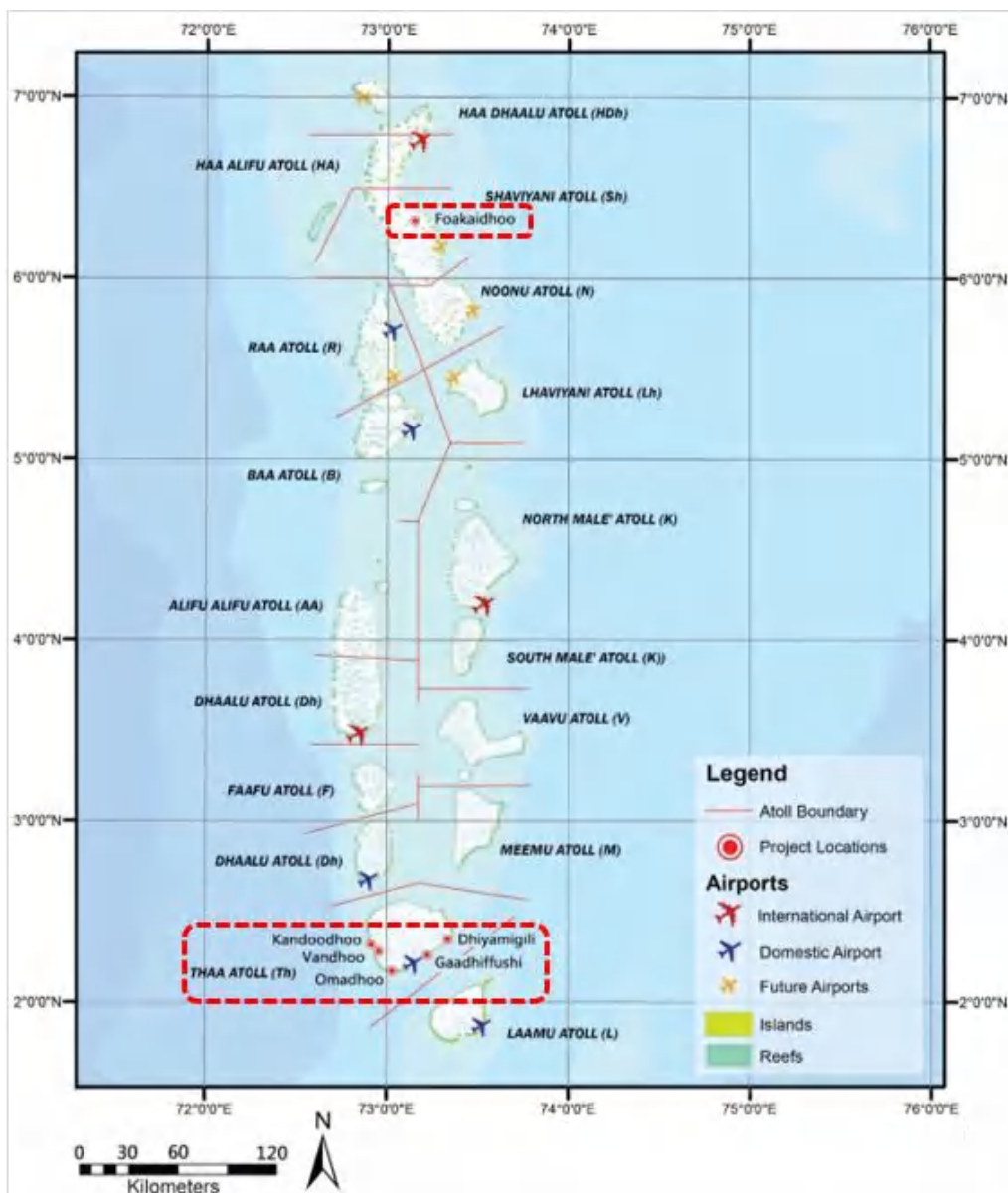


Figure 1-1: Location Map of Selected Six islands in Lot 2

1.3 Structure of the Report

The report has been structured into three broad categories.

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

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

Thirdly, the report outlines the findings of the surveys 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 and findings from the Institutional surveys
- Existing water and sanitation situation
- Results of the Baseline Surveys
 - o Water sources and water use
 - Domestic water use situation
 - Commercial water use situation
 - Institutional water use situation
 - o Groundwater quality
 - o Geophysical surveys
 - o Aerial surveys
 - o Freshwater lens
 - o Water demand
 - o Water balance and recharge
 - o Sustainable yield of the lens
 - o Ground permeability
 - o Steady pumping test results
 - o Groundwater availability
 - o Assessment of groundwater recharge potential
- Conclusive Remarks and Recommendations

The findings of the Baseline Assessment Report(s) will provide essential background and existing condition data for the subsequent studies and Managed Aquifer Recharge (MAR) designs as prescribed under Specific Objectives b) and c) in Section 1.2 above.

1.4 Methodology of Data Collection

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

In each island, eight (8) different types of surveys (investigations) were undertaken. They are;

- 1) Groundwater assessment (Physiochemical and microbiological tests for groundwater quality).

- 2) Geo-physical surveys (Depth to the groundwater table, Depth to the freshwater-saline water interphase to estimate thickness of the freshwater lens based on collected Electrical Resistivity (ER) data)
- 3) Socio-economic surveys (Household/Institutional surveys with water usage survey to establish Water demand and recharge-depletion pattern and meetings with the Local Councils to assess the Existing water use, Recharge, Flood extent/frequency data, Present impacts on the freshwater lens and the Quality of other water sources, etc.)
- 4) Rainwater catchment and infiltration survey (To establish natural recharge and drainage pattern)
- 5) Topographic surveys and UAV Mapping (Contributory catchment identification to estimate rates of groundwater recharge and discharge)
- 6) Groundwater level survey (To monitor groundwater table depletion and study aquifer water balance and depletion-recovery)
- 7) Soil permeability tests and Soil profiling (To estimate infiltration and recharge characteristics)
- 8) Steady pumping tests (To recognize well drawdown and recovery and aquifer parameters)

The following sections outline the detailed methodology of how the above surveys and data collection procedures were undertaken in the field or on each island.

1.4.1 Groundwater well survey – (Physiochemical and Microbiological)

The scope of the assessment required the 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

For the physicochemical survey of the groundwater, as per the TOR, a minimum of 40 or representative adequate number of samples should be collected for all physiochemical tests and 15 or a representative adequate number of samples should be collected for all microbiological tests. 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 to represent 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 includes 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:

- Stratified random sampling points throughout the island to cover the entire aerial extent,
- Sampling points were proximal to where the ER surveys have been undertaken for comparison,
- Cross-sectional profiles of the island to the extent of the shoreline vegetation, and covering
 - Residential areas,
 - Agricultural areas,
 - Industrial areas
 - Forest type vegetated areas,
 - Barren lands, and
 - Areas of other specific land use (existing reclamation, newly reclaimed, industrial areas, etc.)

1.4.1.1.1 Parameters tested

The following physiochemical parameters were measured for each island:

- Temperature (°C)
- pH
- Salinity (mg/L)
- Electrical Conductivity (EC), $\mu\text{S}/\text{cm}$
- Dissolved Oxygen (DO), mg/L
- Turbidity, NTU
- Ammonia, mg/L
- Nitrate, mg/L
- Phosphate, mg/L

The electrical conductivity measurements were used to determine the areal extent and depth spread (depth to freshwater-saline interphase) of the freshwater lens. For the survey, the practical limit of EC for freshwater was considered to be 2,500 $\mu\text{S}/\text{cm}$, 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:

- o Physiochemical: The following parameters were tested for each island: pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), Turbidity, Temperature, Salinity, Ammonia, Nitrate, and Phosphate (at least 40 samples per island, from existing groundwater wells)
- o Microbiological: The following parameters were tested for each island: Total coliform and Faecal coliform (at least 15 samples per island, from existing groundwater wells)

Samples for laboratory testing was collected using properly decontaminated and labelled High Density Poly Ethylene (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 were 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 (~ 10 cm - 15 cm). In situations where the auger could not be used, the hole was dug manually using a spade or hand auger.

1.4.1.1.2.2 Instruments for water quality testing

Temperature, pH, salinity, DO, EC and turbidity have been tested in-situ using Hanna Multiprobe Test Meter (HI 9829). Hanna Multiprobe has been calibrated using the calibration solution prior to commencement of testing (each day or as necessary). The quick calibration solution was used to calibrate all physical parameter sensors.

Chemical parameters (Ammonia, Nitrate and Phosphate) have been analysed through the Water Quality Assurance Laboratory (MWSC) or National Health Laboratory (NHL) of Maldives Food and Drug Authority (MFDA).

1.4.1.2 Sampling methodology – Microbiological surveys

To understand the severity and extent of 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 and wells at identified institutions/locations.

Unlike the physiochemical surveys, the number of samples tested for microbiological contamination was less and the locations concentrated more on the residential areas due to higher risk.

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 degrees Celsius and hence, this temperature was maintained throughout its transit. The details of test procedures are briefly explained below and a summary is provided in Table 1.1. **Error! Reference source not found.**

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	HI 9829
DO	In-situ Multi-probe	mg/L or %	±0.1 mg/L	HI 9829
EC	In-situ Multi-probe	mS/cm	±0.5%	HI 9829
Turbidity	In-situ Multi-probe	NTU	±2.0%	HI 9829
Temperature	In-situ Multi-probe	°C	±0.2°C	HI 9829
Salinity	In-situ Multi-probe	mg/L or ppt	±0.1	HI 9829
Ammonia	In-situ Multi-probe	mg/L as N	0.01 mg/L	HATCH method
Nitrate	In-situ Multi-probe	mg/L as N	0.01 mg/L	HATCH method
Phosphate	Laboratory	mg/L as P	0.01 mg/L	HATCH method

Microbiological Parameters				
Parameter	Test Method	Unit	MDL	Reference
Total coliform	Laboratory	MPN/100 mL		MWSC Lab
Faecal coliform	Laboratory	MPN/100 mL		MWSC Lab

1.4.1.2.1 Data entry

Groundwater sampling locations have been mapped by recording the house/plot names or if in an open area, by using GPS coordinates. The GPS coordinates of the plots have been derived from the survey map. The resultant data has been tabulated for entry into a GIS database as given below. Since some of the water wells are expected to be covered by the roof, the estimated location with the plot has been derived by measuring offsets from walls. The name of the house or data point has been entered into the filename of the water test meter (Logger HI 9829).

Each point had a set of attributes including all the parameters to be tested as well as the name of the house/institution/place. At each sampling point, water quality data has been entered as attribute values on-site, minimizing manual data recording.

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.
- 6- At least two readings were recorded from each well as a cross-check measure.

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 extent and volumes of the freshwater lens in the islands. The TOR further stipulates the requirement for assessing the present impacts on the freshwater lens and the 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 was required to be assessed in the field by measurements and it was 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 (twice during the water quality measurements and at the time of geophysical surveys; i.e. towards the end of the dry period and end of the wet period, respectively).

In addition, these baseline conditions related to presently existing groundwater resources at individual islands were properly established in order to have a better insight into the rates of groundwater recharge and discharge, as well as targeting assessment of potential improvements due to implementation of proposed interventions in future 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 develop groundwater extraction/recharge monitoring protocols and other groundwater and aquifer management strategies and methodologies to be developed following the 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 or ER) methods based on conductance and Electro-Magnetic (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 the source of current and (earth) media, such as encountered in resistivity measurements. This enables the 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. 1-2) 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. The ER based equipment and methodologies have been adopted in the first part of the project focusing on the assessment of baseline conditions in selected 13 islands (Min Env, 2020).

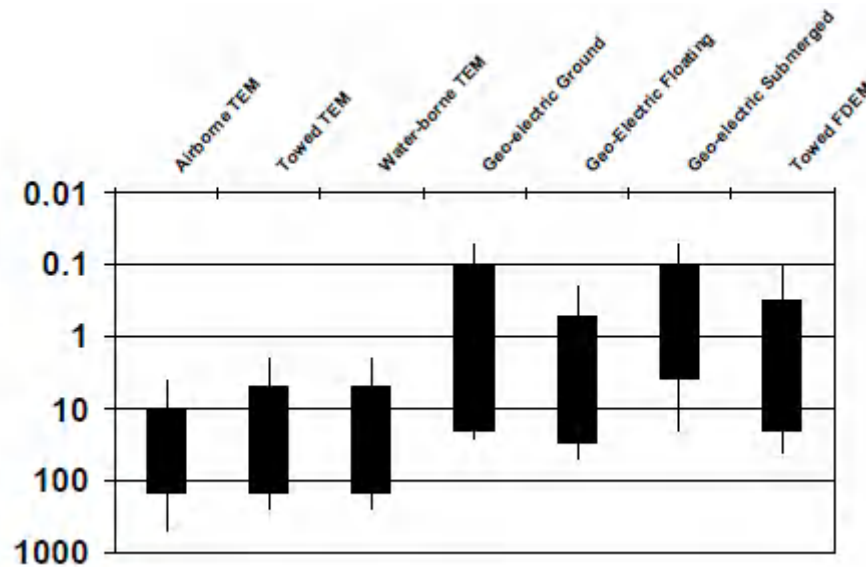


Figure 1-2: Ranges of detectable depths of various ER/EC imaging devices (in metres). Note that airborne FDEM (not shown) has a range similar to but shallower than airborne TEM (Source: Allen, 2007)

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 profiles 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 the unavailability 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 past studies, pilot tests had been carried out in three selected 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 Geonics, SkyTEM were also consulted to establish the most suited ER/EM based application while additional information was referred from the 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 pilot tests carried out in selected three islands from 28th February to 05th March 2019 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 the freshwater lens. Therefore, a 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 $10^{-1} \Omega\text{m}$ to $10^7 \Omega\text{m}$. 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, the 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 investigations. 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 array. The Wenner array is mostly used for profiling to investigate the lateral resistivity variation whereas the Schlumberger array is used for vertical profiling. Schlumberger array is the method used in this study. Figure 1-3 shows the two different electrode arrays.

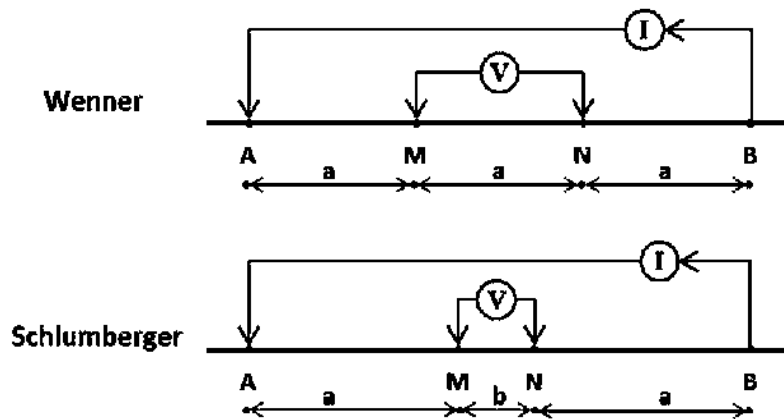


Figure 1-3: Electrode configurations -- Wenner and Schlumberger Arrays (Garofalo, 2014)

Electrode spacing and measurement of test reading

The current and potential electrode spacing used in the field measurements are given in the following table (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	Measured in the field
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.

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

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 (Sources: Left - ABEM Terrameter LS 2 - User Manual, 2017/ Center, Right - Siqueira Neto & Elis)

1.4.3 Socio-economic surveys (Water-usage survey)

A social or public survey at the island community level was carried out to understand the water usage for different purposes, emphasizing groundwater usage in households, tourism, agriculture, fisheries and other economic sectors of the islands. The communities’ perception of the existing condition of groundwater and support information regarding flooding issues experienced on the island have been assessed during the survey. The results of the surveys have mainly been used to determine the generalised quantification of groundwater usages for different uses for the design of aquifer recharge systems and flood mitigation approaches. The usage was quantified by estimating the volume of groundwater used for various purposes. This was determined based on the method of water extraction practiced in households. For example, if they use taps connected to the well, the water extraction pressure of the pump and the estimated time spent running the tap can be used to calculate an estimated volume. The survey interviews included questions that could assist in carrying out the estimations.

1.4.3.1 Sampling methodology

The sampling was carried out at different levels. This includes identification of water usage at;

1. Household-level,
2. Commercial outlets (café’s/restaurants/guesthouses),
3. Industrial activities (agricultural lands/fish processing centres/others)
4. Institutions (schools, health centres, council, other administrative buildings, etc.)

A Stratified-random sampling method has been used to derive the samples where the sample size was determined at a 95% confidence interval.

Table 1.3 below gives the sample size for the household surveys that have been carried out in the selected six (6) islands of Lot 2.

Table 1.3: Sample size for the household surveys in the islands

Island	Total Number of Households	Sample Size at 95% Confidence Interval	Completed Sample Size	Margin of Error (%)
Th. Gaadhiffushi	73	62	60	5
Th. Vandhoo	67	58	56	5
Th. Kandoodhoo	130	98	67	5
Th. Dhiyamigili	121	93	76	5
Th. Omadhoo	115	89	94	4.4
Sh. Foakaidhoo	280	163	147	5

Note: In the case of Th. Omadhoo, 5 additional survey forms were completed, and the additional data was included in the analysis and presented in the findings, as it will improve the reliability of the survey findings and decrease the MOA to 4.4%

1.4.3.2 Survey methodology

The surveys have been conducted using structured questionnaires (See Appendix IV for the questionnaires A, B, C and D, separate questionnaires have been used for the different users). The key areas that were covered in the surveys as per the TOR include:

- Groundwater usage in households (estimates of the quantity of groundwater used per day for various uses (such as drinking, bathing, washing clothes and dishes, flushing toilets, watering plants etc.)
- Perception on groundwater accessibility and quality
- Flooding depths, frequency and causes (this was collected as supporting information to the information collected from the Island Councils)

Given the COVID-19 situation, the surveys have been carried out with the help of enumerators selected from the island communities. A robust sample frame has been obtained to successfully carry out the survey. Enumerators were hired from the island communities and trained to carry out the surveys. The training was conducted in an online session with Google Meet and other platforms based on the convenience of the enumerators. An effort was made to provide equal opportunity for both genders in selecting the enumerators. The training was mainly focused on the following aspects:

- Basic etiquette tips in carrying out a household (HH) survey
- Explain the objective of the survey and the objectives of each question
- Familiarise the enumerators with the questionnaires
- Mock interviews to test interviewing skills of enumerators
- Familiarisation with Google Forms and data entry
- A thorough discussion of the objectives of the survey as well as the objectives of each question was explained during the training process.

1.4.3.3 Data entry and analysis

Data collection was carried out using Google Forms. Once the data collection was completed, the data set was extracted to Microsoft Excel and calculations were performed for individual islands. For each individual island, data for the four (4) categories of water uses were analysed separately. The water usage estimates were calculated based on internationally applied flow rates.

1.4.3.4 Challenges, limitations and mitigation measures adopted

During the data collection process, the survey teams experienced a number of challenges and limitations and the following measures were taken to mitigate the challenges and to ensure quality of the data collected. The following Table 1.4 summarizes this information in detail.

Table 1.4 Challenges, Limitations and Mitigation Measures during Surveys Conducted

Challenges and Limitation	Details	Mitigation Measures Adopted
Inaccuracy in the sample frame provided by the Councils	The councils in each island were requested to provide lists of households, institutions, businesses and the number of people engaged in different business activities in the island. Some of the lists received from the councils were proven to be inaccurate/not up to date during the data collection process. Some councils were also unable to provide the requested data (due to data unavailability, etc.).	The enumerators attempted to correct and update the lists as much as possible
Refusals	Some respondents selected for the survey refused to take part in the survey.	Replacement samples were drawn to achieve the targeted sample as much as possible
Vacant Houses	Some households in the sample were discovered as vacant/ unaccessible	Replacement samples were drawn to achieve the targeted sample.
Non-practicing registered farmers	Some of the registered farmers in the island were not practicing farming at the time of data collection. This includes those who have registered land plots for farming as well. Hence, the lists received from the councils did not provide an accurate/up to date number of farmers in the island and therefore the survey team was unable to reach the targeted sample which was taken from the lists provided by the council.	The enumerators attempted to correct and update the lists as much as possible and replacement samples were taken to reach the sample size as much as possible. However, due to the limited number of actual farmers, the total sample at a 95% confidence level was not reached
Non-practicing fishing vessels and fish processing businesses	Some of the registered fishing vessels and fish processing businesses were not operational at the time of data collection. Hence, the list received from the council did not provide an accurate number of people engaged in these activities in the islands. Consequently, the survey team was unable to reach the targeted samples on these activities, which were taken from the lists provided by the island councils	The data collection team attempted to correct and update the list as much as possible and replacement samples were taken to reach the sample size as much as possible. However, due to the limited number of active businesses (or none in some cases) at the time of data collection, the total sample at

Challenges and Limitation	Details	Mitigation Measures Adopted
		95% confidence level was not reached
Missing data in the completed survey forms	There were a lot of missing data in the completed forms, mostly due to respondents not being able to answer them accurately.	Enumerators were advised to probe respondents as much as possible to get an accurate response.
Issues with generalizing the data across some commercial and /or institutional activities as the activities varied in the nature of work and the level of operation	With regard to some commercial activities or institutional water usage, huge differences were observed in the volume of water used as the kind and level of operations varied. For example, there is a big difference in the amount of water used in the island courts compared to that of a health centre. Similarly, water usage in cafes varied based on their capacity and level of operation.	A total amount of water used is provided rather than per capita or average water usage in these activities.

1.4.3.5 Estimation of rainwater catchment/infiltration and runoff

The development of an aquifer management plan requires an 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.

Aggregate runoff coefficient was taken to estimate the overland flow and following runoff coefficients were considered.

Table 1.5: Considered runoff coefficients for land use type (Source: Tsutsumi et al., 2004)

Land use (type of ground surface)	Runoff Coefficient
Roof cover	0.90
Vegetation	0.15
Bare lands	0.30
Farm Lands	0.20
Roads	0.50
Playground	0.70
Wetlands	0.70

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

1.4.3.5.1 Establishment of Permanent Survey Marks (PSMs)

The PSMs have been established where necessary (project sites where PSMs are not registered at Maldives Land and Survey Authority - MLSA) as per the MLSA guideline of establishing PSMs. Three PSMs were cast on-site as per MLSA guideline (Type A PSM design), while the PSMs were spaced such that best triangulation is achieved (depending on availability of space). The PSMs were placed 10 cm below ground level as recommended in Control Survey Guidelines by MLSA. The PSMs horizontal coordinates were established using Topcon GNSS receivers using the static survey method with horizontal and vertical error within 10mm. The data was processed using the Magnate Tools Office (TOPCON Inc., USA) software. The vertical level was established using predicted tidal data of the nearest tide station and established using the difference of ellipsoid height method (Figure 1-5 to Figure 1-7).

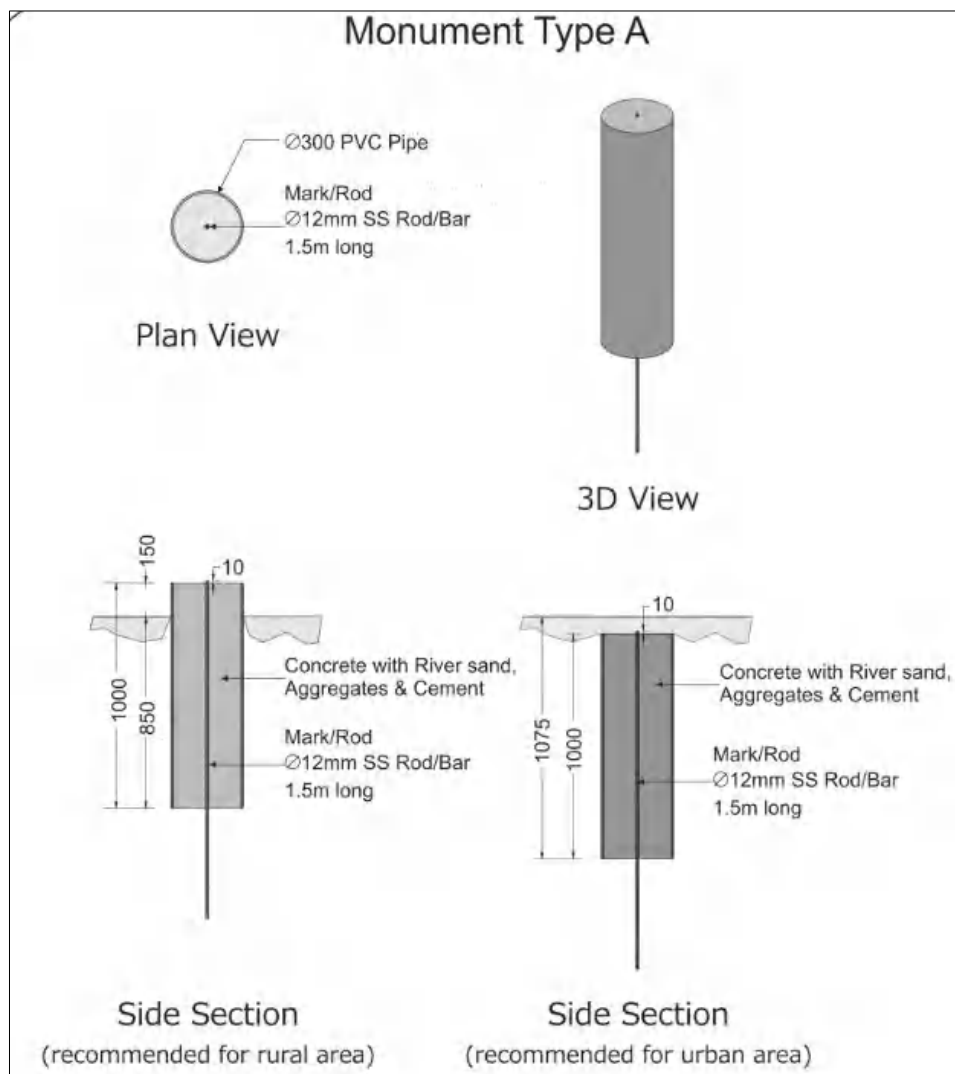


Figure 1-5: Type A PSM design (source: Maldives Land and Survey Authority, Guideline on establishment of Permanent Survey Mark)



Figure 1-6: Example of PSM



Figure 1-7: Example of spacing of PSMs

Two PSMs were located such that both are intervisible to each other while the 3rd was located at a maximum available distance away from intervisible PSMs (and intervisible to both above) as illustrated in Fig. 1-7.

The static survey loop closure was set to a 1 cm error margin, and to attain this accuracy, static survey data was collected for a minimum of 6 hrs on each transect.

1.4.3.5.2 UAV survey

Unmanned Aerial Vehicle (UAV) survey was undertaken using DJI Phantom 4 RTK drone (DJI Inc., China/USA/Europe) with GNSS base station, using RTK correction. Mapping was undertaken at a constant 60 m altitude with reference to the ground with images overlapping at 75% at the front and 65% at the side. At islands with communication towers, flight elevation was decided based on the minimum safe flight elevation possible. Ground Control Points (GCPs) were established around the island (set such that maximum length and width is covered). The GCPs were established using Topcon GNSS receivers in RTK mode with errors fixed to 15 mm (Vertical and Horizontal). Depending on the size of the island, a minimum of 10 GCPs were used for processing the image and georeferencing.

The images captured have been processed using Drone Deploy online service (DroneDeploy business subscription) with GCPs. The final maps were exported in UTM coordinate system WGS 1984, Zone 43N. Further checks were carried out to verify the accuracy of Orthomosaic images with established GCPs (Fig. 1-8).

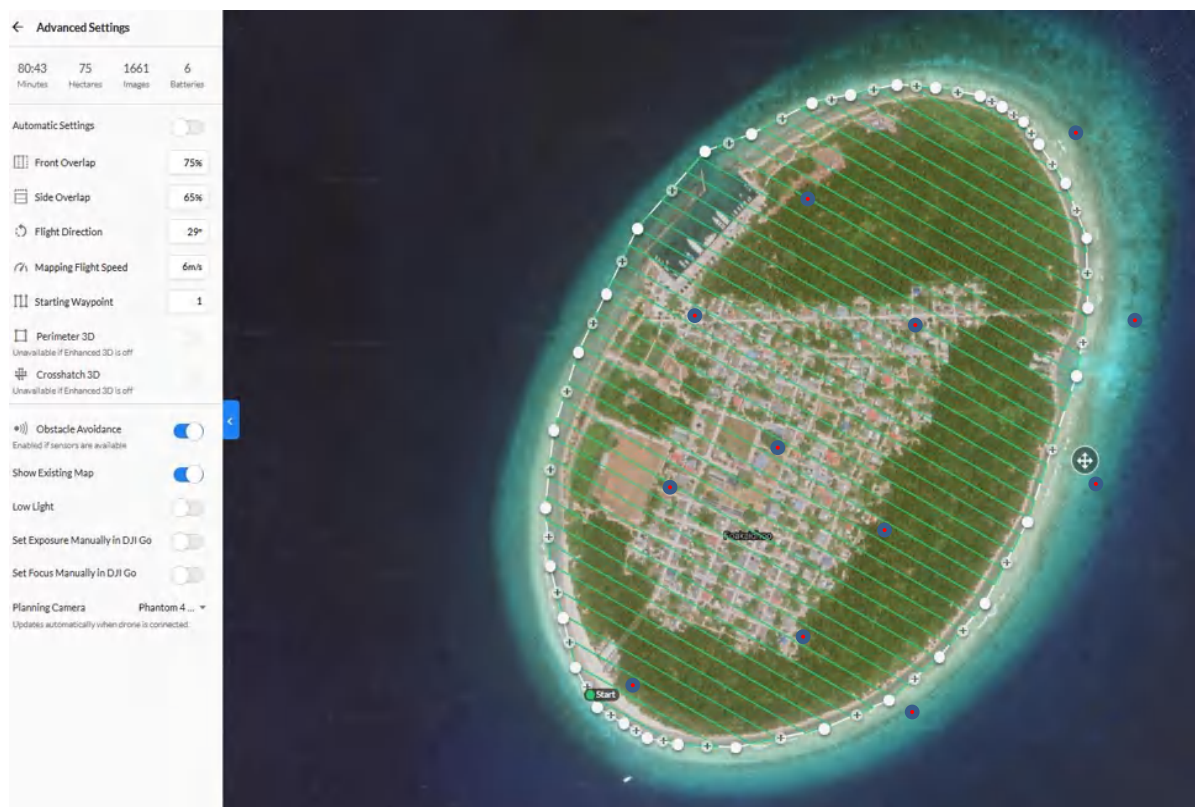


Figure 1-8: Example of a Flight Plan using Drone Deploy application and an example of spacing of Ground Control Points (GCPs) (red points) – Sh. Foakaidhoo.

1.4.3.5.2.1 Outputs from UAV mapping

The main outputs from UAV mapping are the Orthomosaic and Digital Surface Model (DSM). The Orthomosaic can be produced in very high resolutions at 2 cm per pixel. This data can be 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 areas (in red) on an island extracted using a UAV survey (Fig. 1-9). The total roof areas can then be easily calculated without having to measure them individually from house to house. The results can be used to accurately estimate the rainwater catchment potential, how much water is discharged into the ground, etc.

Similarly, all empty areas, vegetated areas and other similar land use and terrain features can be extracted. These data will help hydrogeologists to accurately model rainfall runoff, rainwater infiltration and provide vital estimates on groundwater recharge.



Figure 1-9: Calculation of Roof Cover in an island using UAV survey in the 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 depths to groundwater table and saline-freshwater interphase in each cross-section and along the longitudinal transect and the existing freshwater volume at the time of investigation can be extracted as the difference between the two respective subsurface terrain layers using ArcGIS software (ESRI, USA, ArcGIS/ArcMap version 10.8).

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 Agisoft Metashape Professional image processing software.

The methodology proposed by Bailey and Kivi (2017) has been tested for nine islands of varying sizes in the Maldives and Micronesia during the course of the initial study (Min Env, 2020). 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 in the present study for generating volumetric estimates of the freshwater lens using 3D Analyst Tools of ArcGIS (version 10.8) software (ESRI, USA). Furthermore, it is noted that the above algebraic equations can be effectively used in estimating the possible growth of freshwater lens following the replenishment due to the recharge generated from the monsoonal rainy period. The social surveys were conducted in the islands during the period from February to March towards the end of the dry period in the Maldives while initial ER measurements in the islands were carried out in September/October towards the end of the monsoon rainy period. Based on these, the 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, field investigations for soil profile using core data 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.

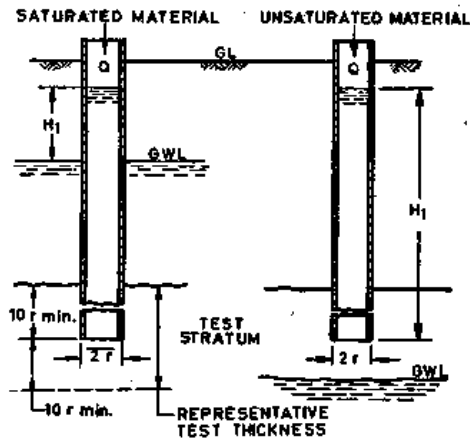
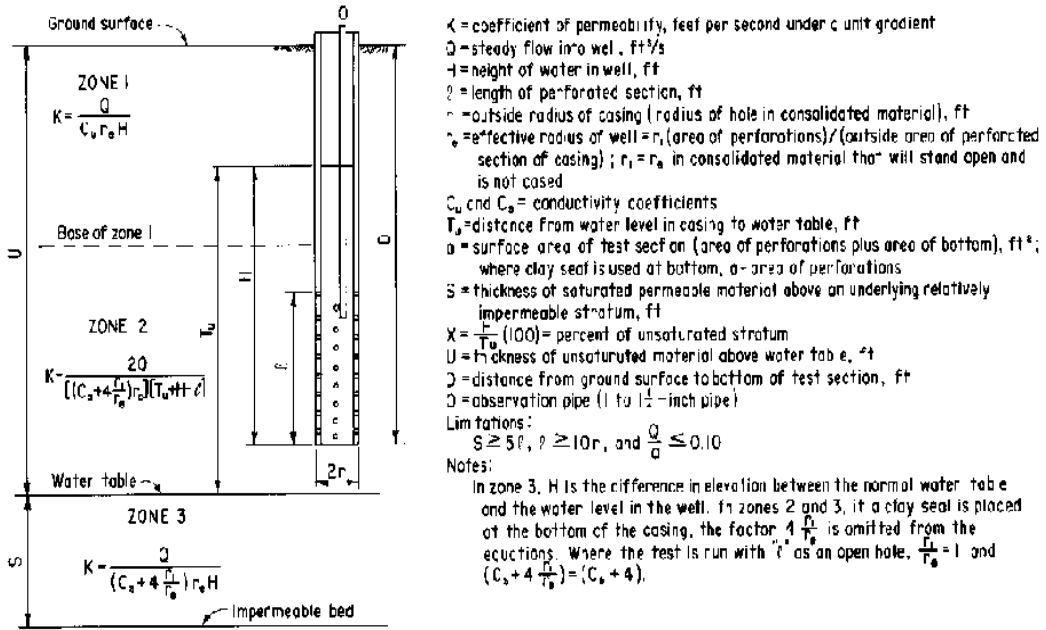
The data on groundwater usage characteristics, existing household/institutional level measures and arrangements for groundwater recharge and the quality of other water sources were collected based on the social/institutional surveys and water quality tests carried out as described in previous sections.

Field permeability testing in the unsaturated zone was carried out by measuring water absorbance at a constant water head in a 4-inch (10 cm) hole dug with a fuel-driven (gas powered) mechanical auger to a depth of ~1.2 m. 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 1-9. A minimum of five (5) representative locations were selected in each island depending on the size of the island, land use and hydrogeological and soil overburden characteristics.

The natural or artificial recharge of groundwater aquifers directly depends on the infiltrated water moving through the impeding upper subsurface soil layers which are 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) following the Maryland Stormwater Manual (2009).

An average depth of 0.5 m - 1.5 m in the unsaturated zone above the 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.

The in-situ soil overburden profile and layering at each well location were determined by the investigation of excavated soil core data and identifying distinct layers and depths by visual inspection of texture, colour and grain sizes. These data were recorded and entered into a GIS database with geo-referenced/geo-tagged photographic information and coordinates, which were subsequently used for generating aquifer profile maps and soil water-bearing volumes for establishing freshwater lens volumes during dry and wet periods, respectively.



The permeability by constant head method (open-end test) should be obtained from the following relation determined by electrical analogy experiments:

$$K = \frac{Q}{5.5rH} \quad \dots (1)$$

where

- K = coefficient of permeability;
- Q = constant rate of flow into the hole;
- r = internal radius of casing; and
- H = differential head of water = H_1 (gravity head) - H_f (head loss due to friction).



Figure 1-10: Methodology for Constant Head Gravity Permeability Tests

1.4.5 Soil profiles and sieve analysis

Considering the existing water table height of the particular area, three (03) – five (05) soil profiles were taken for each island covering at least a 50 cm to 110 cm depth. Soil sample drilled out for the permeability test was safely arranged in the form of an undisturbed core sample and measured laterally to verify the geological cross sections generated based on the ER transects. The photographs of the soil profiles of each island taken during field work are annexed under Annex X.

Moreover, four common layers were identified considering the nature of the soil layers during the field works and sieve analysis tests were carried out for those representative soil samples collected at Ha. Muraidhoo Island and the soil laboratory test reports are attached under Annex XI.

Table 1.6: Comparison of sieve analysis test results of representative soil samples

Sample ID	Depth for the Collected Sample from Ground Level (mm)	Uniformity Coefficient (Cu) [D60 / D10]	Remarks
Sample 1	0 – 200	12.22	High permeable
Sample 2	200 – 400	2.78	Moderately permeable
Sample 3	400 - 600	3.43	Moderately permeable
Sample 4	600 - 1000	4.00	Moderately permeable

1.4.5.1 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. 1-11. However, the bottom layer was karstic limestone bed and the freshwater lens is limited to the upper soil overburden in the majority of the islands, and thus the well penetration was only limited to the saturated zone below the water table.

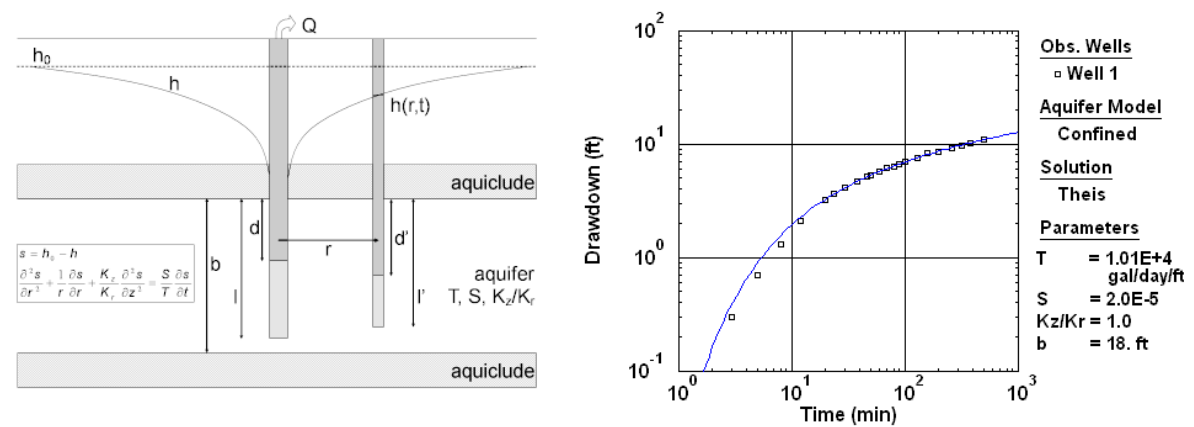


Figure 1-11: Typical well configuration for pumping test in nonleaky confined aquifer and Estimation of aquifer properties by matching Theis (1935) type-curve solution to time-drawdown data

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 (almost all) 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. 1-12).

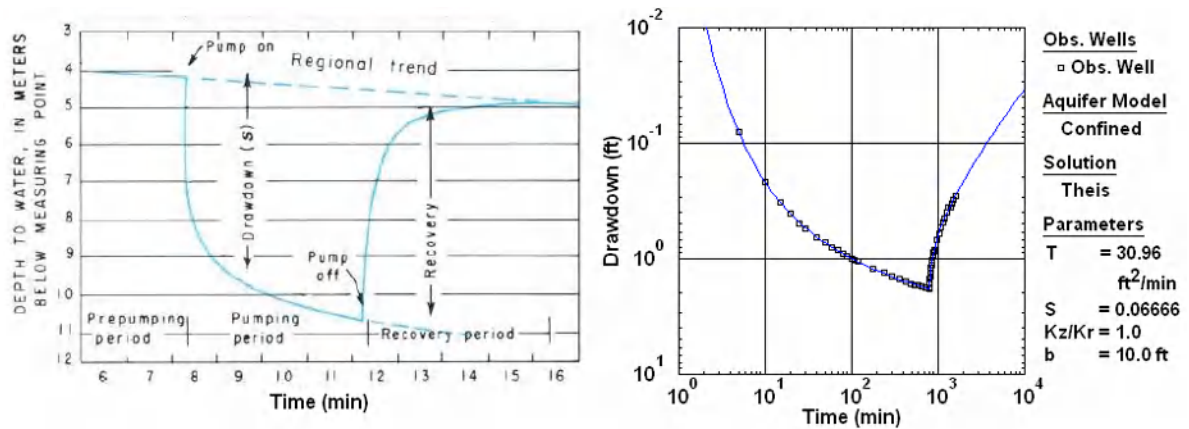


Figure 1-12: Typical well configuration for pumping recovery test in a confined aquifer and Estimation of aquifer properties by matching Theis (1935) type-curve solution to time-drawdown data

1.4.6 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 the above and collected land use, built-up area, local flood extent data and terrain data.

2 GROUNDWATER IN THE MALDIVES

This section briefly outlines the background about groundwater in the Maldives, a vital source of information for the reader in order to understand the broader context of overall water resources management in the island nation. The groundwater occurrence of the islands is discussed based on the available information such as previous reports (Integrated Water Resource Management and Sustainable Sanitation in Maldives (Falkland, 2001), etc.) and recent findings of groundwater surveys.

2.1 Groundwater Occurrence and Freshwater-Saline Interphase

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 the 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. As per the recent findings, two types of groundwater lens are mainly identified in the Maldives islands.

- Freshwater lens that floats over the saline water
- Middle part of the freshwater lens rests on the fresh coral formation and freshwater-saline water interface is observed only at the rim area of the lens

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 electrical conductivity (EC) of 1,500 $\mu\text{S}/\text{cm}$. In some islands, a higher value of EC (e.g. 2,500 $\mu\text{S}/\text{cm}$) has been used as an upper limit, noting that the WHO guidelines are based on taste and not health considerations.

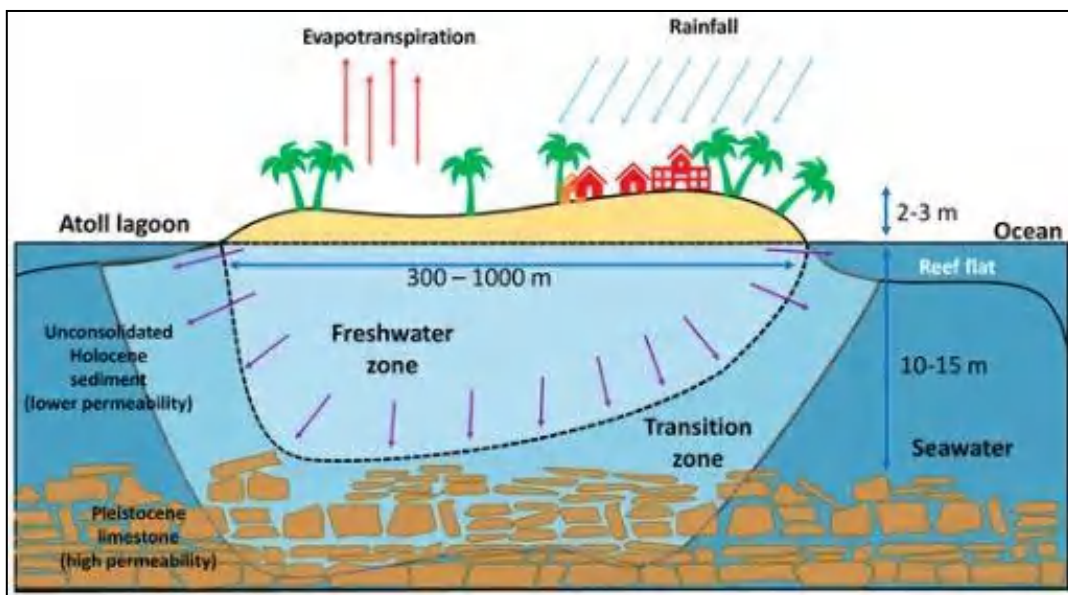


Figure 2-1: Cross section through a small coral island showing main features of a freshwater lens (exaggerated vertical scale) (Source: Jaleel et al., 2020)

Freshwater lens thickness and its geometry on a small coral island are dependent on many factors including:

- Geology of the island
- Topography of the island and changing of island geometry

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

Another potential factor is the height of the groundwater table 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 key determining factor of freshwater lens thickness (amount of freshwater volume stored in the aquifer) and is a key element in determining the sustainable yield of a freshwater lens.

The fresh and seawater dynamics in unconfined aquifers are governed by the Ghyben-Herzberg principle (Falkland, 2000a). If the freshwater level is one meter above the mean sea level, the depth to seawater is 40 m below mean sea level, and vice versa. If sea level was constant and recharge from rainfall was uniform, the saltwater/freshwater interface would remain motionless.

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 have revealed that there are considerable variations in thickness, area and volume of freshwater lenses among 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 to 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 however 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, sediments with higher permeability 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.

So far, there is no clear definition of ‘fresh’ groundwater for islands in the Maldives.

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 $\mu\text{S}/\text{cm}$.

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 $\mu\text{S}/\text{cm}$) 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 $\mu\text{S}/\text{cm}$ (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

Note: WHO = World Health Organisation Drinking Water Quality Guidelines (1993)

Type of Water	Typical EC range ($\mu\text{S}/\text{cm}$)
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 <i>(based on WHO guideline for chloride (250 mg/L))</i>
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

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

- Potable water 1,500 $\mu\text{S}/\text{cm}$
- Non-potable freshwater (desirable): 1,500 $\mu\text{S}/\text{cm}$
- Non-potable freshwater (maximum): 2,500 $\mu\text{S}/\text{cm}$

Above 2,500 $\mu\text{S}/\text{cm}$, the groundwater can be described as brackish.

It is recognized that groundwater with salinity above the suggested maximum limit for freshwater (2,500 $\mu\text{S}/\text{cm}$) 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 and cleaning (i.e. floors, yards, etc.) 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.

2.3 Recent Literature on Groundwater Resources

The National Strategic Framework to Mobilize International Climate Finance to Address Climate Change in the Maldives 2020- 2024 - Ministry of Environment, Republic of Maldives (MoEnv. 2020b) identifies the key climate risks in Maldives, including 1). Land loss (sea level rise), 2). Coastal floods, 3). The intrusion of saline water into aquifers, 4). Coastal erosion, 5). Ocean acidification, 6). Coral bleaching, 7). Increased frequency of extreme rainfall events (heavy rain, droughts), Increased frequency of cyclones, heat waves, longer dry seasons, shorter rainy seasons, and increased average temperature, where items 2), 3), and 7) are coinciding with the scope of the present project.

Furthermore, the groundwater of small islands is highly susceptible to salinization due to the increase in sea-level rise, higher extraction rates, and inadequate recharge. Over-extraction of groundwater is a commonly reported issue in Small Island Developing States (SIDS). At the same time, the groundwater is increasingly contaminated by activities of the increasing population and urbanization combined with the lack of sewerage infrastructure, both of which are typical characteristics of many SIDS (Jaleel, et al., 2020).

An important reason for the vulnerability of groundwater in coral islands like those of the Maldives is the fact that their bedrock is made of carbonate rock (Pleistocene limestone), which is susceptible to dissolution in rainwater creating karst landforms. These are highly permeable due to the presence of organized networks of open fractures, karst conduits, and caves in the subsurface and facilitate contaminant transport, particularly saltwater intrusion, increasing the fragility of the aquifer. The soil of these islands typically contains Holocene sediments, which comprises a mix of sands, coral fragments, and organic matter. Unaltered Holocene sediments (Coral sands) are moderately permeable but lose permeability due to cementation. Groundwater occurs as a thin “freshwater lens” over seawater in coral island aquifers. This shallow freshwater lens is fed by rainwater recharge through the coral sands and is in a dynamic equilibrium depending on the level of recharge (Jaleel, et al., 2020).

Over extraction especially during extended dry spells causes this freshwater lens to sink, allowing the aquifer to become vulnerable to increased salinity intrusion, and how and to what extent the managed aquifer recharge (MAR) can be used to restore the system back to its original state is the basis of this present project.

The findings of the baseline assessments conducted in individual islands are presented here onwards.

3 TH. KANDOODHOO ISLAND

3.1 General Overview of the Island

The island of Kandoodhoo (Figure 3-1) is located on the south western periphery of Thaa Atoll at coordinates 72°55'00"E, 02°19'17"N. The island has an area of about 0.81 km² and measures about 0.47 km in width and 1.2 km in length. The population of the island was found to be about 742 residents as of December 2021. The island has a harbour on the Eastern side of the island. Additionally, breakwaters were constructed on the north eastern side as coastal protection measures. The following table outlines some basic information about the island and the following map outlines the location of Kandoodhoo.

Table 3.1: Basic statistical information on Kandoodhoo island in Thaa Atoll.

Name of the island	Th. Kandoodhoo
Longitude and Latitude	72°55'00"E, 2°19'17"N
Area	80.62 ha (0.81 km ²)
Population (Dec 2021)	742
Distance from Male'	215 km
Harbour	Present
Island sewerage network	No
Water supply network	Under construction
Other infrastructure	No

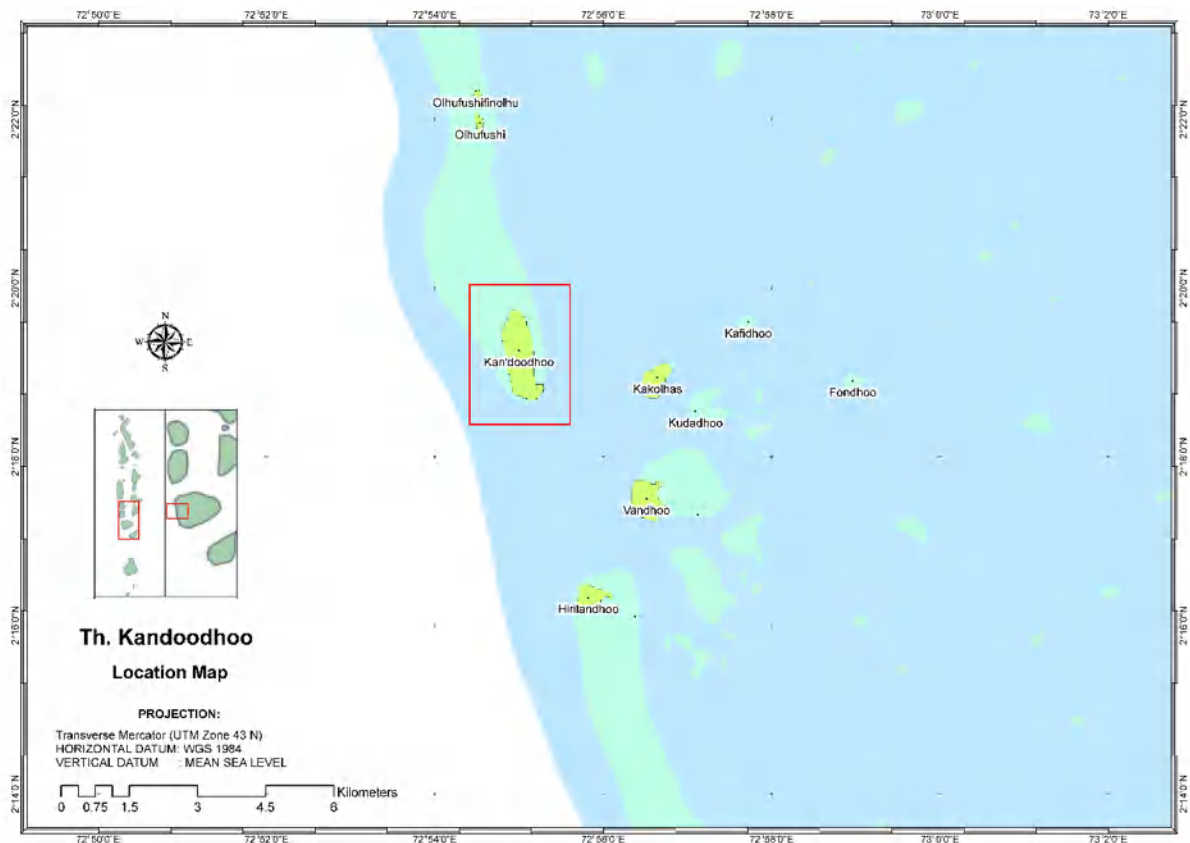


Figure 3-1: Location map for Kandoodhoo Island, Thaa Atoll.

3.2 Topography and Geology

Kandoodhoo island is located on the western side of the Thaa Atoll (Fig. 3-1). The island is characterised by its location south of a submerged coral reef which elongates and extends about 22 km in length. Kandoodhoo island itself is an elongated island but the width is changing as it is wider in the southern part and getting narrower towards the north. The coastal line also shows some discontinuities as the underlain coral bed may have distinct variations in the terms of hardness, texture, structures and shape. Therefore, basic topography and the geological setting is characterised mostly based on the properties of the underground coral beds and the actions of ocean waves and currents. The elevation of the island varies from 0 to 1.8 m and small elevated peaks could be observed in the southern part of the island. Therefore, both the island geometry and topography are varying towards the north, as the northern part is narrowing down and elevation is also getting decreased. The general geological profile in the island is commonly composed of topsoils and beach sand deposits underlain by sandy coral (Figure 3-2). The sand coral bed is always situated on the weathered coral rock which is underlain by hard fresh coral rock. From the cross-sections, it is noted that there exist a topsoil and beach sand layer of 0.3 m to 0.4 m in north to south direction and mostly the beach sand layer is prominent as the top layer. Sandy coral layer is about 0.5 to 1.8 m thick and mostly consists of an unconsolidated and permeable layer. Weathered coral rock bed is varying between 0.5 m to 5.8 m and it is a semi-permeable layer. Hard coral layer is mostly unconsolidated and impermeable and it deepens from about 2.9 m to 14 m in depth. According to the compositional and structural differences of coral formation, differential weathering could be observed in the island. However, the general trend is that the central part of the island shows higher weathering compared to the coastal area and some deep weathered zones could also be found sporadically located in the island.

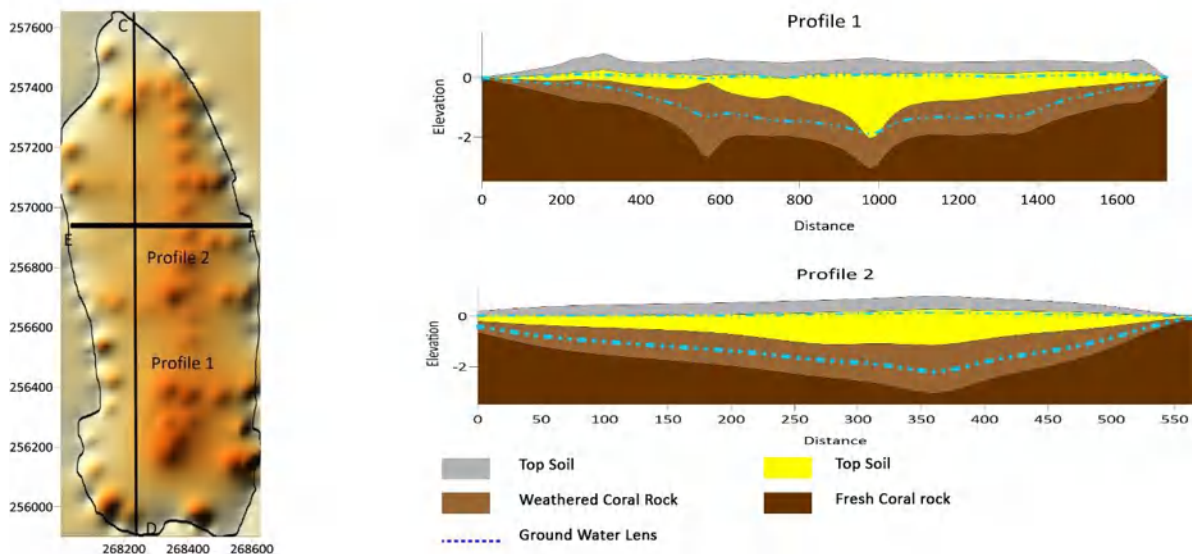


Figure 3-2: A geological section of the island showing subsurface geological characteristics

3.3 Climate

Kandoodhoo island experiences the typical two monsoons in the Maldives namely, the North-east monsoon from December/January to March/April and the South-west monsoon from Mid-May to November. There are no specific wind and rainfall data available for Kandoodhoo as there are no weather monitoring stations on the island itself. Based on the rainfall data of the nearest weather monitoring station, it shows a declining trend in rainfall for the past 30 years (Inception Report, 2021).

The historical rainfall data records from Kadhdhoo Island (not included in the 6 selected islands in Lot 2) located in the Laamu atoll (85 km to the southeast from Kandoodhoo Island) has an annual average rainfall of 2,242 mm with a standard deviation of 370.4 mm and the trend with the decadal means were shown in the following graph (MEE, 2021).

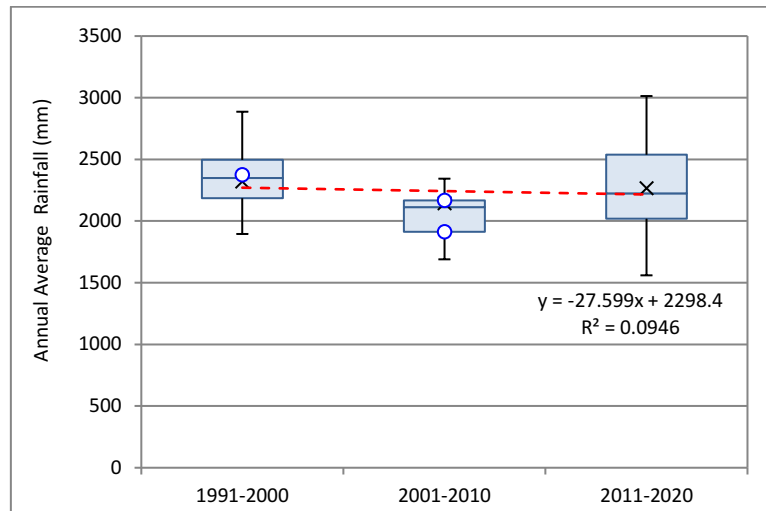


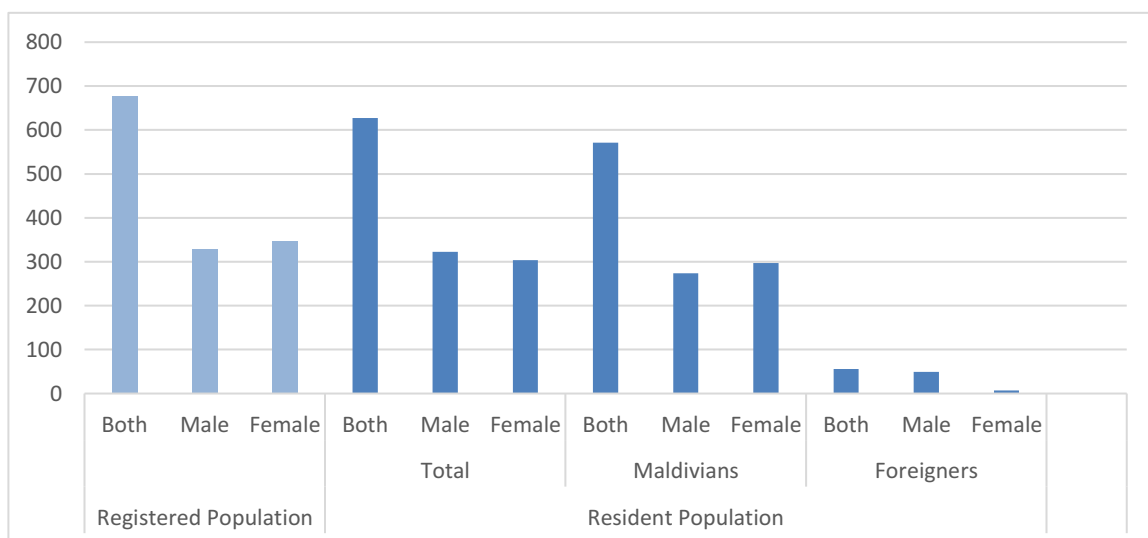
Figure 3-3: Decadal means and trend for rainfall in Kadhdhoo (1990 - 2020).

3.4 Demography

Kandoodhoo has a registered population of 677 as of December 2021 (as per data provided by Kandoodhoo Island Council for this project). However, at present, the resident population is 627 with 571 locals and 56 foreigners. Foreigners include teachers, medical staff and the labour force working on different projects that are currently being undertaken in the island. Total number of households residing in Kandoodhoo at the moment is 130. The following Table 3.2 and Figure 3.4 illustrate the population breakdown for Kandoodhoo Island.

Table 3.2: Demographic Breakdown of Kandoodhoo Island

Registered Population	Resident Population										
	Total			Maldivians			Foreigners				
Both	Male	Female	Both	Male	Female	Both	Male	Female	Both	Male	Female
677	329	348	627	323	304	571	274	297	56	49	7



Note: Registered population represents the number of people registered in Kandoodhoo. Resident population represents the number of people currently living in Kandoodhoo. Total resident population indicates the total number of locals and foreigners currently living in Kandoodhoo

Figure 3-4: Population breakdown of Kandoodhoo (Maldivians & Foreigners)

3.5 Socio-economic Condition

3.5.1 Natural resources and land use

With an area of 80.62 hectares, the island is considered to be one of the largest inhabited islands of Thaa Atoll where a large percentage (more than 50%) of land is used for agricultural activities. With wetlands located at the Southwestern side of the island, agricultural lands are mostly located at the northern side and central area of the island. Human settlement is mostly observed on the North eastern side of the island.

There is no formal land use plan prepared to date. The Island Council now has the authority to allocate lands for different purposes with an approved land use plan.



Figure 3-5: Summary of household and socio-economic activities

3.5.2 Economic activities

The main economic activity of the island is Agriculture. The island is famous for the type of Chilli (Scotch Bonnet) they produce. As per the records from the council, there are total of 290 registered farmers in the island. Other income earning activities practiced in the island include employment in service provision sectors such as teaching, health sector, and tourism sector. Some are also involved in fisheries, both fishing (56 people) and fish processing (16 people). There are three (3) cafés operational in the island.



Figure 3-6: Agricultural Lands allocated at the northern side of the island

Though the island is famous for its chillies, the farmers also grow bananas in abundance. The general practices of farming in Kandoodhoo as similar to most islands of the Maldives include planting trees straight in the ground or in large containers such as empty oil barrels. For bananas, they excavate pits on the ground until it almost touches the water lens whereas for other plants, it is usually by making beds or planting in pots or barrels. The use of fertilisers and chemicals are practiced in most islands of Maldives and is the case in Kandoodhoo as well. However, to grow trees like coconut palms, bananas, mangos, breadfruits, etc., they do not use any chemicals or fertilisers as they grow easily without them too.

3.5.3 Accessibility and transport

The only direct mean of access to the island is via sea transport by speed boats or Dhonis. It can be private hire or by ferries. Other means of transport is via air to the domestic airport at Thimarafushi of the same atoll and launch transfer from the airport to Kandoodhoo.

A harbour with quay walls located on the northeast side of the island is used to access the island. It was noted that after the construction of the harbour while it eased the accessibility to the island for passengers and also for transport of cargo, the rate of erosion has also increased followed by exacerbated swell surges.

3.5.4 Services and infrastructures

The island is equipped with basic services and supporting infrastructures.

3.5.4.1 Public facilities and amenities

The public facilities available in the island include:

- Health Center
- Preschool
- Primary/Secondary School
- Government institutions (Office for Island Council, Island Court)
- Mosques

3.5.4.2 Water supply

Currently, rainwater is used for drinking and cooking when needed, although bottled water sourced from Male' is also used. Groundwater is used for other purposes such as bathing and washing. This is further discussed in Sections 3.6 and 3.7.

3.5.4.3 Energy supply

Kandoodhoo has electricity for 24 hours generated from the island powerhouse operated by Fenaka.

3.5.4.4 Waste and wastewater disposal

Solid Waste: The island does not have a waste management plan or a well-equipped waste management center. However, they have an organized system for waste disposal with the limited availability of resources. Waste collection is carried out at the household level by the council for a fee of MVR100. Food waste is disposed of at sea. Waste segregation is carried out to some extent within the waste dumping area which includes the separation of plastics and metals while open burning is practiced for disposal of combustibles including green waste, nappies, etc.

Sewage Disposal: Main method of sewerage disposal at Kandoodhoo is by means of septic tanks. Each household has a septic tank within close proximity and the collected effluent is infiltrated into the ground. This is further discussed in Section 1.3.

3.5.5 Sites with historical significance and cultural interests

The island has a mosque from the 17th Century. This 300-year-old mosque is located not far from the residential area of the island and is known as ‘*Kandoodhoo Hukuru Miskiy*’.

3.6 Existing Water and Sanitation Situation

3.6.1 Water

Currently, the island does not have a piped drinking water system.

Groundwater is the main source of water for all uses except drinking and cooking. They do not have major issues with regards to groundwater quality although sometimes discoloration is observed. It was reported that they keep the soakage pit of the septic tanks away from the groundwater well to prevent contamination. However, it was also noted that some households experienced deterioration of groundwater quality during dewatering carried out for the sewerage network project which is still ongoing.

Rainwater and bottled water are mainly used for drinking and cooking. Rainwater is harvested at both household level and island level. At the household level, each household has at least one water tank with a capacity of 2,500 L. The Council has established 6 community tanks of 5,000 L for rainwater harvesting. Currently, only 2 are being used as the remaining 4 needs repair and maintenance.

The general practice of rainwater harvesting at the island level is to clean the roofs thoroughly and letting the first flush pass to the roads which would eventually seep into the ground. Excess rainwater is also discharged to the roads in a similar manner. This sometimes causes flooding as well.

A rainwater harvesting system is also established where roofs of all government institutions buildings/offices (Council, Mosque, Health Center, School, etc.) will be used to collect rainwater into public tanks which will then be filtered and distributed to 3 different areas of the island through common water taps to be used by the public. However, the system is yet to be made operational.

In addition, the establishment of an RO Plant with household connection is ongoing and is expected to be completed and ready to use by the early next year 2022.

3.6.2 Wastewater and sewage disposal

Currently, sewage is disposed by means of septic tanks. Each household has a septic tank within close proximity which is infiltrated into the ground. It was noted that most of the households keep the soakage pits outside the house, away from the groundwater wells although the septic tank is inside the house, to reduce the impact of sewage to the groundwater. According to the social survey that was carried out under this study, about 60% of the respondents kept the septic tanks 15 ft or more away from the well.

Establishment of a proper sewerage system with household connections is currently ongoing. It is expected to be completed by end of this or early next year 2022. Once the new sewerage facility has been established, the existing facility will be abandoned. The septic tank inflows from the pipes will be ceased by disconnecting the inflow pipes. The remaining sludge in the pipes and septic tanks will then be removed by sewer jetting and released to the sea via an outfall pipe.

3.7 Results of the Baseline Surveys

3.7.1 Summary of socio-economic surveys

As detailed in the methodology section of this report, a survey was carried out to determine the water usage at households (HHs), commercial entities (cafés), institutions, and places with industrial uses (agricultural lands, fish processing). The survey was carried out from 19th May to 22nd May 2021 with the help of local enumerators. The following Table 3.3 summarizes samples taken for each sector at a 95% confidence interval and the total number of completed surveys for each.

Table 3.3 Population and Sample taken for the social survey

Categories	Population	Sample	Forms Completed
Households	130	84	67
Farmers	290	10	9
Fishing Vessels	7	7	7
Fish Processing	16	15	0
Institutions	4	4	4
Café/restaurants	3	3	3

Note: A number of mitigation measures were adopted to ensure to achieve the 95% confidence level sample size. The challenges and limitations and the measures undertaken to mitigate the challenges are listed in Section 1.4.3.3.

The key findings from this survey show that a total of 297.8 liters of groundwater are estimated to be used per capita per day for various domestic uses. The respective water use situations including domestic, commercial, and institutional uses are illustrated in the following sections.

3.7.2 Water usage for domestic purposes

3.7.2.1 Domestic water usage

A household (HH) survey was carried out at a 95% confidence interval. A total of 67 HHs were surveyed. As presented in Table 3.4, 87% of HHs have at least one of 2,500 L capacity HDPE rainwater tanks at their homes to collect rainwater for daily uses. Among the 67 HHs, 73% uses rainwater for drinking while 96% also uses it for cooking.

Groundwater is mainly used for non-potable use in all the households surveyed.

Table 3.4: Groundwater and rainwater use data for Kandoodhoo Island

Rainwater	Per cent (%)
Households with rainwater tanks	87%
Rainwater use for drinking	73%
Rainwater use for cooking	96%
Groundwater	Per cent (%)
Groundwater as a drinking source	0%
Groundwater for cooking	12%
Groundwater for non-potable use	91%
Total number of household wells surveyed	67
Percentage of wells surveyed fitted with pumps	96%

Based on the survey carried out, the 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 3.5. The total domestic water use is estimated to be 297.8 liters per capita per day.

Table 3.5: Domestic Water Usage in Kandoodhoo 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
160.3	45.0	35.9	66.9	308.1

3.7.2.2 Perception on groundwater

The HHs were also asked about their general perception on groundwater, if it is safe to use for daily purposes and whether the quality of groundwater is good or bad.

As it can be seen from Figure 3-7, a total of 69% agreed that the groundwater of Kandoodhoo is safe to use for daily uses and they have been using it for the past period. Among this 69%, 13% strongly agreed that it is safe. This indicates that the groundwater condition in Kandoodhoo is not as bad as that in some other islands surveyed under this project.

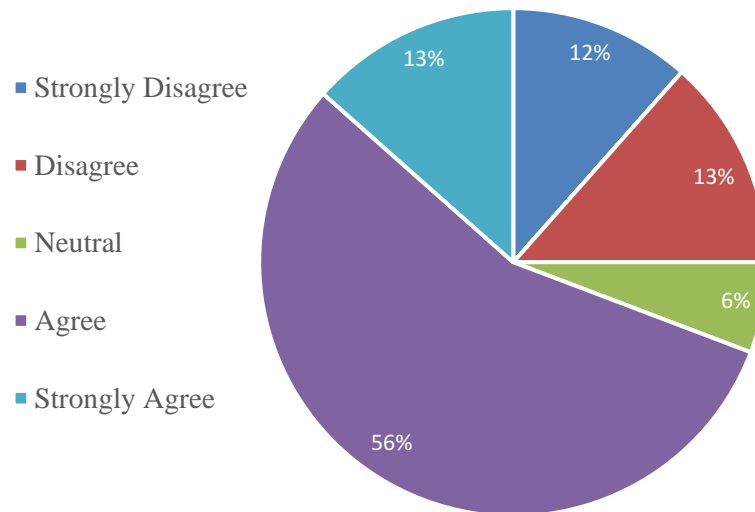


Figure 3-7: Perception of HHs on the safety of Groundwater

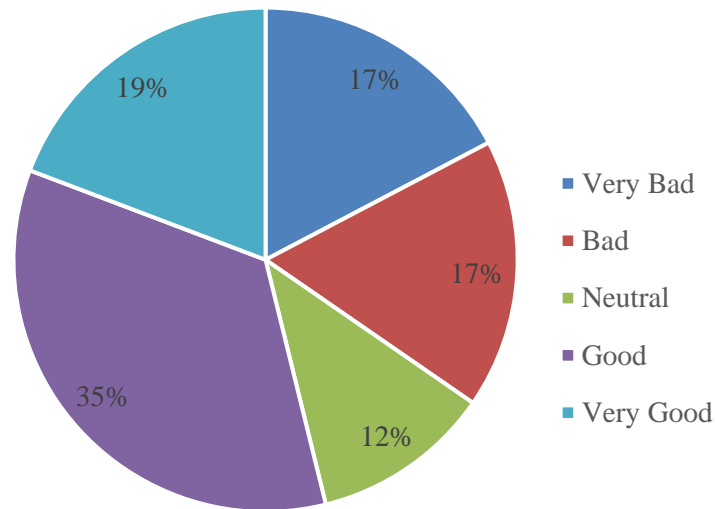


Figure 3-8: Perception of HHs on quality of groundwater

Furthermore, the HHs were asked about the quality of groundwater with regard to their experience. While 35% said the quality is good, 12% said it is very good. But it is important to note that a total of 36% thought the groundwater quality is not good. The varying opinion on groundwater quality is because in Kandoodhoo, in different parts of the island, water quality is different. While in general, it was noted even by the Island Council that groundwater quality is not bad in most parts of the islands, while it was noted that in some parts, discoloration and odour is observed.

3.7.2.3 Water usage for commercial activities

Kandoodhoo has three (3) cafés considered as commercial entities. These 3 cafes were surveyed. There was no guesthouse in Kandoodhoo.

Table 3.6 below presents a summary of water usage by the cafés.

Table 3.6: Water Usage by commercial activities in Kandoodhoo

Cafés	Total Volume of water per day (Liters)
1	54.6
2	273.0

For the cafés, the main use of groundwater was for dishwashing. From the total three (3) cafés that were surveyed, the total groundwater consumption for these cafés was estimated to be 327.6 liters.

3.7.2.4 Water usage by institutions

Based on the survey carried out to collect data on water consumption by institutions, four institutions were surveyed for this study which are the island powerhouse, island court, school and health center.

Groundwater in the institutions in Kandoodhoo is mainly used for mopping floors, flushing toilets and to some extent, gardening. A total of approximately 9,610 liters of groundwater are estimated to be used per day by the institutions. Therefore, a total of approximately 418 liters of groundwater are estimated to be used per capita per day by the institutions of Kandoodhoo Island (Table 3.7).

Table 3.7: Water Usage by commercial activities in Kandoodhoo Island

Th. Kandoodhoo	Water Flushed (Liters)	Gardening (Liters)	Mopping (Liters)	Sub-Total Water Used (Liters)	Total Water Used (Liters)	Institutional Groundwater Usage (Liters Per Capita Per Day)
Power House	450	1,227	45	1,722	9,610	418.38
Court	120	0	3	123		
School	1,140	4,908	20	6,068		
Health Center	450	1,227	20	1,697		

3.7.3 Water usage for farming

A total of nine (9) farmers participated in the survey. This is 10% of the total number of registered farmers in the island. Farmers mainly use groundwater for watering plants. All 100% of the surveyed farmers use groundwater extracted from wells using pumps to water their plants using simple pipe networks. Table 3.8: below summarizes the water usage to water the plants every day.

Table 3.8: Water Usage by Farmers in Kandoodhoo Island

Farmlands	Area of Farmland (Sqft)	Volume of Water used per day (Liters)	Total Volume of Water used per day (Liters per sqft)
1	21,000	14,724	0.70
2	10,000	9,816	0.98
3	15,000	7,362	0.49
4	75,000	2,954	0.04
5	1,200	160	0.13
6	20,000	2,454	0.12
7	45,000	14,724	0.32
8	20,000	2,454	0.12
Total		54,648	

From the total nine (9) farmers that were surveyed, a total of approximately 54,648 liters of groundwater are estimated to be used per day by the farmers. This is equivalent to a value of 0.264 liters of groundwater per square foot per day.

3.7.4 Water Usage for Fisheries Activities

In Kandoodhoo, the survey team was able to survey three (3) fishing boats. All boats use groundwater for different purposes. They store groundwater in tanks present in the boats. It was found that 2 out of 3 use groundwater even for drinking. Thus in average approximately 30.95 litres of groundwater is used by a fishing boat in Kandoodhoo.

Table 3.9: Water Usage by Fisheries Activities in Kandoodhoo Island

Fishing Boats	Total Volume of water per day (Liters)
1	35.7
2	21.4
3	35.7

3.7.5 Groundwater quality

Groundwater quality measurements were made at selected wells in Kandoodhoo Island for both physical and microbiological testing in two occasions.

The following Table 3.10 summarizes the water quality results collected during the dry period (April - June).

Table 3.10: Summary of groundwater quality tests from Kandoodhoo Island in 2021

Sample No.	EC (µS/cm)	pH	Turbidity (NTU)	DO (ppm)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
Samples in Residential Areas											
K1	673.00	7.48	0.117	0.14	28	0.33	6.10	0.02	0.20	1120.00	6.00
K2	671.27	7.59	0.120	3.97	28	0.32	0.20	0.02	0.13	>2420	488.00
K3	196.50	7.49	25.300	0.62	28	0.09	2.90	0.02	0.58		
K4	635.90	7.96	0.286	4.47	28	0.31	1.20	0.02	0.11		
K20	641.10	7.57	0.133	1.52	28	0.31	2.40	0.02	0.17	387.00	118.00
K21	735.90	7.76	0.104	4.81	28	0.36	1.20	0.02	0.20	172.00	83.00
K23	0.41	7.36	0.100	0.00	28	1.41	35.60	0.02	1.42		
K24	376.10	7.92	0.143	4.29	28	0.18	0.80	0.02	0.24		
K25	510.00	7.78	0.100	3.66	28	0.24	10.30	0.02	1.22		
K26	711.00	7.53	0.162	1.53	28	0.34	3.20	0.02	0.18	2420	35.00
K27	571.00	7.74	0.161	2.86	28	0.27	0.40	0.02	0.16	517.00	26.00
K28	675.50	7.39	3.550	1.67	28	0.33	2.60	0.02	1.62		
K29	758.20	7.86	0.109	5.49	28	0.37	0.10	0.10	0.17	2420	28.00
K30	474.00	7.23	0.157	4.89	28	0.23	0.10	0.02	0.54		
K31	437.00	7.89	0.100	5.88	28	0.21	1.40	0.02	0.64	2420	71.00
K32	571.00	7.82	0.133	2.84	28	0.27	1.00	0.02	0.26	228.00	12.00
K33	682.80	7.82	0.201	5.01	28	0.33	0.50	0.02	0.16	2420	387.00
K34	585.00	7.48	0.316	5.98	28	0.28	0.30	0.02	0.18	2420	276.00
K35	618.00	7.76	0.174	3.63	28	0.30	0.40	0.02	0.20	345.00	11.00
K37	586.00	7.19	0.116	3.11	28	0.28	3.10	0.02	0.24		
K38	561.00	7.80	0.100	4.52	28	0.27	0.50	0.02	0.24		
K39	491.10	7.70	0.100	5.39	28	0.23	5.20	0.02	0.14		
K40	530.00	7.72	0.127	4.34	28	0.25	5.30	0.02	0.15	921.00	102.00
Samples in Agricultural Areas											
K5	652.00	7.72	0.154	5.46	28	0.31	23.50	0.02	0.61		

Sample No.	EC (µS/cm)	pH	Turbidity (NTU)	DO (ppm)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
K6	305.70	8.03	0.198	6.53	28	0.14	0.60	0.03	0.18		
K8	578.80	7.80	0.101	6.37	28	0.28	25.20	0.02	0.22		
K9	569.90	7.78	0.119	5.32	28	0.27	0.40	0.02	0.39		
K10	1729.00	7.53	0.247	4.09	28	0.87	2.20	0.02	1.32		
K11	501.50	7.87	0.100	5.87	28	0.24	25.60	0.02	0.20		
K12	426.40	7.55	0.269	2.51	28	0.20	1.10	1.14	0.44		
K14	710.70	7.77	0.311	5.99	28	0.34	1.20	0.02	0.20		
K15	561.40	7.97	0.138	5.97	28	0.27	28.70	0.02	0.15		
K17	1721.00	7.78	0.160	4.44	28	0.86	72.70	0.02	0.18		
K18	730.50	7.84	0.166	5.53	28	0.35	26.60	0.02	0.17		
K19	3683.00	7.99	0.175	5.52	28	1.93	0.60	0.07	0.18		
Samples in Industrial Areas											
K22	1846.20	7.76	0.127	3.87	28	0.93	10.00	0.02	0.18	248.00	36.00
Samples in Other Areas											
K7	2666.40	7.22	29.700	1.67	28	1.37	44.50	0.03	4.94		
K13	802.70	7.25	244.000	2.76	28	0.39	0.40	0.26	0.08		
K16	905.40	7.86	0.135	6.04	28	0.44	1.50	0.02	0.32		
K36	551.80	7.86	0.107	4.89	28	0.26	7.90	0.02	0.06	2420	1300.00

Based on the full results and the summary shown in Table 3.10, the following can be summarized for Kandoodhoo Island:

- The EC of the groundwater is generally low, with an average of 790.85 µS/cm which is below an acceptable limit for potable water of 1500µS/cm. The electrical conductivity readings range from 0.41 to 3683µS/cm. 88% of readings fall within the acceptable limit.
- The pH of groundwater ranged from 7.19 to 8.03 with an average of 7.69. The pH values of all samples were within the WHO permissible limits of 6.5-8.5.
- Turbidity ranged from the lowest of 0.1 NTU to 244.00 NTU with an average of 7.70 NTU.
- Total Dissolved Solids recorded ranged from 0 mg/L to 6.529mg/L with an average of 4.09mg/L.
- The salinity of groundwater ranged from 0.09 PSU to 1.93 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 8.94 mg/L and therefore it exceeded the WHO guideline limit of 5.09 mg/L. But 14 of the 40 tested water samples exceeded this limit of 5.09 mg/L. The Nitrate concentrations ranged from 0.1 mg/L to 72.7 mg/L.
- Ammonia concentrations were generally low. The average ammonia concentration was 0.78 mg/L. This is within the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. No samples were tested exceeding this limit (ranged from 0.02 to 1.14 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 were within the range 0.06 - 4.94 mg/L with an average of 0.47 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). There were 2 samples tested below 0.1 mg/L.

- Total coliform levels were also found to be significant and ranged from the lowest count of 172 MPN/100 mL to the highest count of more than 2420 MPN/100 mL, with an average count of 1318.43 MPN/100 mL. Faecal Coliform levels were found to be less significant and ranged from the lowest count of 6 MPN/100mL to the highest count of 1300 MPN/100mL.

EC values of the selected wells were collected at the start of wet period (September – October) and following table show the summary of all the result collected during dry and wet periods based on the land use distribution.

Table 3.11: Comparison of WQ results based on land usage

Land Use	Number of samples	Results are lined with conditions	Increase of measured parameters	Remark
Residential area	28	28		
Industrial Areas	1	1		
Agricultural area	30	24	K7, K12, K17, K19, KW 9, KW 19	K7-Located at Agricultural area and higher EC could be due to higher extraction. K12 and K17-Higher ammonia and nitrate are due to leaching of nitrate base fertilizers. K19-High EC due to it is close to sea. KW 9 and KW 19 –Higher EC is due to higher extraction.
Total	58	52	6	

Considered desirable water quality limits:

- 1) EC < 2500 $\mu\text{s}/\text{cm}$ (water could be used for potable and non-potable use depending of EC).
- 2) Nitrate (<50 mg/l), Phosphate (<5 mg/l), and ammonia (<0.5 mg/l) as per WHO guideline.

Limited residents’ plots are located within the island and most of land areas are used for the agricultural activities. About 28 samples within residential area have been analysed and measured nitrate, ammonia, and phosphate concentrations are as per WHO guideline. It revealed that present sewerage contaminations status is not up to alarming level.

Three areas close to sampling points (K7, KW9, and KW 19) within agricultural areas has recorded high EC and it could be due to higher groundwater extraction.

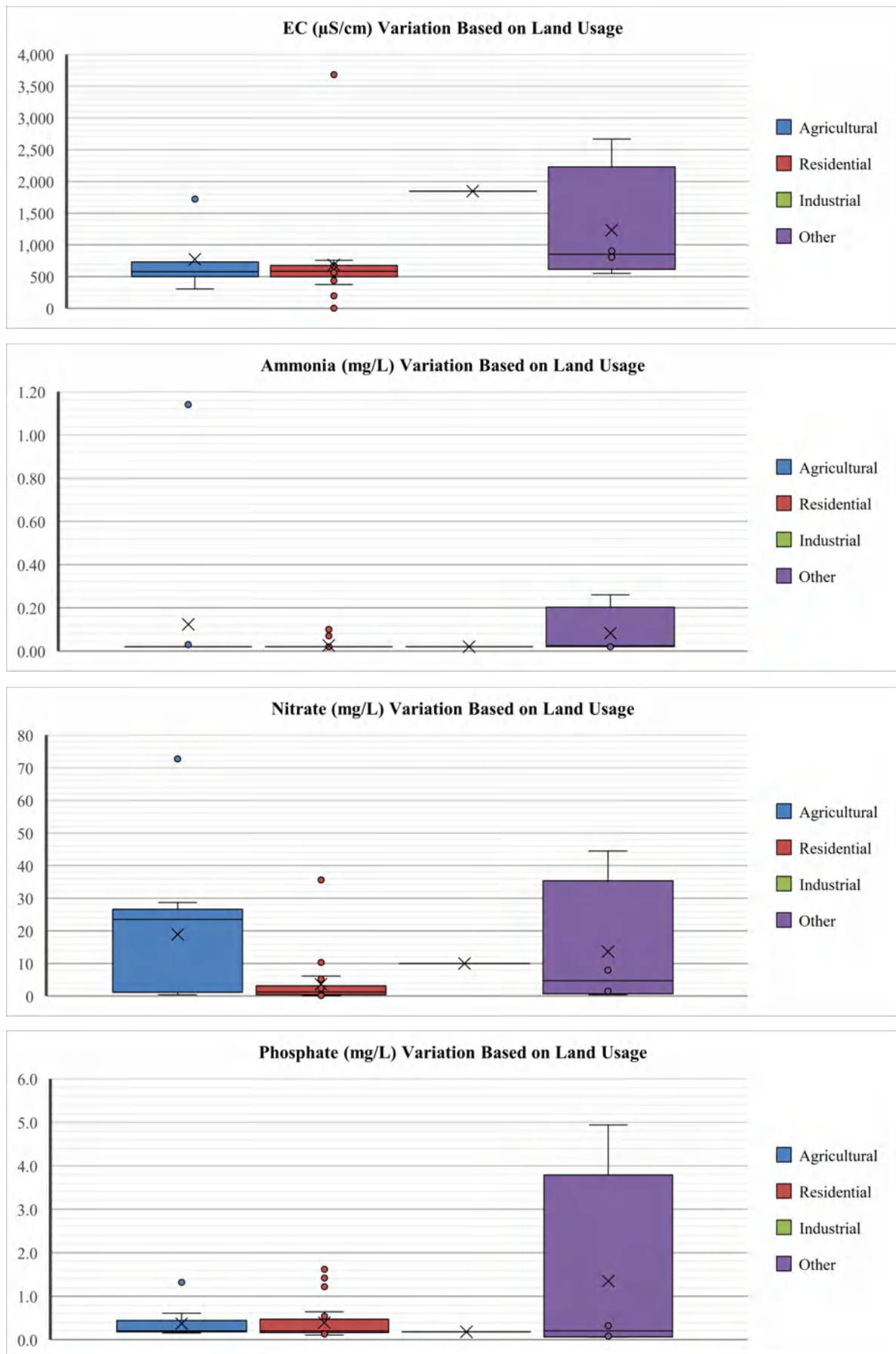


Figure 3-9: Variation of measured WQ parameters in Kandoodhoo Island

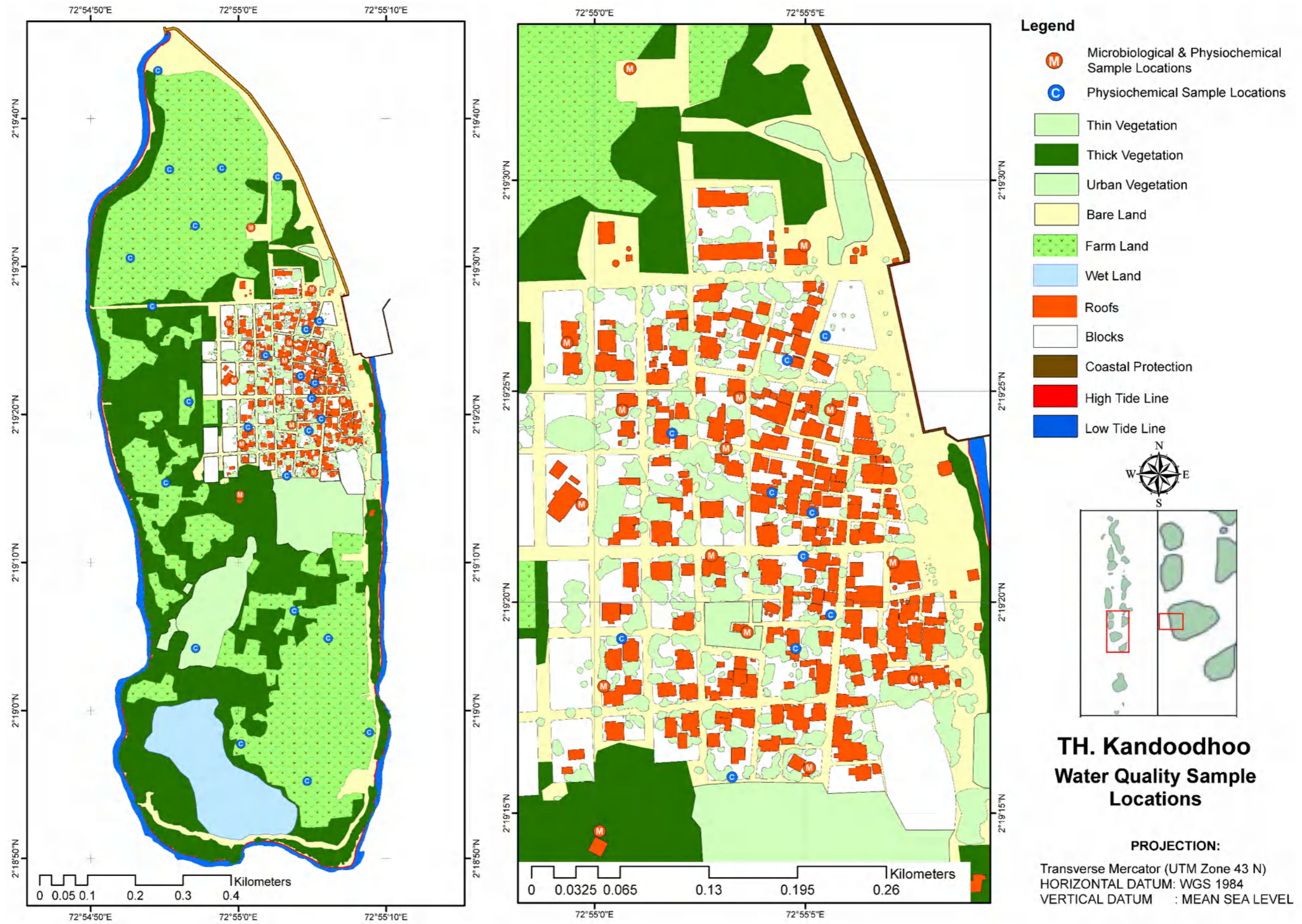


Figure 3-10: Location of groundwater sampling points in Kandoodhoo Island

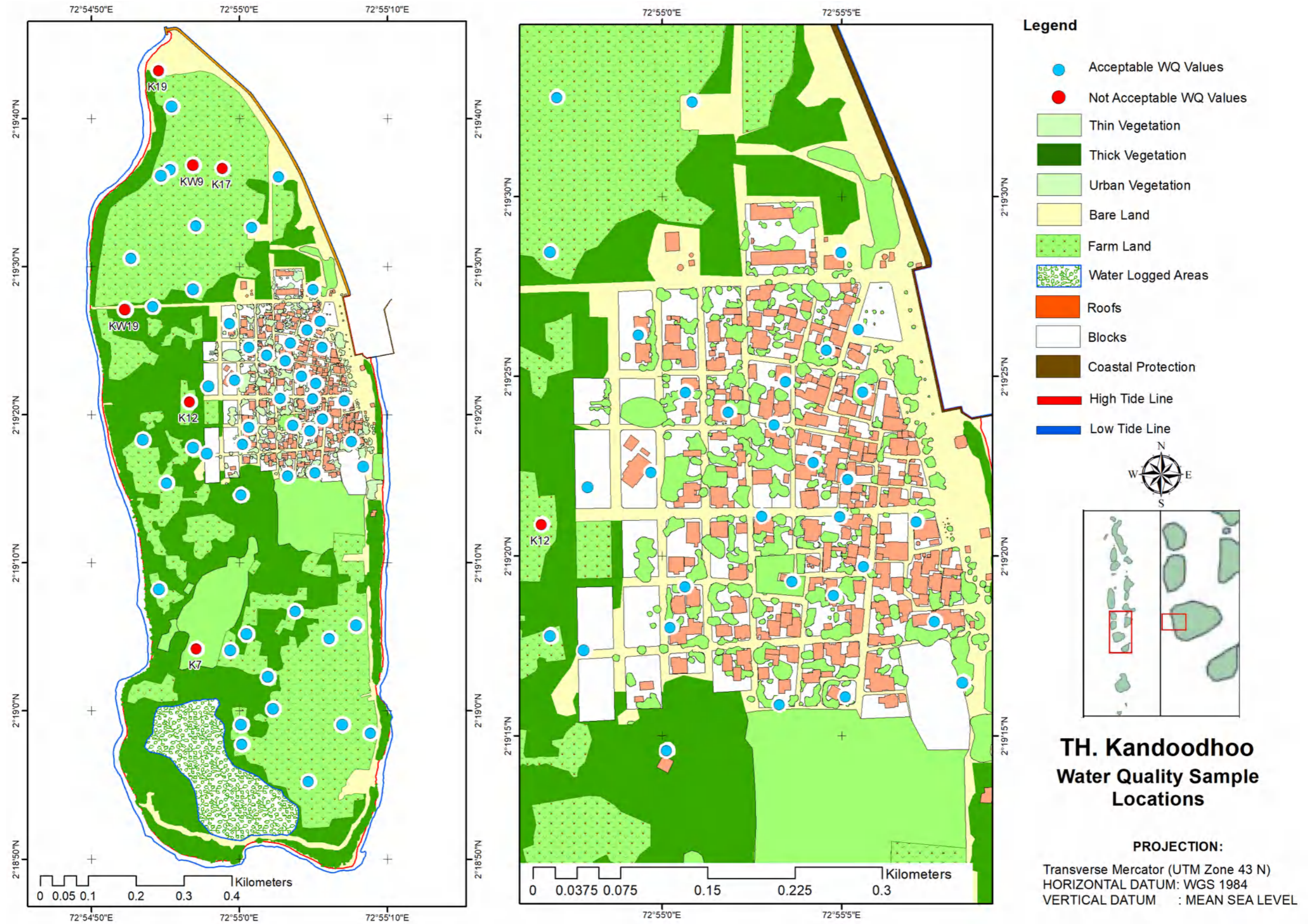


Figure 3-11: Location of groundwater sampling points with critical WQ values in Kandoodhoo Island

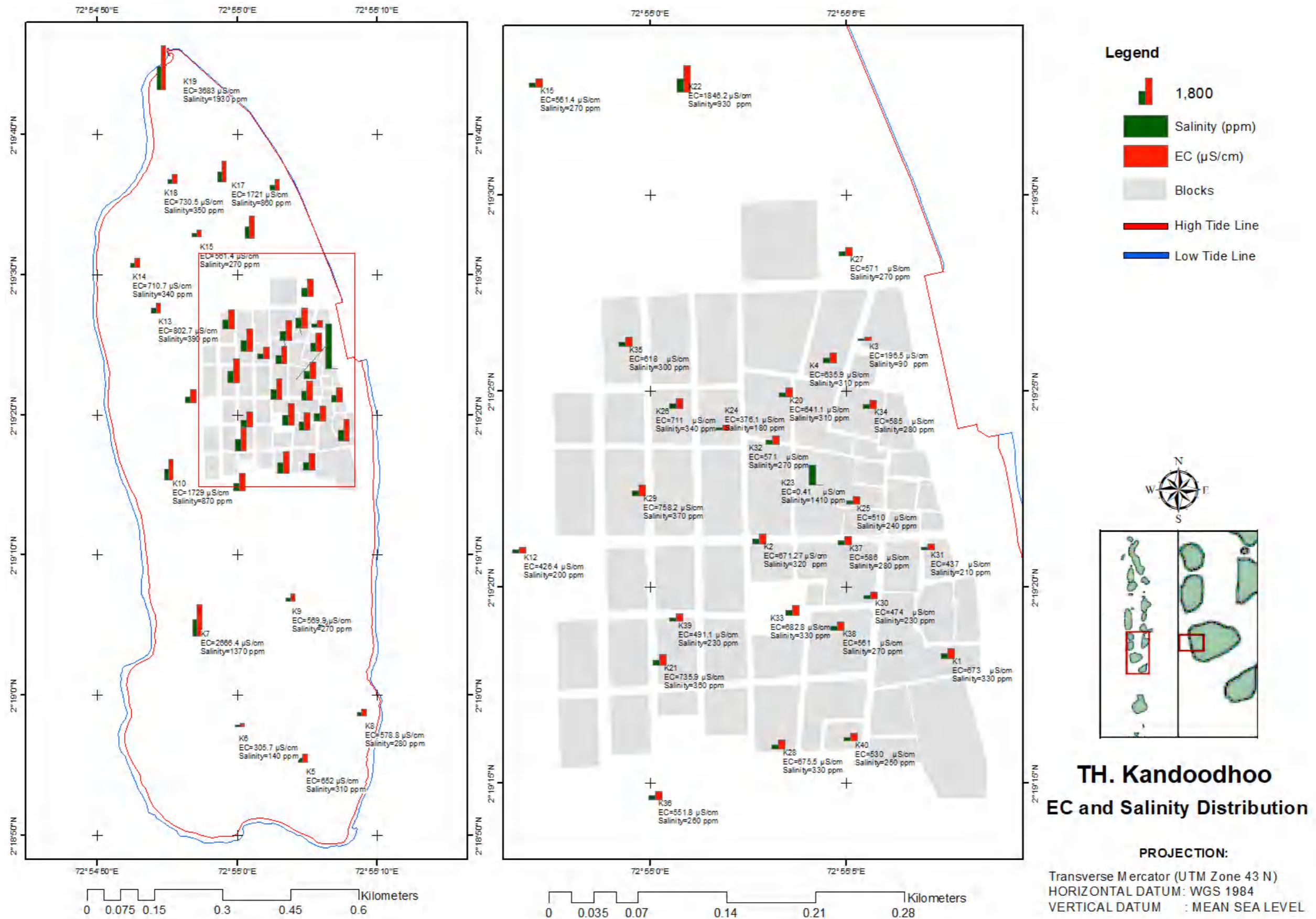


Figure 3-12: EC and Salinity Distribution in Th. Kandoodhoo Island

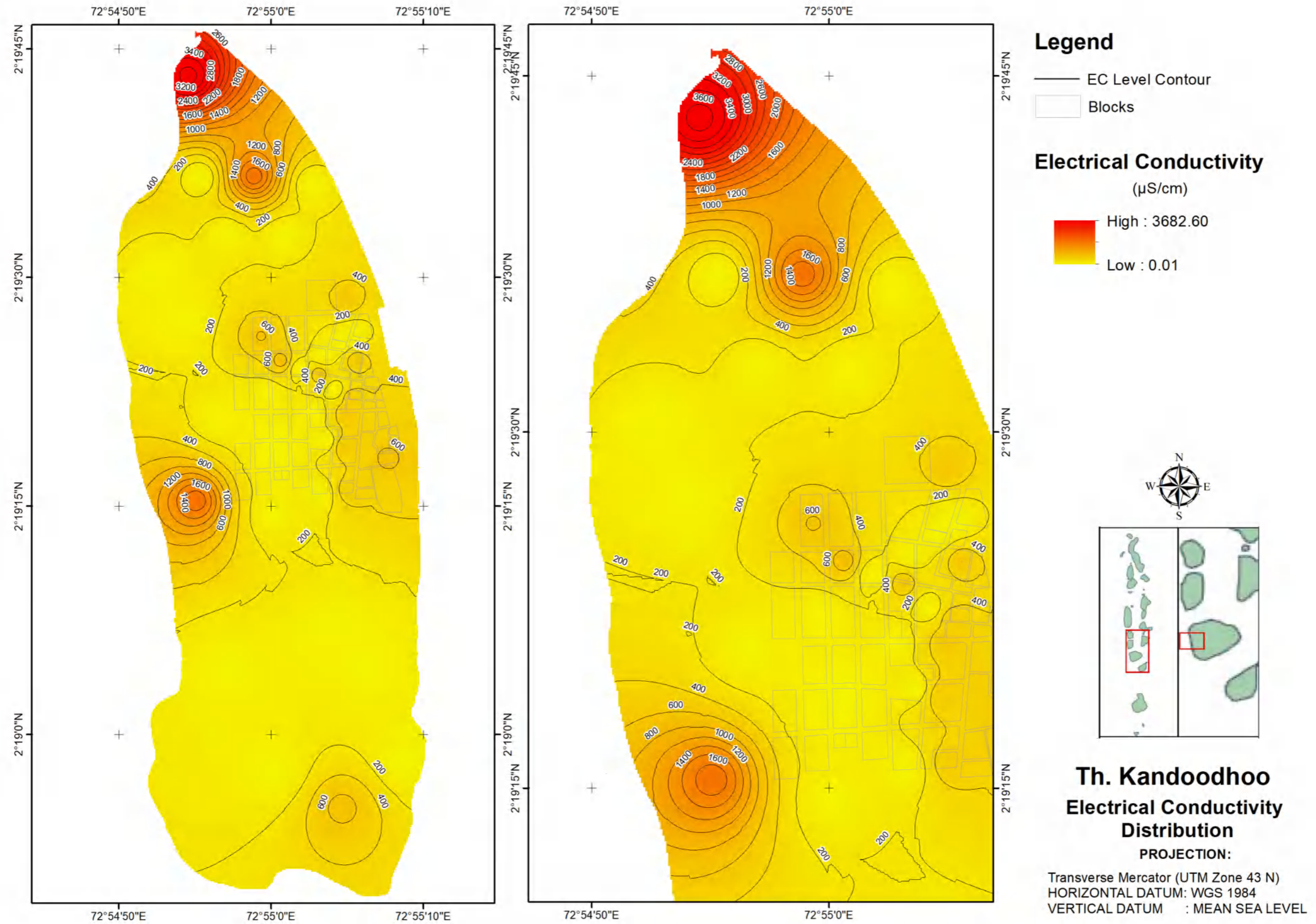


Figure 3-13: EC Distribution in Th. Kandoodhoo Island

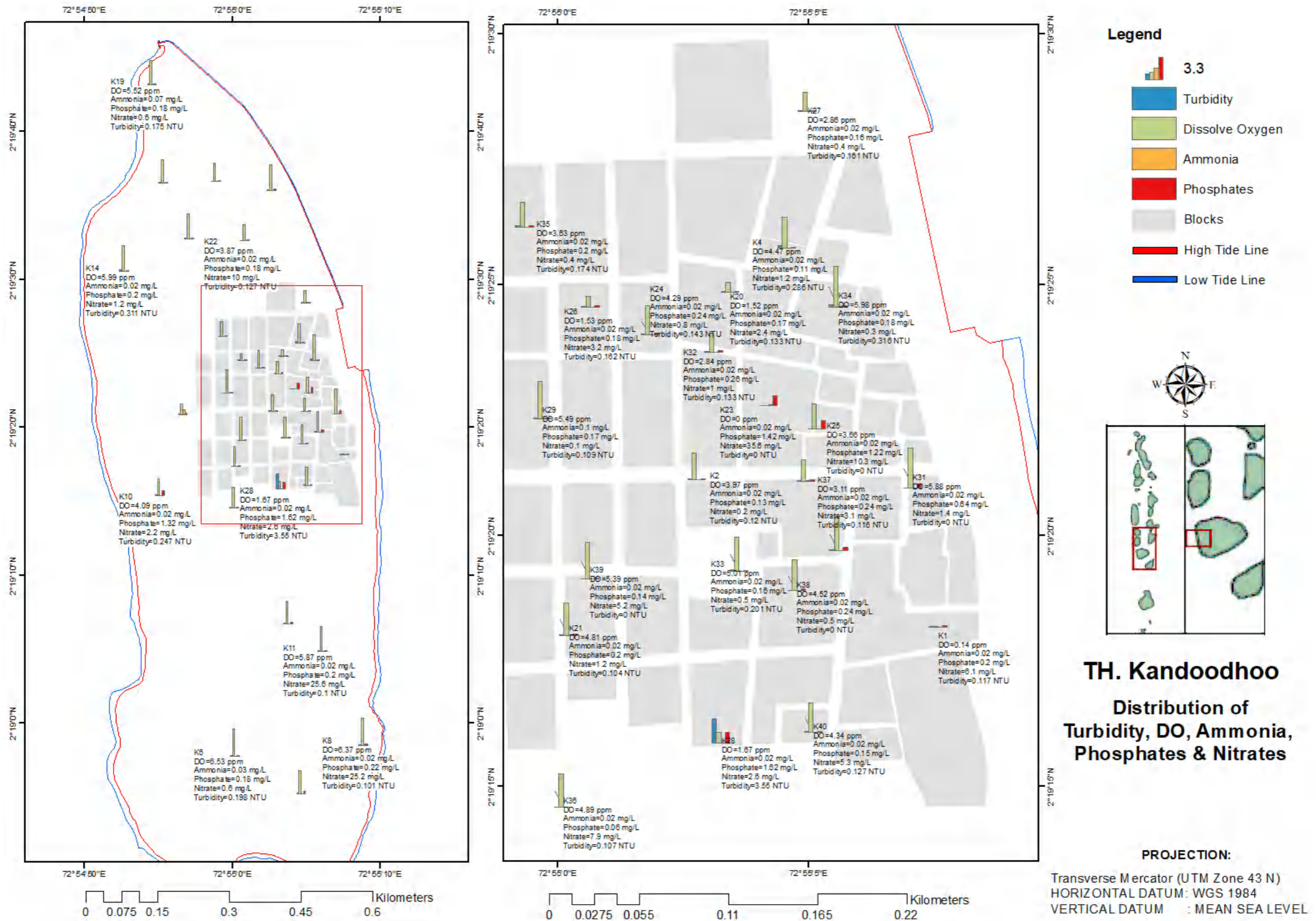


Figure 3-14: Distribution of Turbidity, DO, Ammonia, Phosphates and Nitrates in Th. Kandoodhoo Island

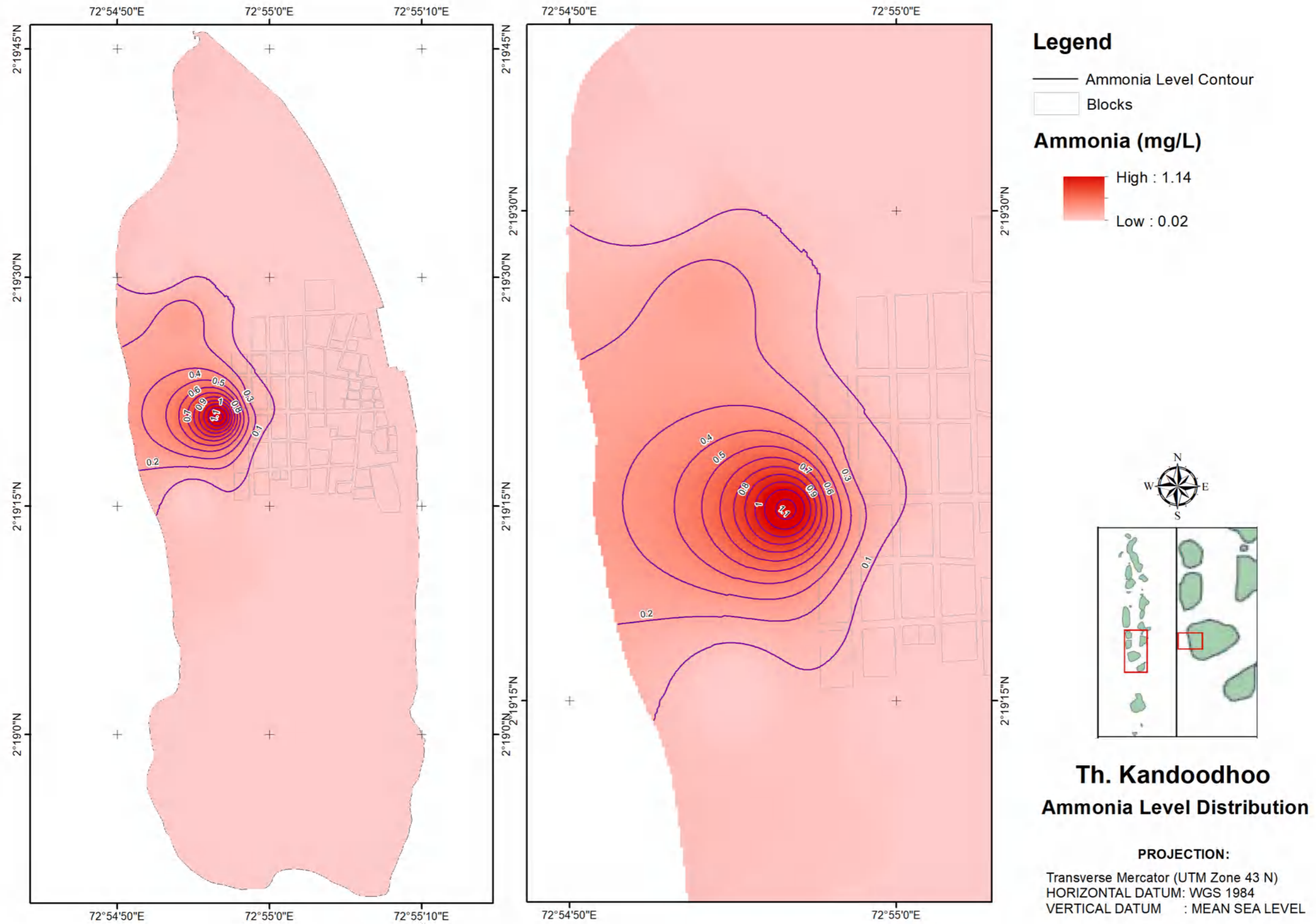


Figure 3-15: Ammonia Level Distribution in Th. Kandoodhoo Island

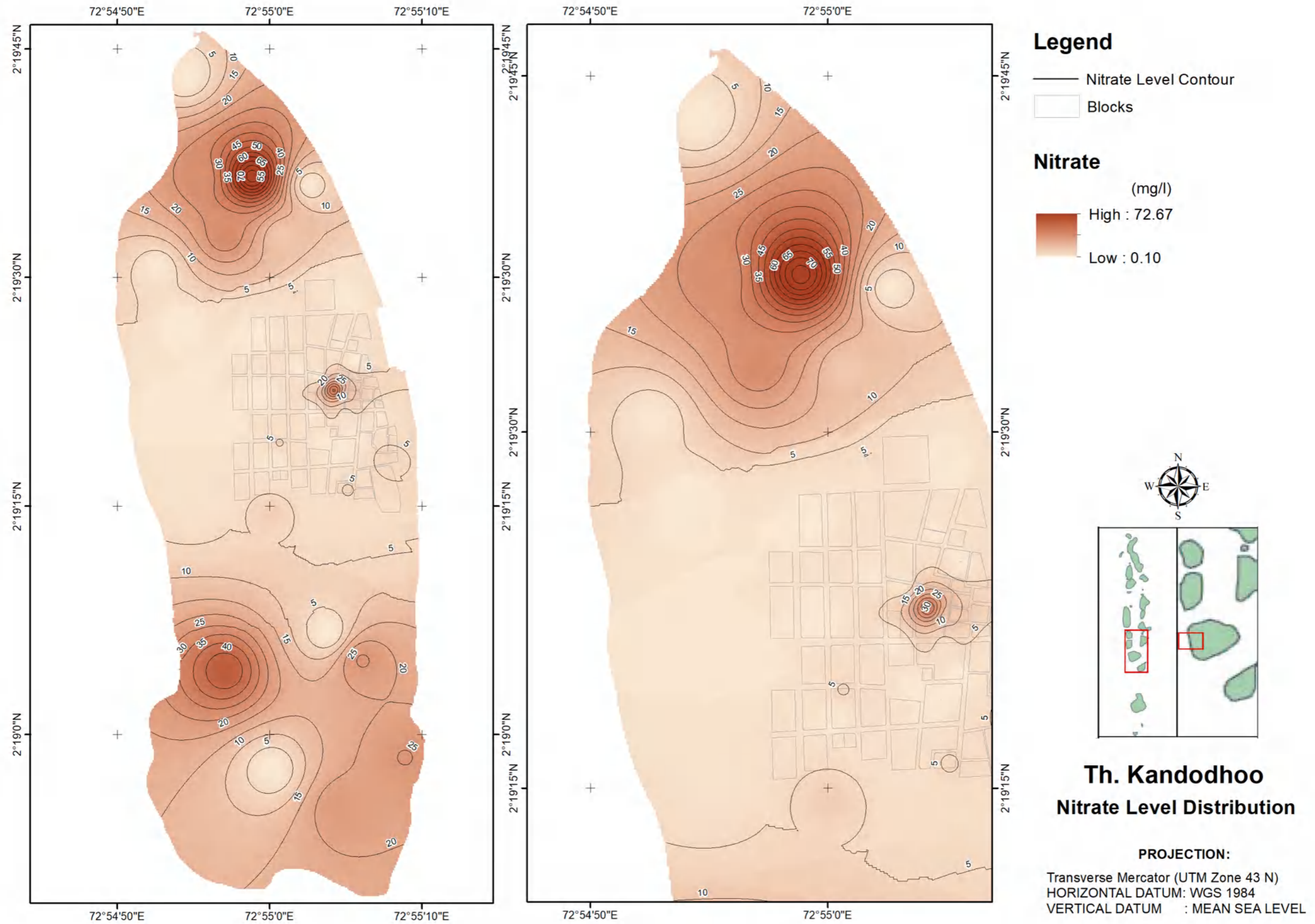


Figure 3-16: Nitrate Level Distribution in Th. Kandodhoo Island

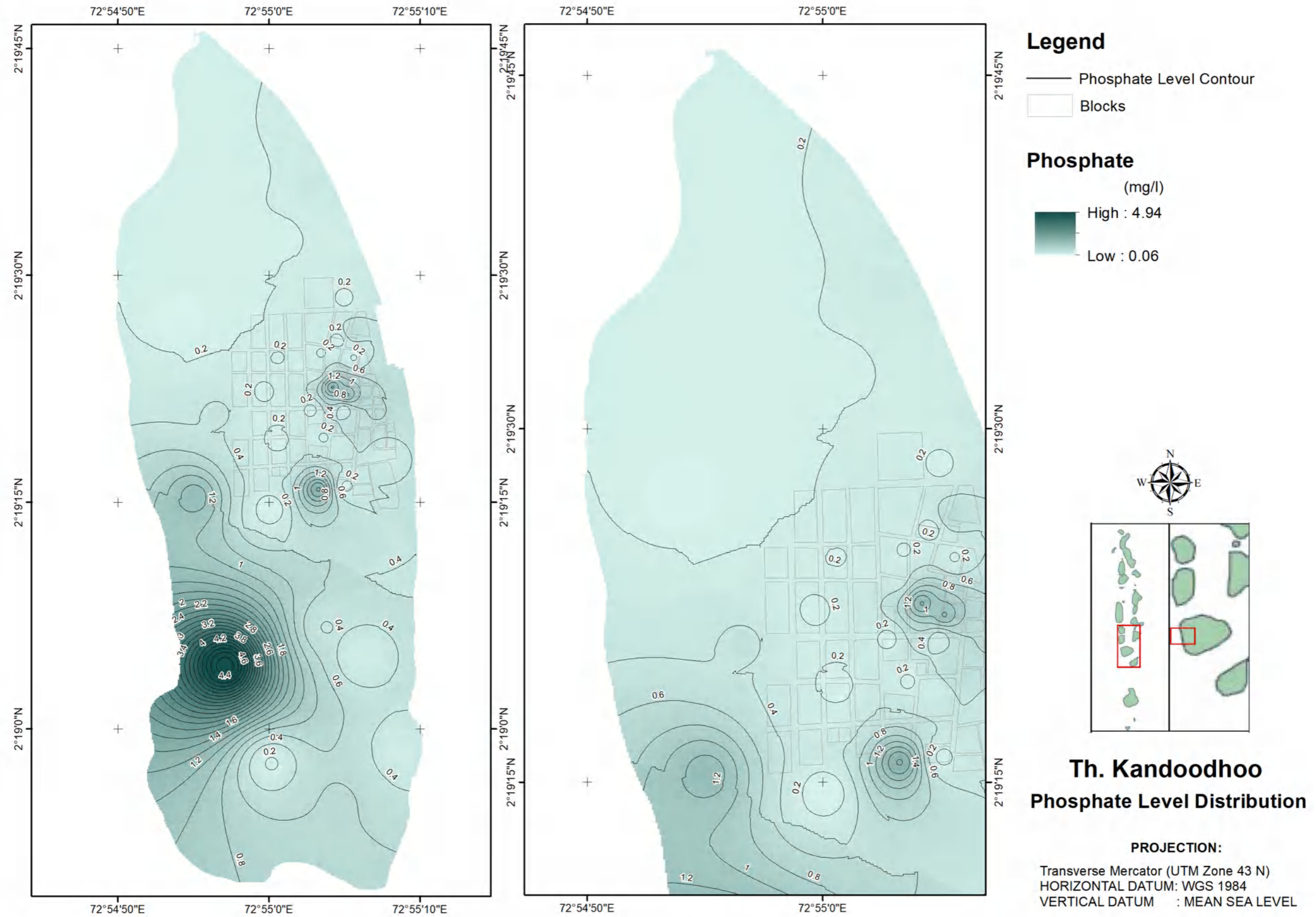


Figure 3-17: Phosphate Level Distribution in Th. Kandoodhoo Island

3.7.6 Geophysical survey

The Electrical Resistivity (ER) tests were carried out in the locations as outlined in Figure 3-18 below. The ER survey included test points along 11 transects selected representatively based on reconnaissance surveys to adequately characterise different land uses and island cross-sections. The main transects were aligned along existing roads to maintain consistency and uniformity.

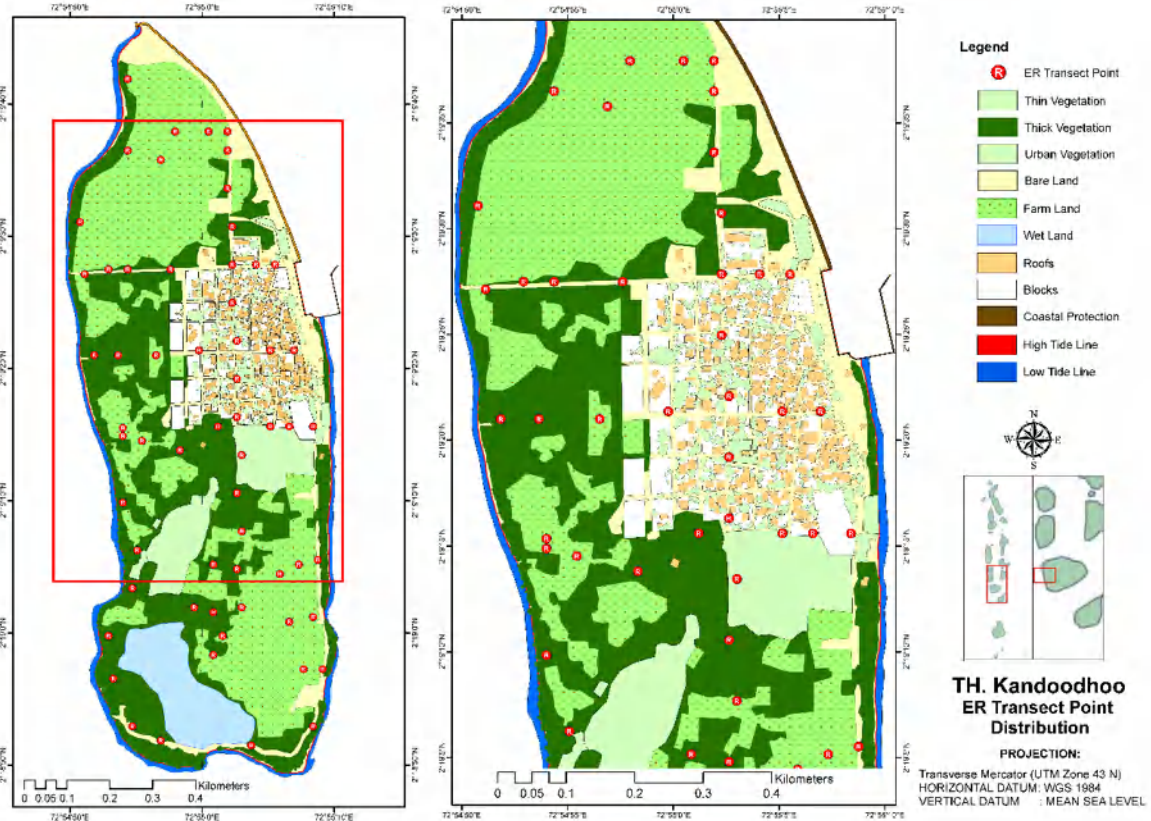


Figure 3-18: Location of ER points in Kandoodhoo Island

3.7.7 Aerial surveys

Based on the aerial survey, a multiple data set consisting of buildings, roof cover, land cover, change detection and shoreline were extracted. This data is shown in Figure 3-20. The total roof cover for this island is 26,316 m².

3.7.8 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 yards, road surfaces, etc., is not usable as there is no mechanism for its collection and treatment.

3.7.9 Freshwater lens

Based on the Electrical Resistivity (ER) surveys, the depth to groundwater level and the freshwater-saline water interface were determined for a set of transverse transects as shown in Figure 3-19. Plots in Figure 3-21 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.

Volume of the lens has been calculated with aid of ArcGIS and Surfer Software.

$$\text{Volume of lens} = 835,316 \text{ m}^3$$

$$\text{Groundwater Storage} = \text{Porosity (15\%)} \times \text{Lens volume (m}^3\text{)} = 125,297 \text{ m}^3$$

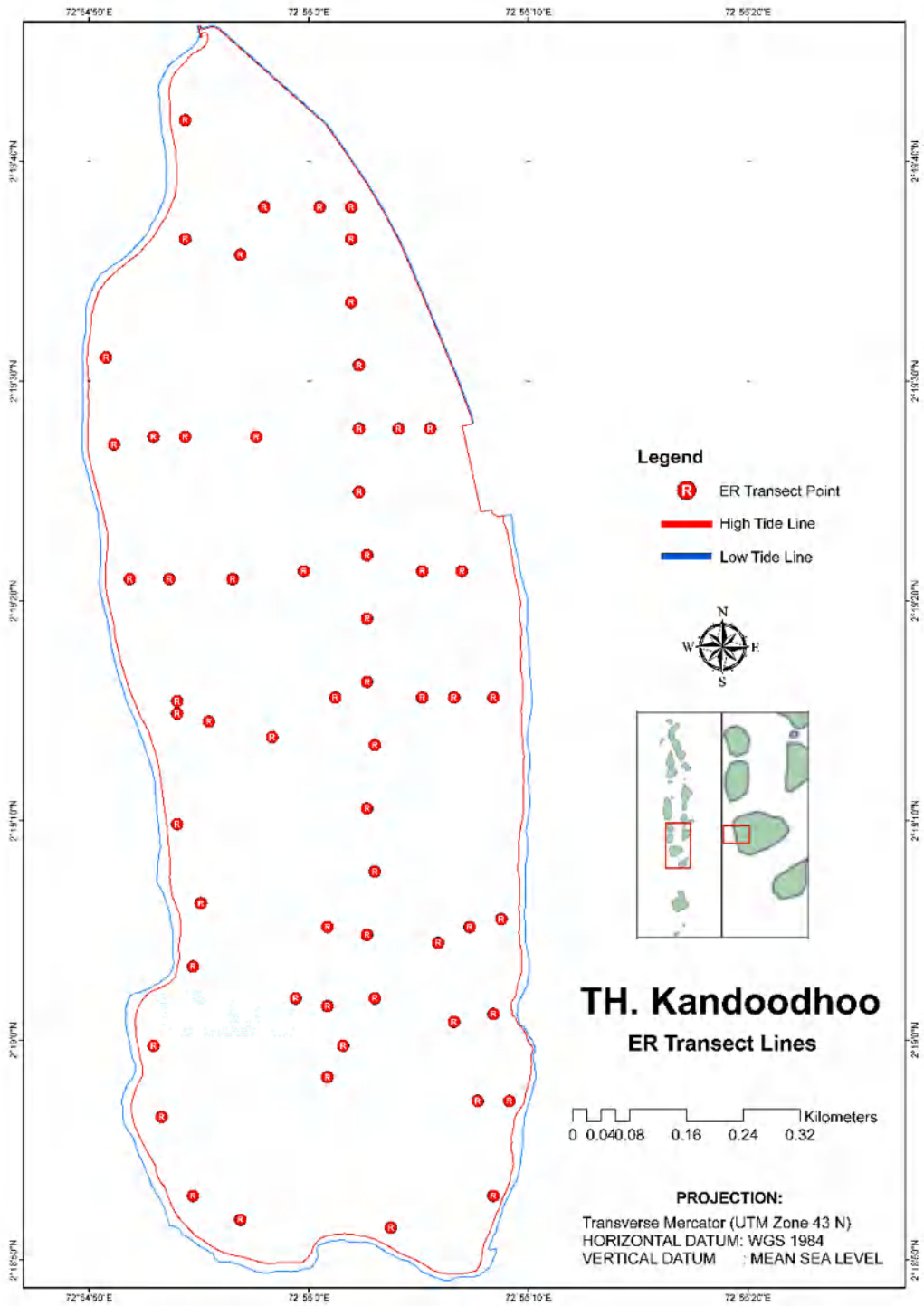


Figure 3-19: ER Test Points and Transect Lines in Kandoodhoo Island

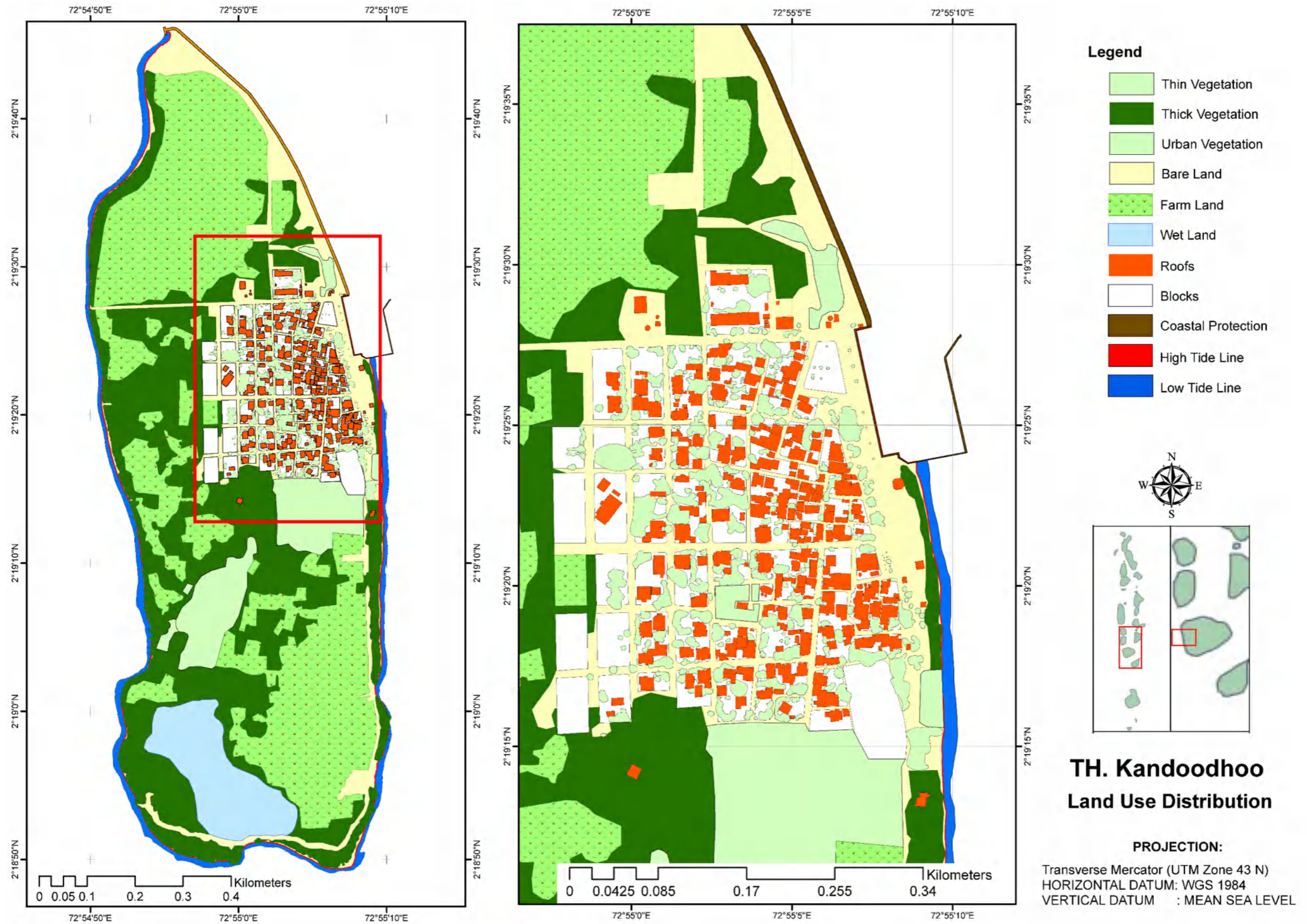


Figure 3-20: Roof Cover in Kandoodhoo Island based on UAV Survey

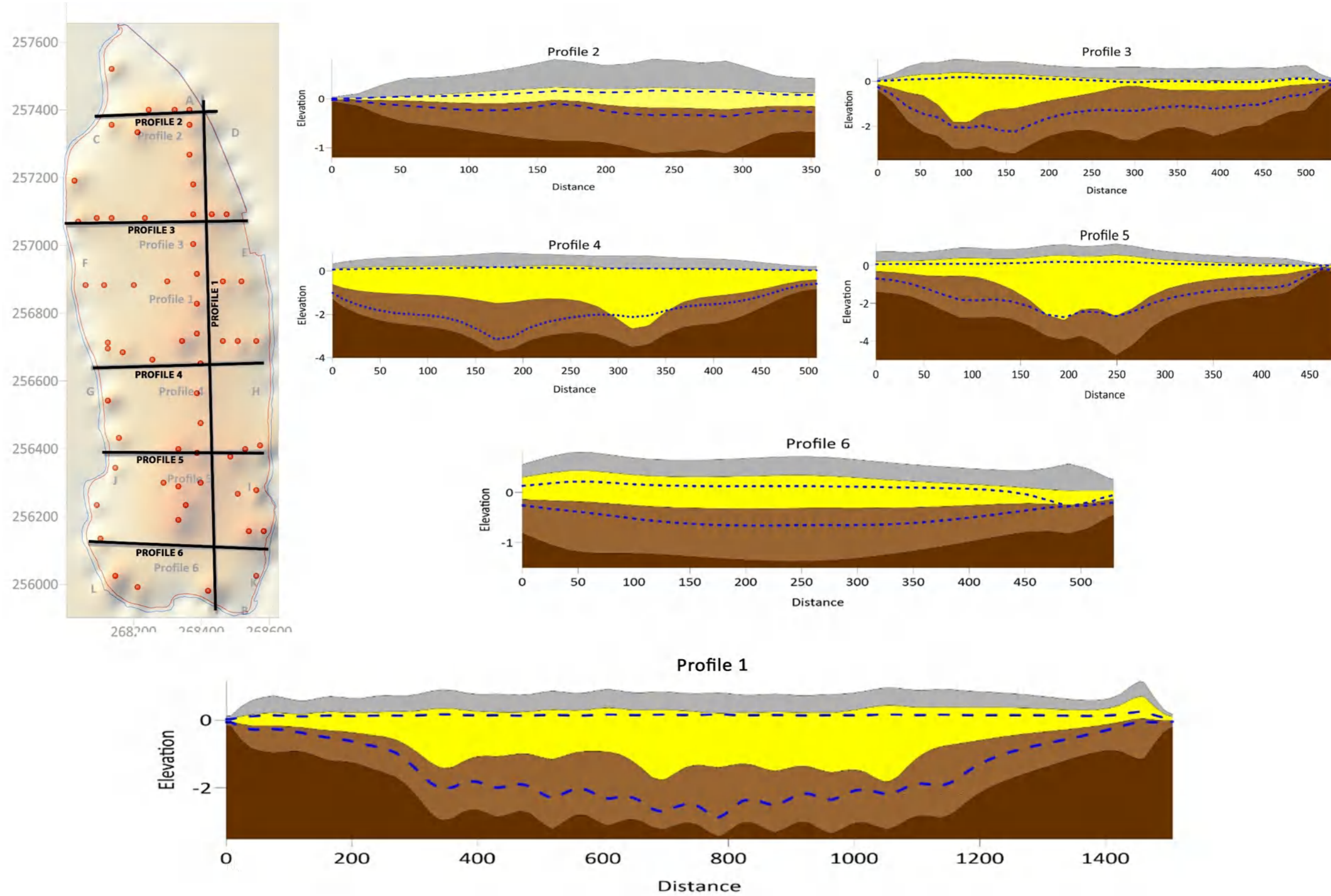


Figure 3-21: Cross sections and Sub-soil Profiles of Kandoodhoo Island

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented below in Figures 3-15 to 3-17.

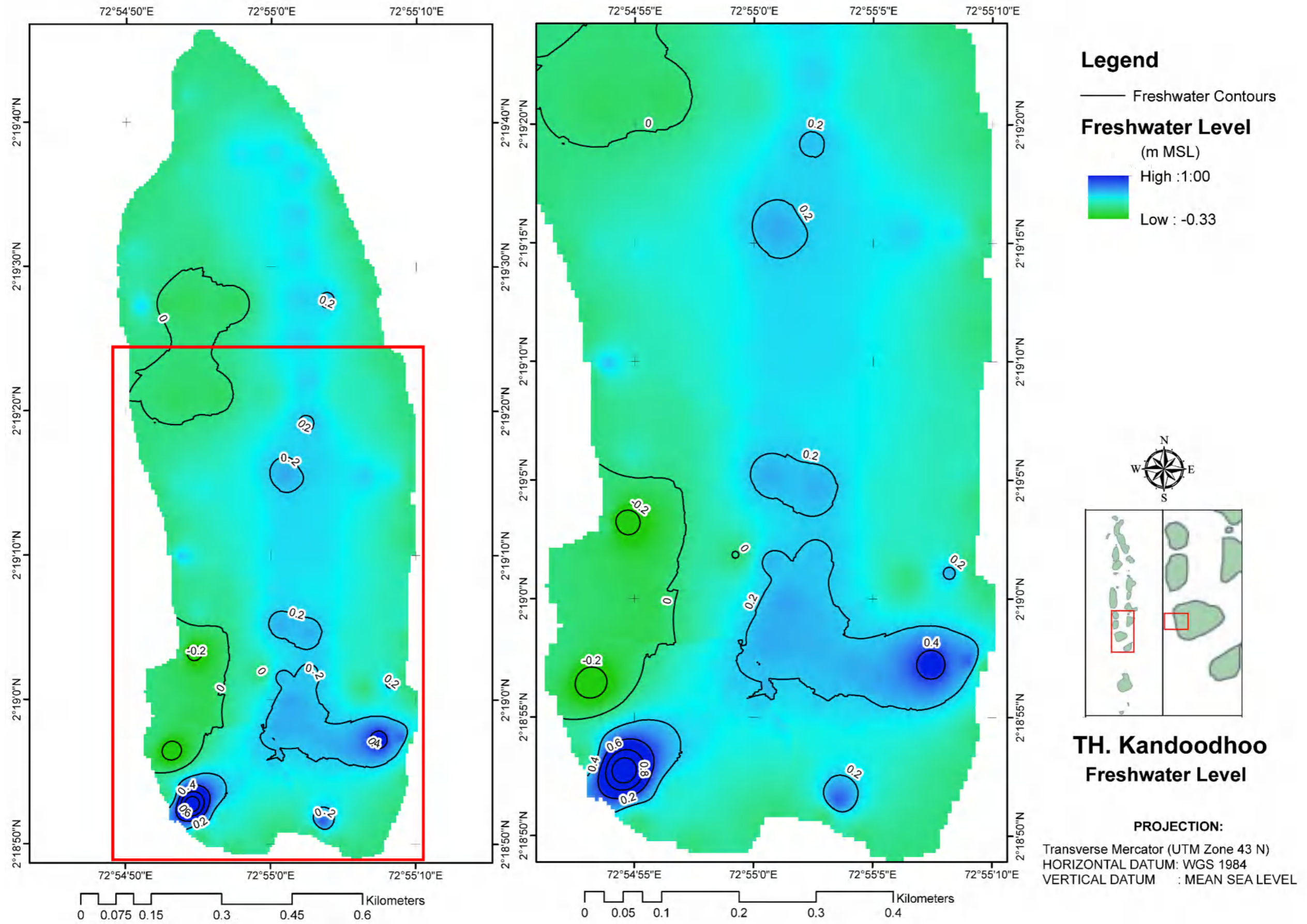


Figure 3-22: Freshwater Level in Kandoodhoo Island

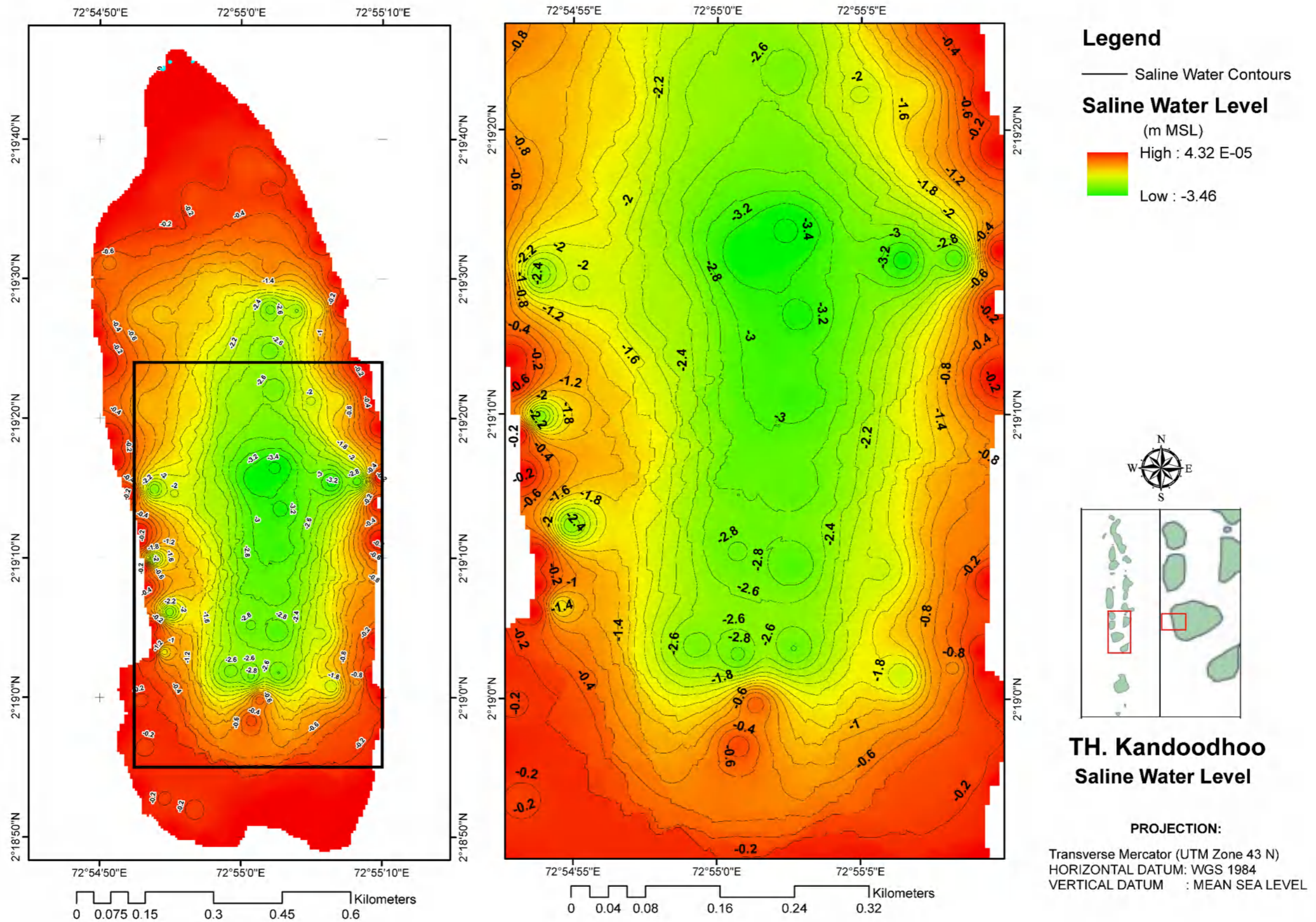


Figure 3-23: Saline water Level in Kandoodhoo Island

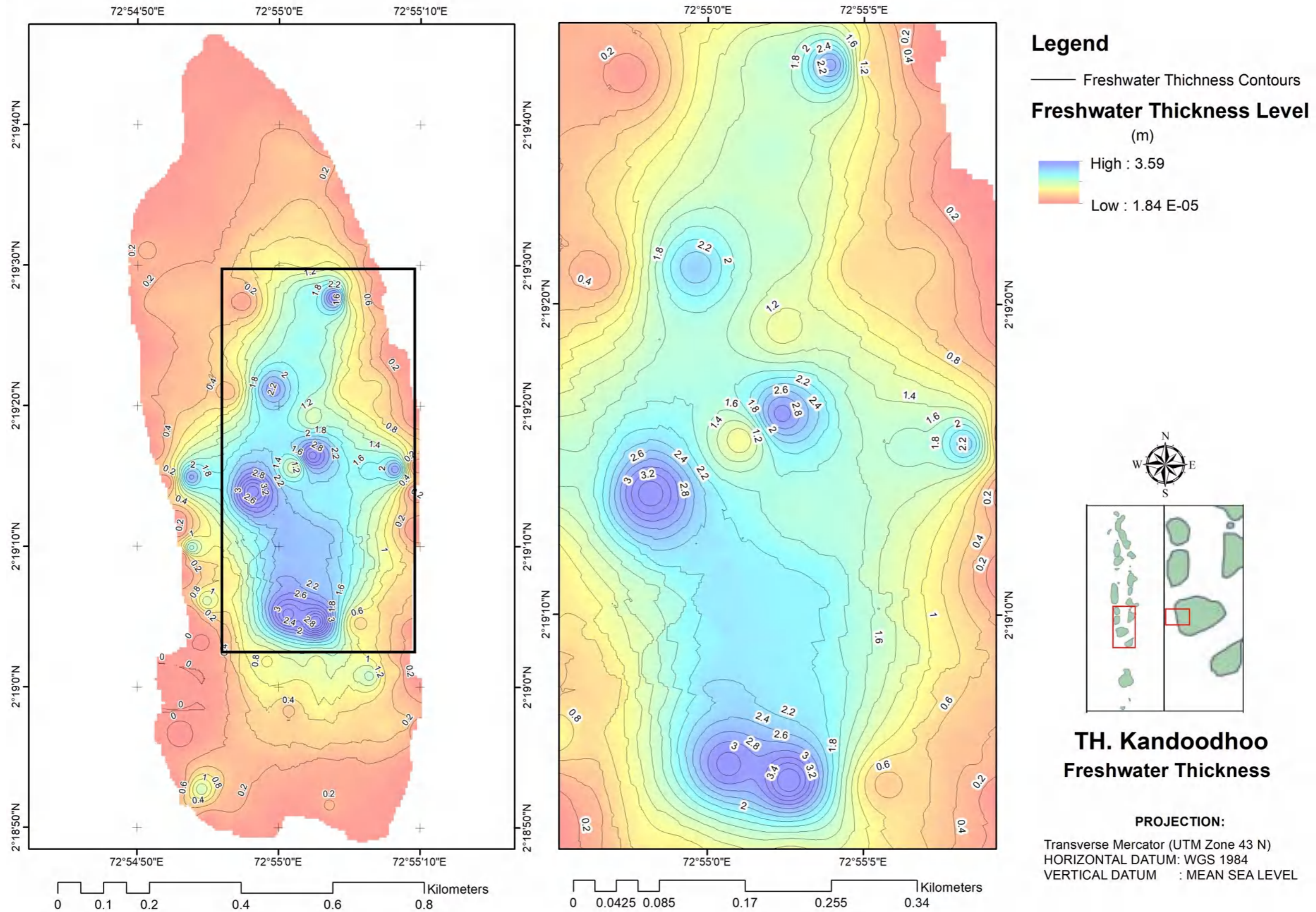


Figure 3-24: Freshwater thickness in Kandoodhoo Island

The maximum freshwater thickness of the island is 3.59 m (It is noted here that these readings were taken in September/October, which is the wet season and the with a reasonably higher number of wet days per month of the year).

3.7.10 Water balance and recharge

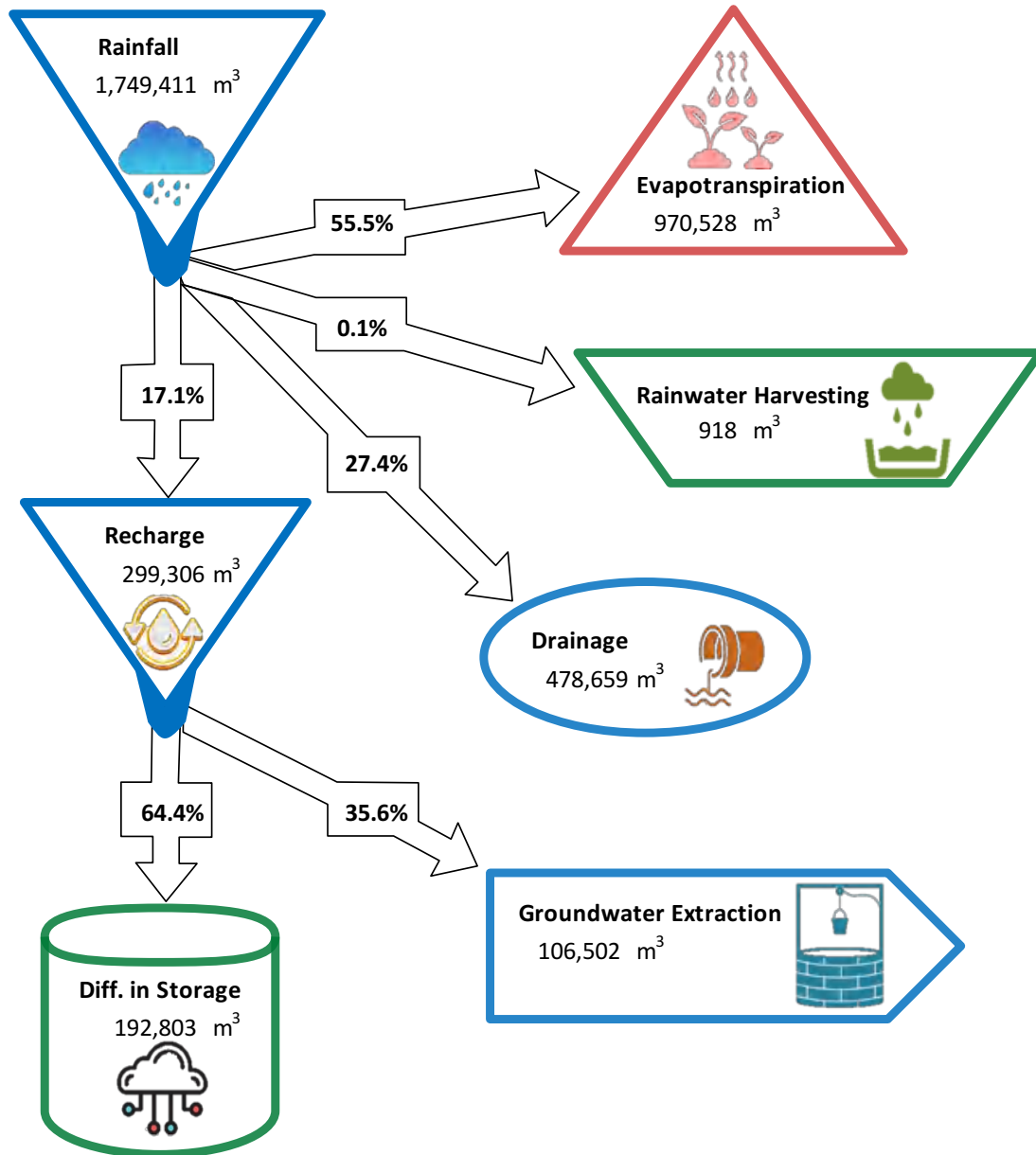


Figure 3-25: Schematic of water balance in Kandoodhoo Island

An annual estimation is carried out based on the water balance method (Falkland, 2000). Rainwater harvesting is calculated using the number of rainwater harvesting units on the island. According to the spatial mean annual rainfall of the Maldives, the annual average rainfall of Kandoodhoo Island is reported as 2,170 mm/year. Evapotranspiration was estimated using crop water requirements for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. Drainage or the surface runoff was calculated by considering an aggregate runoff coefficient for the island based on the land usage (roof cover, bare land, farmland, roads, playgrounds, wetlands). 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 the difference in storage.

3.7.11 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 2,120 m³ per day which was calculated by subtracting groundwater extraction from recharge volume derived from the schematic water balance model in Figure 3-25.

3.7.12 Permeability test

Permeability tests were carried out in the selected locations as outlined in the following figure.

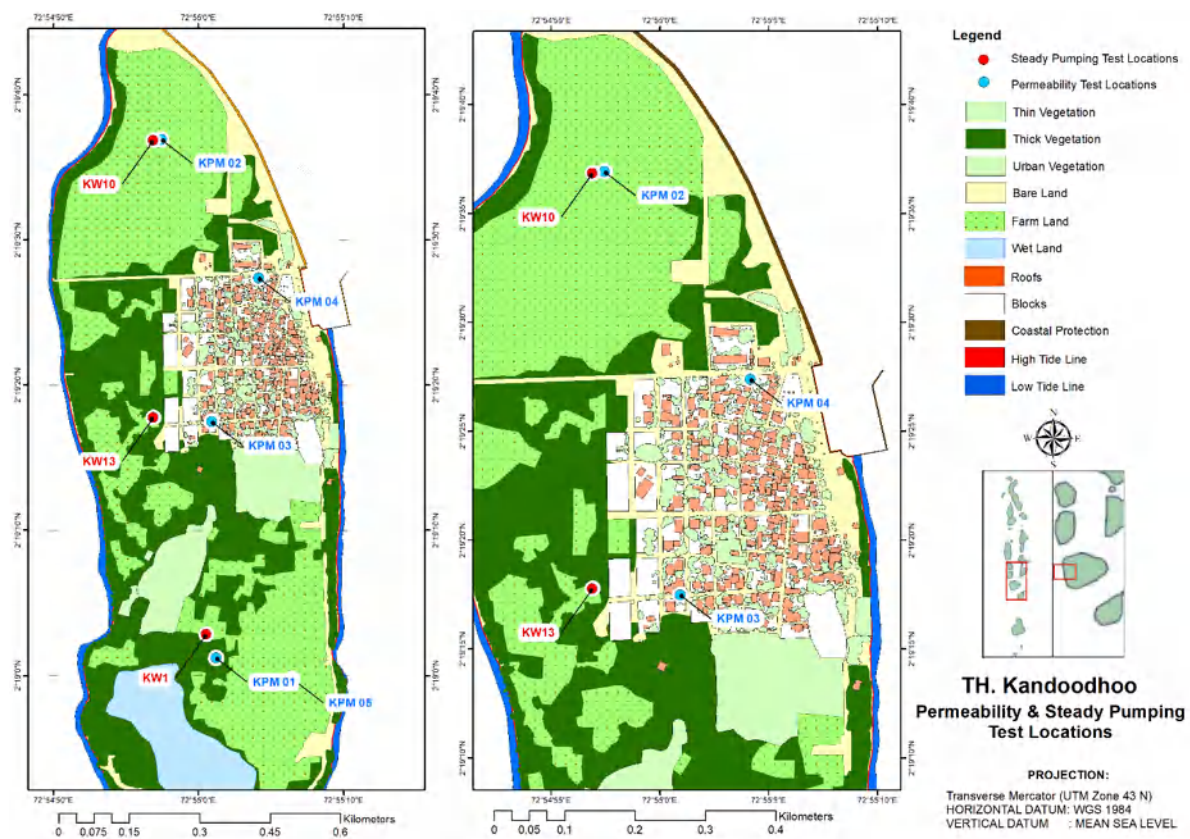


Figure 3-26: Locations of permeability and steady pumping tests in Kandoodhoo Island

The estimated permeability values for the above test locations are presented below in Table 3.12. The data will be comparatively verified and interpreted when additional data is acquired and calculations for other islands are completed.

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m³/s), H = Height of water in well (m), l = length of the perforated section (m), r_1 = outside radius of the casing (radius of the 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 the casing to water table (m).

Table 3.12: The Estimated Soil Permeability Values in Kandoodhoo Island

Point	KPM 01	KPM 02	KPM 03	KPM 04	KPM 05
D (m)	0.750	0.600	0.880	0.700	0.600
H (m)	0.750	0.600	0.880	0.700	0.600
l (m)	0.750	0.600	0.880	0.700	0.600
U (m)	0.850	0.700	1.000	1.000	0.700
T _u (m)	0.850	0.700	1.000	1.000	0.700
r (m)	0.076	0.076	0.076	0.076	0.076
Q (m ³ /s)	7.79E-05	4.22E-05	4.44E-05	1.17E-04	1.39E-05
r ₁ (m)	0.076	0.076	0.076	0.076	0.076
r _e (m)	0.010	0.010	0.010	0.010	0.010
T _u /l	1.133	1.167	1.136	1.429	1.167
X = (H/T _u x 100)	88%	86%	88%	70%	86%
Section	Zone 2	Zone 2	Zone 2	Zone 2	Zone 2
l/r _e	72.18	57.74	84.69	67.37	57.74
C _s	110	90	120	100	90
K (m/s)	1.27E-04	9.73E-05	5.73E-05	1.74E-04	3.20E-05
K (m/day)	10.94	8.41	4.95	15.00	2.77

3.7.13 Steady Pumping Test

Pumping tests were conducted in three existing wells to estimate the aquifer properties of unconfined water bearing formation and transmissivity of the water bearing formation was estimated using Muskat's Method, as follows;

$$T = \frac{C'A}{2\pi t'} \ln \left(\frac{S_1}{S_2} \right)$$

where $C' = \ln \frac{r_o}{r_w}$

T - Transmissivity

A - Cross-sectional area

r_o - Distance of which drawdown is negligible at the end of pumping

r_w - Radius of the well

S₁ - Drawdown at the time pumping stops

S₂ - Residual Drawdown at the time of t' after pumping stops.

Table 3.13: Selected Steady State Pumping Test Locations in Kandoodhoo Island

Well No.	C'	A (m ²)	t' (s)	ln ($\frac{S_1}{S_2}$)	T (m ² /s)
KW 1	4.01	10.17	3300	5.76	0.011
KW 11	3.86	4.09	480	2.65	0.013
KW14	4.60	3.12	2700	2.51	0.002

The measured transmissivity (m^2/s) values ranged from a minimum of $0.002 m^2/s$ to a maximum of $0.013 m^2/s$, with an average of $0.0086 m^2/s$.

3.7.14 Status of groundwater availability in Kandoodhoo Island

- 1). The selected Kandoodhoo island has dimensions of width = 552 m and length = 1744 m, with a total land area of 80.62 ha, a population of 742 persons, and a land use of Roof cover (Built up area) 3.24 ha (4.0%), Vegetation (Thick) 28.66 ha (35.6%), Vegetation (Light) 2.63 ha (3.3%), and Wetlands (Inland) 3.29 ha (4.1%).
- 2). In order to recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of the freshwater lens (FWL) and its associated recharge-discharge characteristics, Electrical Resistivity (ER) location readings along 12 representatively selected transects were collected.
- 3). Soil overburden permeability tests (constant head) were carried out at 05 locations while steady-state pumping tests were conducted at 03 locations. In addition, the groundwater level was also recorded at 40 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 $2.77 m/day$ to a maximum of $15.00 m/day$, with an average of $8.32 \pm 4.92 m/day$ (Mean \pm Standard Deviation).
- 5). The ground elevation values ranged from a minimum of $2.49 E-05 m$ MSL to a maximum of $1.59 m$ MSL, with an average of $0.61 \pm 0.31 m$ MSL (Mean \pm Standard Deviation).
- 6). The upper boundary of the freshwater lens (FWL) varied from a minimum of $0.33 m$ MSL to a maximum of $-1.00 m$ MSL, with an average of $0.09 \pm 0.09 m$ MSL (Mean \pm Standard Deviation).
- 7). The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of $-3.46 m$ MSL to a maximum of $4.32 E-05 m$ MSL, with an average of $-1.14 \pm 0.98 m$ MSL (Mean \pm Standard Deviation).
- 8). Accordingly, the freshwater lens (FWL) volumetric values ranged from a minimum of $0 m$ to a maximum of $3.83 m$, with an average of $1.19 \pm 0.72 m$ (Mean \pm Standard Deviation).
- 9). The groundwater profile in the island is characterized by a relatively Low (0.05%) Rainwater Harvesting (%) relatively Low (27.36%) Drainage (%) relatively Very Low (17.11%) Recharge (%) while the water use shows relatively High (35.58%) Groundwater extraction (%) leading to relatively High (64.42%) Difference in Balance Storage (%).
- 10). The freshwater lens (FWL) volume calculated based on ER transect test data is $835,316 m^3$ with a maximum FWL thickness of $3.59 m$ and a steady state groundwater storage of $125,297 m^3$.

3.8 Conclusion

The Safe Yield for the island estimated based on 'Recharge - Extraction' is $2,120 m^3$ per day, while it is $479 m^3$ per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is $292 m^3$ per day and this is about 55% of the allowable Safe Yield in the island (not stressed). At present, there exists no island wide sewerage network or water supply network.

Relative hydraulic condition of the island lies in 'Semi-pervious' state while present aquifer condition remains at 'Poor' state based on the hydraulic conductivity estimation carried out as per Bear (1972) and transmissivity of the formation was compared as per Krany (1993). Moreover, general status based on transmissivity ranged 'High' to 'Very High' and potential for groundwater recharge remains 'Low' – 'Moderate' as per the estimations.

4 TH. VANDHOO ISLAND

4.1 General overview of the island

The island of Vandhoo (Figure 4-1) is located on the south western periphery of Thaa Atoll at coordinates 72°56'30"E and 2°17'30"N. The island has an area of about 0.25 km² and measures about 0.5 km in width and 0.67 km in length. The population of the island was found to be about 321 residents as of December 2021. The island has a harbour on the Eastern side of the island. The following table outlines some basic information about the island and the following map outlines the location of Vandhoo.

Table 4.1: Basic statistical information on Vandhoo island in Thaa Atoll.

Name of the island	Th. Vandhoo
Longitude and Latitude	72°56'30"E , 2°17'30"N
Area	25.13 ha (0.25 km ²)
Population (Dec 2021)	321
Distance from Male'	218 km
Harbour	Present
Island sewerage network	Under Construction
Water supply network	No
Other infrastructure	No

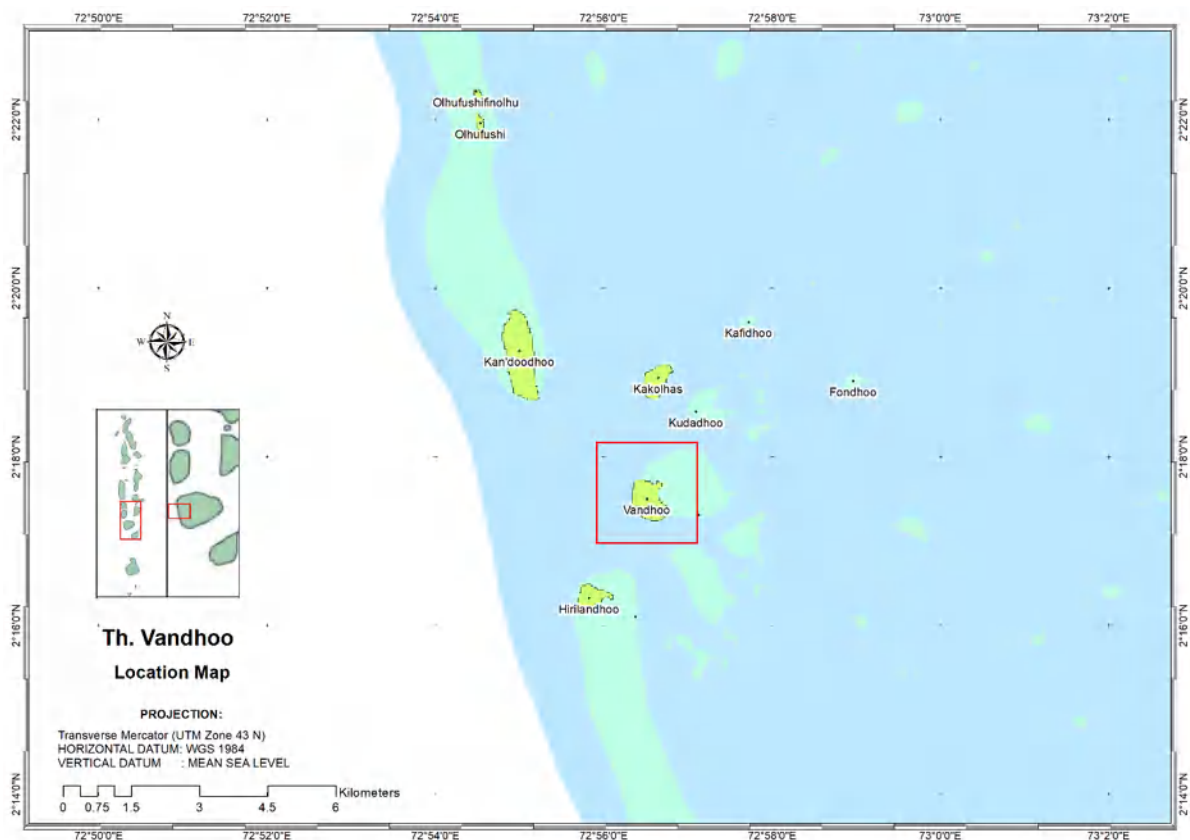


Figure 4-1: Location map for Vandhoo Island, Thaa Atoll.

4.2 Topography and Geology

Vandhoo island is in the western side of the Thaa Atoll between Kandoodhoo and Hirilandhoo islands. The Vandhoo island is located as an isolated island, between long north - south trending two submerged coral reefs. It is rounded in shape and extend about 660 m (N-S) in length and about 480 m (E-W) in width. Here, basic topography and the geological setting is mostly based on the properties of the underground coral beds and actions of ocean waves and currents. The elevation of the island varies from 0 to 1.8 m and generally flatland through the island. General geological profile in the island is composed of topsoil and beach coral sand deposits underlain by sandy coral rock (Figure 4-2). The sandy coral rock consists of a weathered coral rock layer and hard fresh coral rock. From the cross sections north to south, it shows a thin topsoil layer (0-0.5 m) and beach coral sand layer about 0.3 m in thickness in beach areas and about 1.8 m thickness in the middle of the island. In beach areas, mostly beach coral sand exists as the top layer. Coral sand layer is mostly unconsolidated and permeable. Weathered coral rock depth is varying between 0.5 m to 4.0 m and it is a semi permeable layer. Groundwater lens occupied both the coral sand layer and weathered coral rock. Hard coral layer is mostly unconsolidated and impermeable and present as a fresh rock. As the compositional and structural differences of coral formation, differential weathering could be observed in the island. The general trend of E-W cross sections in the central part of the island shows higher weathering compared to the coastal area. However, the N-S cross sections clearly show some deep weathered zones in northern areas in the island.

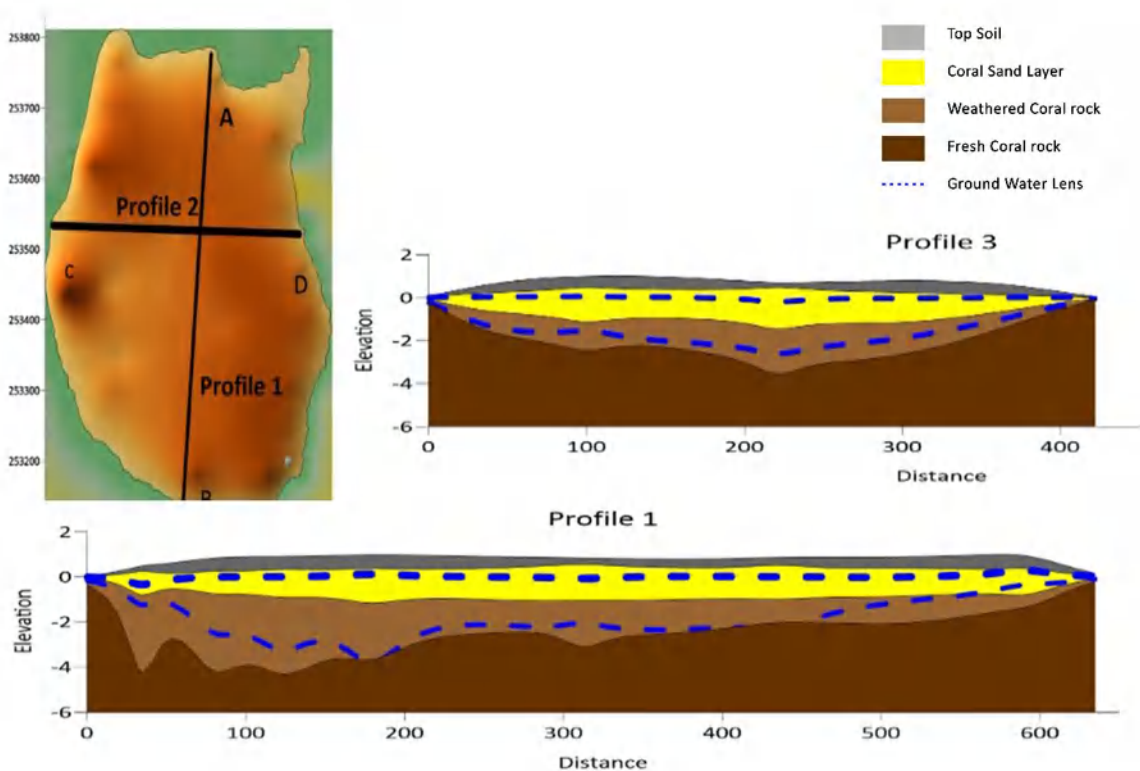


Figure 4-2: A geological section of the island showing subsurface geological characteristics

4.3 Climate

Vandhoo experiences the typical two monsoons in the Maldives namely, the North-east monsoon from December/January to March/April and the South-west monsoon from Mid-May to November. There are no specific wind and rainfall data available for Vandhoo as there are no weather monitoring stations on the island itself. Based on the rainfall data of the nearest weather monitoring station, it shows a declining trend in rainfall for the past 30 years (Inception Report, 2021).

The historical rainfall data records from Kadhdhoo Island (not included in the 6 selected islands in Lot 2) located in the Laamu atoll (80 km to the southeast from Vandhoo Island) has an annual average rainfall of 2,242 mm with a standard deviation of 370.4 mm and the trend and the decadal means were shown in the following graph. (MEE, 2021).

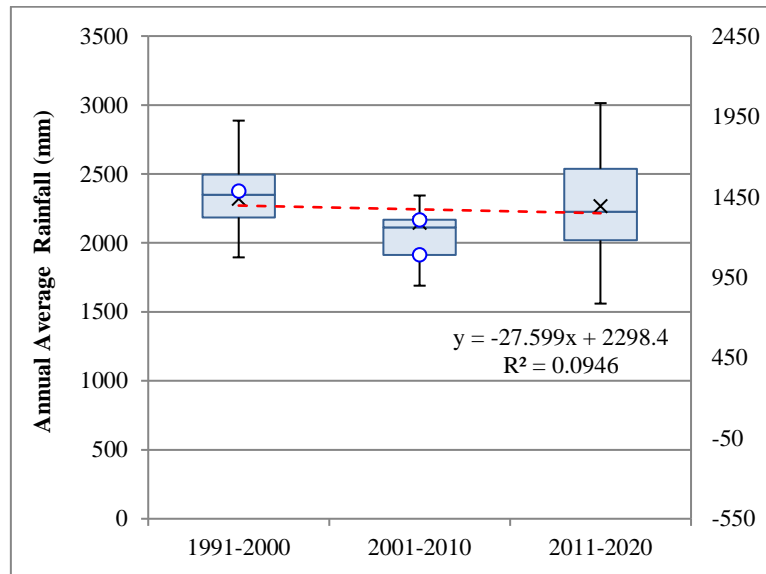


Figure 4-3: Decadal means and trend for rainfall in Kadhdhoo (1990 - 2020).

4.4 Demography

A total of 402 people is registered in Vandhoo although approximately 321 are currently residing in the island of which 306 are locals and about 15 are foreigners. It is expected that there are unaccounted foreigners as well working in different infrastructure development projects. The following Table 4.2 and Figure 4-4 illustrates the population breakdown for Vandhoo.

Table 4.2: Demographic breakdown of Vandhoo Island as of December 2021

Registered Population (locals)			Resident population								
			Total			Maldivians			Foreigners		
Both	Male	Female	Both	Male	Female	Both	Male	Female	Both	Male	Female
402	215	187	330	-	-	306	-	-	24	-	-

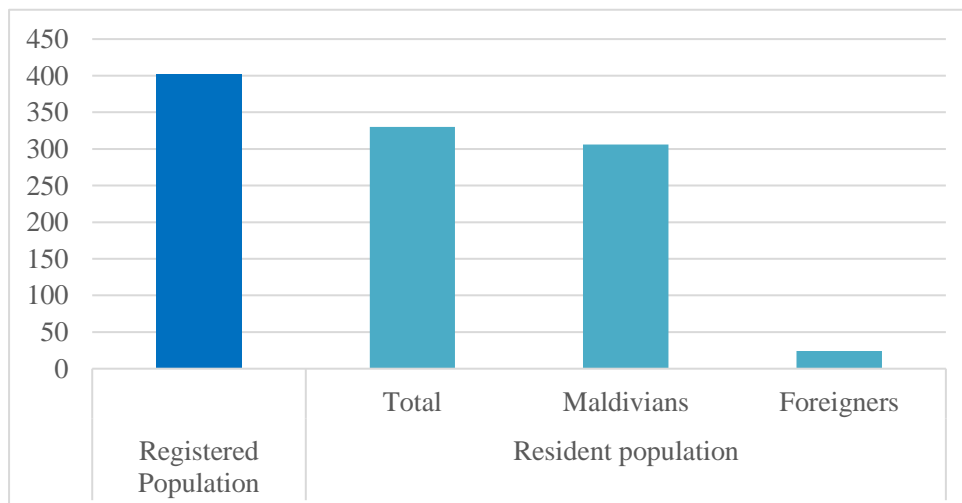


Figure 4-4: Population breakdown of Vandhoo (Maldivians & Foreigners)

4.5 Socio-economic Condition

4.5.1 Natural resources and land use

Th. Vandhoo has an area of 25.13 ha of which approximately 35% is occupied by the residents. A large area is also used for agricultural purposes. With wetlands located at different parts of the island, agricultural lands are mostly located at

There is no formal land use plan prepared till date. The island council now has the authority to allocate lands for different purposes with an approved land use plan.



Figure 4-5: Summary of household and socio-economic activities

4.5.2 Economic Activities

The main economic activity of the island is fisheries (mainly tuna, with few reef fishermen). Other areas through which income is earned includes construction and carpentry industry, employment in service provision sectors such as teaching and health sector, business operations and agriculture. While the majority of people involved in all sectors are Maldivians, there are a few foreigners involved in each sector.

4.5.3 Accessibility and Transport

The only direct mean of access to the island is via sea transport by speed boats or Dhonis'. It can be private hire or by ferries. Other means of transport is via air to the domestic airport at Thimarafushi of the same atoll and launch transfer from airport to Vandhoo.

A harbour with quay walls located at the eastern side of the island is used to access the island. It was noted that after the construction of the harbour, the rate of erosion increased. The island experiences severe erosion and coastal protection measures are under way to reduce the rate of erosion and its impact on the island.

4.5.4 Services and Infrastructures

The island is equipped with the basic services and supporting infrastructures.

4.5.4.1 Public Facilities and Amenities

The public facilities available in the island include:

- Power House
- Health Center
- Preschool
- Primary/Secondary School
- Mosques
- Government institutions (Office for Island Council, Island Court)
- Postal service
- Cable TV

4.5.4.2 Water supply

Currently, rainwater is used for drinking and cooking when needed, although bottled water sourced from Male' is also used. Groundwater is used for other purposes such as bathing and washing. This is further discussed in Section 4.6 and 4.7.

4.5.4.3 Energy supply

The island community has access to power 24 hours a day. The powerhouse on the island has a total capacity of 480 kW (through 3 generator sets of 160 kW each). The average load at present is 120kW.

4.5.4.4 Waste and Wastewater disposal

Solid Waste: An Island Waste Management Plan was formulated by the Island Council in 2016 and quite effectively enforced till the recent COVID 19 pandemic, at which time, due to financial difficulties, waste management methods have had to be changed.

During the implementation of the plan, waste collection from the households was undertaken by employees of the Council, for a monthly charge of MRF 100 per household. Waste was segregated at household level. Waste collected from households was taken to a temporary waste management area, about 50m to the north of the proposed IWRMC site. Disposal was through open burning of the waste. However, the waste collection services by the council were discontinued recently due to financial difficulties. The households now have to take their waste to the allocated site at the allocated time (between 6 to 8 am and 4 to 6 pm), where the biodegradable waste is disposed off through open burning, and non-biodegradable waste is stocked in piles. The food waste is disposed at the shoreline near the project site.

Sewage Disposal: Sewage disposal at present is through a septic tank system from where the effluent is disposed to sea. This is further discussed in Section 4.6.

4.6 Existing Water and Sanitation Situation

4.6.1 Water

Currently, the island does not have piped drinking water system though it is being established. Groundwater is the main source of water for all uses except drinking and cooking. The groundwater quality of the island is observed to be in bad condition especially in areas at the periphery of the island than the areas at the central part where the water lens is thicker. It was noted that the groundwater is mainly affected due to the current sewage management practices. Discolouration and odour indicate the pollution level.

Rainwater and bottled water are mainly used for drinking and cooking. Rainwater is harvested at both household level and island level. At the household level, each household has at least one water tank with a capacity of 2,500 L. The council have established 8 community tanks of 5,000 L for rainwater harvesting. However, at present none are being used for drinking purposes as the tanks are not well maintained hence it is not safe for drinking. Nevertheless, it was noted that during dry seasons, some use it for drinking after boiling.

The general practice of rainwater harvesting at island level is to clean the roofs thoroughly and letting the first flush pass to the roads which would eventually seep into the ground. Excess rainwater is also discharged to the roads in a similar manner. This sometimes causes flooding as well.

A rainwater harvesting system is also underway where roofs of all government institutions buildings/offices (council, mosque, health center, school, etc.) will be used to collect rainwater into public tanks which will then be filtered and distributed to 3 different areas of the island through common water taps to be used by the public.

In addition, the establishment of an RO Plant with household connection is ongoing and is expected to be completed and ready to use by the early next year 2022.

4.6.2 Wastewater and Sewage Disposal

Currently, sewage is deposited through a septic tank system from where the effluent is disposed to sea. Establishment of a proper sewerage system with household connections is currently ongoing. It is expected to be completed by end of this year or early next year 2022. Once the new sewerage facility has been established, the existing facility will be abandoned. The septic tank inflows from the pipes will be ceased by disconnecting the inflow pipes. The remaining sludge in the pipes and septic tanks will then be removed by sewer jetting and released to the sea via an outfall pipe.

4.7 Results of the Baseline Surveys

4.7.1 Summary of socio-economic surveys

As detailed in the methodology section of this report (Section 1.4.3.2), a social survey was carried out to determine the water usage at households (HHs), commercial entities (cafés/restaurants), institutions and places with industrial uses (agricultural lands, fish processing). The survey was carried out from 19th May to 22nd May 2021 with the help of local enumerators. The following Table 4.3 summarizes samples taken for each sector at a 95% confidence interval and the total number of completed surveys for each.

Table 4.3: Population and Sample taken for the social survey

Categories	Population	Sample	Forms Completed
Households	67	58	56
Farmers	69	8	5
Fishing Vessels	45	2	2
Fish Processing	5	3	2
Institutions	4	4	1
Guest houses	0	0	0
Café/restaurants	1	1	1

Note: A number of mitigation measures were adopted to ensure to achieve the 95% confidence level sample size. The challenges and limitations and the measures undertaken to mitigate the challenges are listed in Section 1.4.3.3.

The key findings from this survey show that a total of 486.62 liters of groundwater are estimated to be used per capita per day for various domestic uses. The respective water use situations including domestic, commercial and institutional uses are illustrated in the following sections.

4.7.2 Water usage for domestic purposes

4.7.2.1 Domestic Water Usage

A household survey was carried out at a 95% confidence interval. A total of 56 HHs were surveyed. As presented in Table 4.4, 86% of HHs have at least one of 2,500L capacity HDPE rainwater tanks at their homes to collect rainwater for daily uses. Among the 56 HHs, 84% uses rainwater for drinking

while 93% also uses it for cooking. Groundwater is mainly used for non-potable use in all the households surveyed.

Table 4.4: Groundwater and rainwater use data for Vandhoo

Rainwater	Per cent (%)
Households with rainwater tanks	86%
Rainwater use for drinking	84%
Rainwater use for cooking	93%
Groundwater	
Groundwater as drinking source	0%
Groundwater for cooking	4%
Groundwater for non-potable use	95%
Total number of household wells surveyed	56
Percentage of wells surveyed fitted with pumps	93%

Based on the survey carried out, an average daily groundwater demand per capita for domestic non-potable 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 4.5. The total domestic groundwater use is estimated to be 486.62 liters per capita per day.

Table 4.5: Domestic Ground Water Usage in Vandhoo

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
101.0	45.0	32.3	103.0	281.2

4.7.2.2 Perception on Groundwater

The HHs were also asked about their perception on groundwater, if it is safe to use for daily purposes and whether the quality of groundwater is good or bad.

As it can be seen from Figure 4-6, a total of 66% agreed that the groundwater of Vandhoo is safe to use for non-potable uses. Among this 66%, 20% strongly agreed that it is safe.

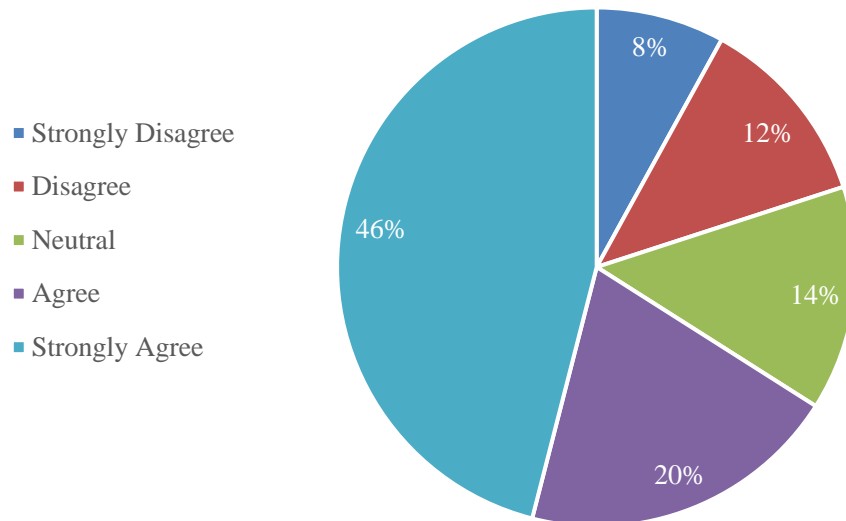


Figure 4-6: Perception of HHS of Th. Vandhoo on safety of groundwater

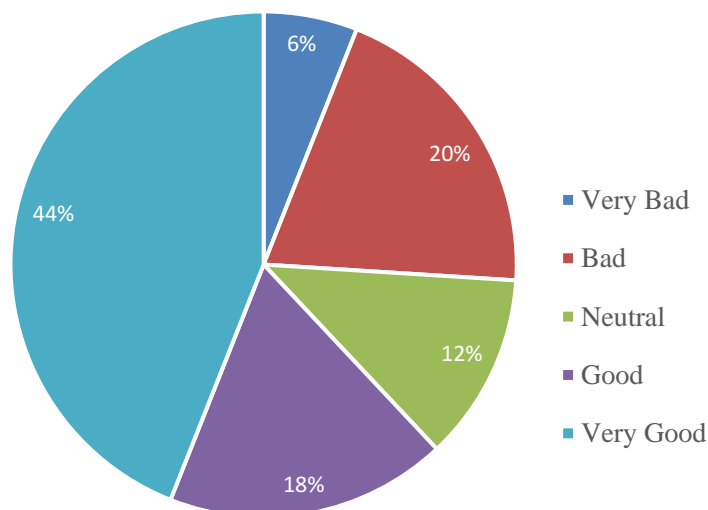


Figure 4-7: Perception of HHS of Th. Vandhoo on quality of groundwater

Furthermore, the HHs were asked about the quality of groundwater with regard to their experience. A total of 62% of the respondents said the quality good (44% said good, 18% very good). Only 26% thought the quality was bad of which 6% considered it very bad. From this finding, it is safe to say that the groundwater quality of Vandhoo is generally good as per the respondents. This is good compared to other islands that were surveyed. A key reason for this could be that they have been pumping out sewage while in other islands it is infiltration to the ground.

During the consultation, it was noted that during the rainy season when they experience *Udha* (storm surges), the houses near those areas experience an increase in the salinity of groundwater.

4.7.3 Water Usage by Commercial Activities

Vandhoo has only one 1 café. There were no guesthouses. It is estimated that approximately 863 liters of groundwater are used for purposes such as dishwashing, watering the front yard and toilet needs per day.

4.7.4 Water Usage by Institutions

Based on the survey carried out to collect data on water consumption by institutions, although the island has five places that can be considered as institutions which are the island council, power house, island court, school and health center we only got response from the magistrate court.

Groundwater in the institutions in Vandhoo are mainly used for mopping floors, flushing toilets and to some extent gardening. However, water usage data was only provided by the island magistrate court. Data from the rest of the institutions were incomplete hence not presented. As per the court, they spend approximately 58 liters of groundwater per day. Based on this data, 14.5 liters of groundwater are used per staff per day (Table 4.6:).

Table 4.6: Water Usage by commercial activities in Vandhoo

	Water Flushed(Liters)	Gardening(Liters)	Mopping(Liters)	Sub-Total Water Used (Liters)	Total Water Used (Liters)	Institutional Groundwater Usage (Liters Per Staff Per Day)
Power House	N/A	N/A	N/A	N/A	58	14.5
Court	48	0	10	58		
School	N/A	N/A	N/A	N/A		
Health Center	N/A	N/A	N/A	N/A		

4.7.5 Water Usage for Farming

A total of 5 farmers participated in the survey. This is only 7% of the total number of registered farmers in the island. Farmers mainly use groundwater for watering the plants. 100% of the surveyed farmers use groundwater extracted from wells using pumps to water their plants.

Table 4.7: below summarizes the water usage to water the plants every day.

From the total five (5) farmers that were surveyed, due to missing data only data from three (3) farmers were able to be used in the analysis. Hence, this is not a statistically significant sample. Nevertheless, from the available data, it can be observed that a total of approximately 0.65 liters (650 ml) of groundwater per sqft per day is used by farmers of Vandhoo to water their farmlands.

Table 4.7: Water Usage by Farmers in Vandhoo

Farmlands	Area of farmland	Volume of water used per day (Liters)	Total volume of water used per day (Liters) per sqft
1	N/A	613.5	-
2	N/A	50	-
3	5,625 sqft	2,454	0.44
4	3,600 sqft	4,908	1.36
5	4,000 sqft	1,227	0.31
Total		9,252.5	

4.7.6 Water Usage for Fisheries Activities

In Vandhoo, we were able to survey 2 fishing boats. All boats use ground water for different purposes. They store groundwater in tanks present in the boats.

Table 4.8: Water Usage by Fisheries activities in Vandhoo

Fishing Boats	Total Volume of water per day (Liters)
1	480
2	170
Total	650

As per the table, volume of water used by the 2 boats have a big difference. This may be due to the difference in the capacity of the vessels and type of fishery practiced. As this is not a statistically significant sample, a generalization of water usage per vessel cannot be deduced from the findings.

4.7.7 Groundwater quality

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

The following Table 4.9 summarizes the water quality results.

Table 4.9: Summary of groundwater quality tests from Vandhoo Island in 2021

Sample No	EC (µS/cm)	pH	Turbidity (NTU)	DO (ppm)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
Samples in Residential Areas											
V1	1297.10	7.35	0.100	3.47	27.78	0.64	1.20	0.09	0.09		
V2	1034.10	7.55	0.162	5.00		0.51	3.60	0.13	0.08		
V3	1173.10	7.45	221.000	3.64		0.58	0.70	0.19	0.09	2420	70.00
V6	1395.00	7.52	0.118	4.29		0.69	0.10	0.15	0.11		
V7	348.40	7.95	1.600	6.72		0.16	1.20	0.18	0.08		
V8	514.90	7.72	0.100	5.32		0.25	0.40	0.06	0.10	1203.00	150.00

Sample No	EC ($\mu\text{S}/\text{cm}$)	pH	Turbidity (NTU)	DO (ppm)	Temp ($^{\circ}\text{C}$)	Salinity (PSU)	Nitrates (mg/L)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
V9	1705.70	7.70	0.283	4.75		0.86	0.90	0.13	0.06	248.00	51.00
V11	474.90	7.85	0.208	5.39		0.23	0.80	0.09	0.16	2420.00	43.00
V12	661.60	7.66	0.101	4.60		0.32	0.60	0.10	0.74		
V13	921.60	7.70	0.195	5.07		0.45	0.50	0.22	0.19	921.00	261.00
V14	1610.00	7.61	0.343	4.71		0.81	0.10	0.10	0.06	2420.00	133.00
V15	499.30	7.53	0.352	4.01	27.76	0.24	0.10	0.24	0.17		
V19	701.60	8.16	0.100	6.23		0.34	0.10	0.10	0.14		
V21	1257.30	7.83	0.173	4.75		0.62	0.50	0.13	0.16	980.00	7.00
V22	855.70	7.59	0.106	4.11		0.42	3.30	0.11	0.10	2420	14.00
V23	2872.40	7.33	0.100	2.09		1.48	18.20	0.08	0.09		
V24	865.60	7.59	0.169	5.38		0.42	0.90	0.16	0.19		
V25	1727.30	7.68	0.176	4.71	27.88	0.87	2.70	0.07	0.08		
V28	763.30	8.03	5.830	5.80		0.37	3.00	0.13	0.08		
V29	1610.40	7.61	0.102	2.29		0.81	0.80	0.08	0.25		
V31	3185.90	7.53	0.122	3.19		1.65	1.10	0.08	0.13	2420	261.00
V32	952.10	7.66	0.108	4.40		0.47	31.10	0.08	0.17		
V33	1185.50	7.80	0.146	5.42		0.59	0.40	0.17	0.13	2420	5.00
V35	410.80	7.55	0.328	5.50		0.20	11.10	0.12	0.11	2420	221.00
V36	698.50	7.66	0.119	4.37		0.34	3.50	0.09	0.14	2420	8.00
V37	708.20	7.32	0.157	1.80		0.34	0.30	0.14	0.10		
V38	705.50	7.72	0.118	5.48		0.34	0.10	0.18	0.10		
V39	259.60	8.25	0.100	4.85		0.12	1.10	0.12	0.30		
V40	468.40	7.93	0.100	5.57		0.22	0.10	0.11	0.16	816.00	145.00
V41	442.27	7.73	0.102	5.78	27.72	0.21	7.40	0.10	0.23		
Samples in Agricultural Areas											
V5	613.60	7.66	0.148	3.53		0.30	3.50	0.14	0.15		
V6	1395.00	7.52	0.118	4.29		0.69	0.10	0.15	0.11		
Samples in Industrial Areas											
V26	383.60	7.93	0.110	6.20		0.18	0.10	0.14	0.05		
V27	430.40	7.89	<0.1	6.73		0.20	4.10	0.09	0.13		
Samples in Water Logged Areas											
V28	763.30	8.03	5.830	5.80		0.37	3.00	0.13	0.08		
V16	50263.00	7.32	0.260	4.14	27.93	32.85	0.40	0.73	0.13		
V17	2221.00	7.70	1.630	4.63		1.13	4.00	0.62	1.24		
V18	28130.00	7.21	18.800	1.67		17.26	8.30	0.56	1.22		
V30	3753.40	7.45	68.800	3.15		1.97	2.70	0.63	1.28		
Samples in Other Areas											
V10	1431.10	7.11	304.000	1.48		0.71	1.30	2.38	0.17		
V20	815.70	7.66	7.710	2.68		0.40	1.40	0.46	0.11		
V34	47248.00	7.32	3305.000	1.17		30.66	3.50	1.30	0.32		

Based on the full results and the summary shown in Table 4.9, the following can be summarized for Vandhoo Island:

- The EC of the groundwater is generally high, with an average of 4077.87 $\mu\text{S}/\text{cm}$ which is above an acceptable limit for potable water of 1500 $\mu\text{S}/\text{cm}$. The electrical conductivity readings range from 259.6 to 3,753.4 $\mu\text{S}/\text{cm}$. 73% of 38 readings fall within the acceptable limit.
- The pH of groundwater ranged from 7.11 to 8.16 with an average of 7.11. The pH values of all samples were within the WHO permissible limits of 6.5-8.5.
- Turbidity ranged from the lowest of 0.1 NTU to 3305.00 NTU with an average of 96.08 NTU.
- Dissolved oxygen levels were low to moderate, with values varying from 1.167 mg/L to 6.726 mg/L with an average of 4.36 mg/L.
- The salinity of groundwater ranged from 0.12 PSU to 32.85 PSU with an average of 2.48 PSU. Salinity is expressed in Practical Salinity Units (PSU) which is equivalent to PPT.
- The average Nitrate concentration was 3.07 mg/L and therefore it does not exceed the WHO guideline limit of 5.09 mg/L. But 5 of the 41 tested water samples exceeded this limit of 5.09 mg/L. The Nitrate concentrations ranged from 0.1 mg/L to 31.1 mg/L.
- Ammonia concentrations were generally low. The average ammonia concentration was 0.78 mg/L. This is within the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. Only 1 tested water samples exceeded this limit (ranged from 0.06 to 2.38 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 were within the range 0.05-1.28 mg/L with an average of 0.23 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). There were 10 samples tested below 0.1 mg/L.
- Total coliform levels were also found to be significant and ranged from the lowest count of 248 MPN/100 mL to the highest count of more than 2420 MPN/100 mL, with an average count of 1809.85 MPN/100 mL. Faecal Coliform levels were found to be less significant and ranged from the lowest count of 5 MPN/100 mL to the highest count of 261 MPN/100 mL.

EC values of the selected wells were collected at the start of wet period (September – October) and following table show the summary of all the result collected during dry and wet periods based on the land use distribution.

Table 4.10: Comparison of WQ results based on land usage

Land Use	Number of samples	Results are lined with conditions	Enrichment of measured parameters	Remark
Residential area	48	43	VW6, VW 8, VW18, V23, V31	VW 6 and VW 18-EC enrichment due to leaching of salt from coral stockpiling site. VW 8 and VW 23-EC enrichment due to sea water mixing.

Land Use	Number of samples	Results are lined with conditions	Enrichment of measured parameters	Remark
				VW 18- EC enrichment due to water flooding.
Agricultural area	3	2	V10	V10 – Leaching on nitrate-based fertilizers from agricultural lands
Industrial areas	2	2		
Other areas	9	4	V16, V17, V18, V30, V34,	V18, V30, V34-Sea water flooding and adding of contaminants from overland flow. These sites are located at low elevated area. V17 –Adding of contaminants from anthropogenic activities through overland flow and it is located at water logged area.
Total	60	49	11	

Considered desirable water quality limits:

- 1) EC < 2500 $\mu\text{s}/\text{cm}$ (water could be used for potable and non-potable use depending of EC).
- 2) Nitrate (<50 mg/l), Phosphate (<5 mg/l), and ammonia (<0.5 mg/l) as per WHO guideline.

Limited residents' plots are located within the island. About 48 samples within resident area have been analysed and measured nitrate, ammonia, and phosphate concentrations are as per WHO guideline. It revealed that present sewerage contaminations status is not up to alarming level.

The measured water quality within the island revealed that there is no indication of water quality changes due to groundwater extraction.

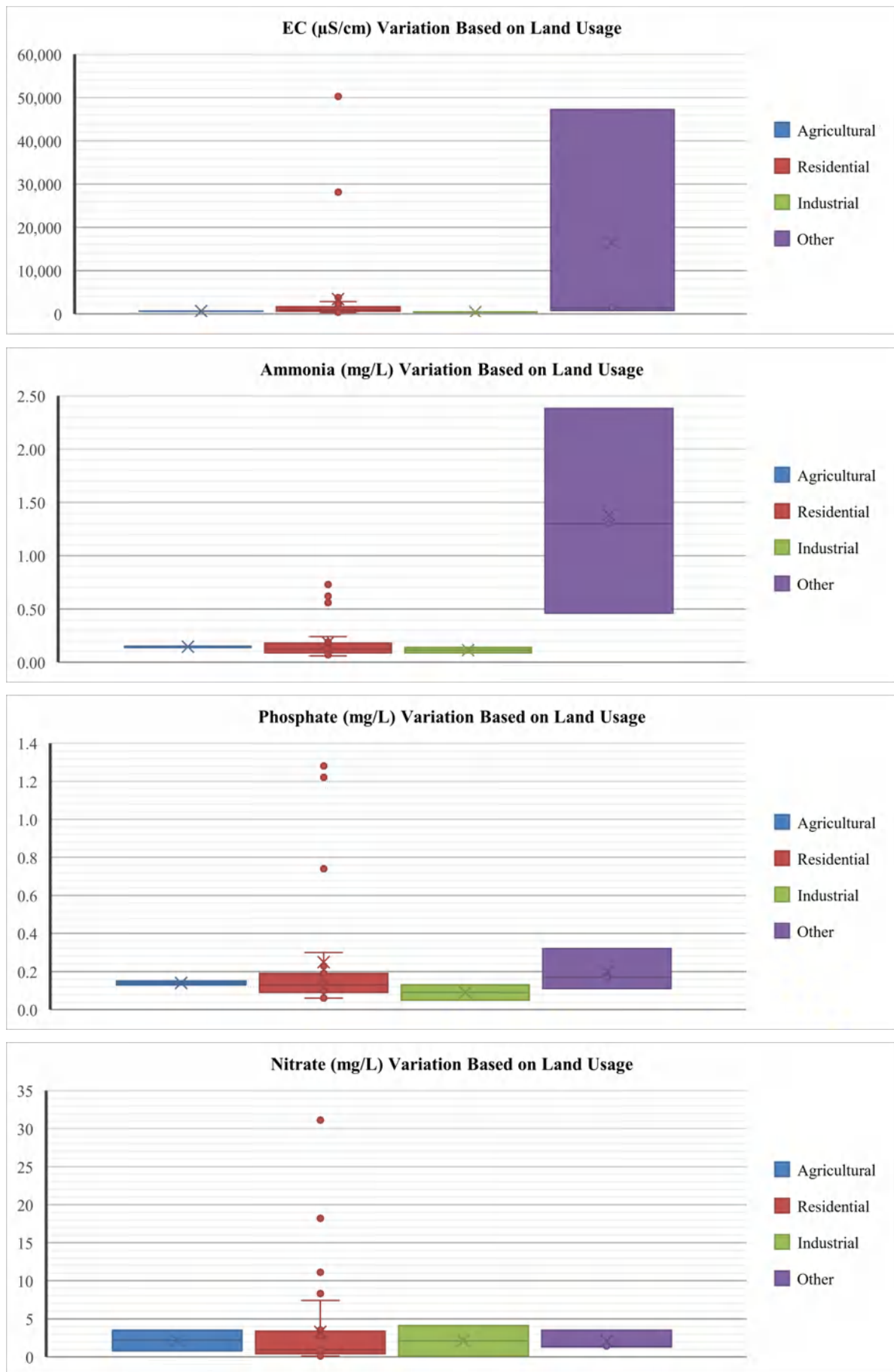


Figure 4-8: Variation of measured WQ parameters in Vandhoo Island

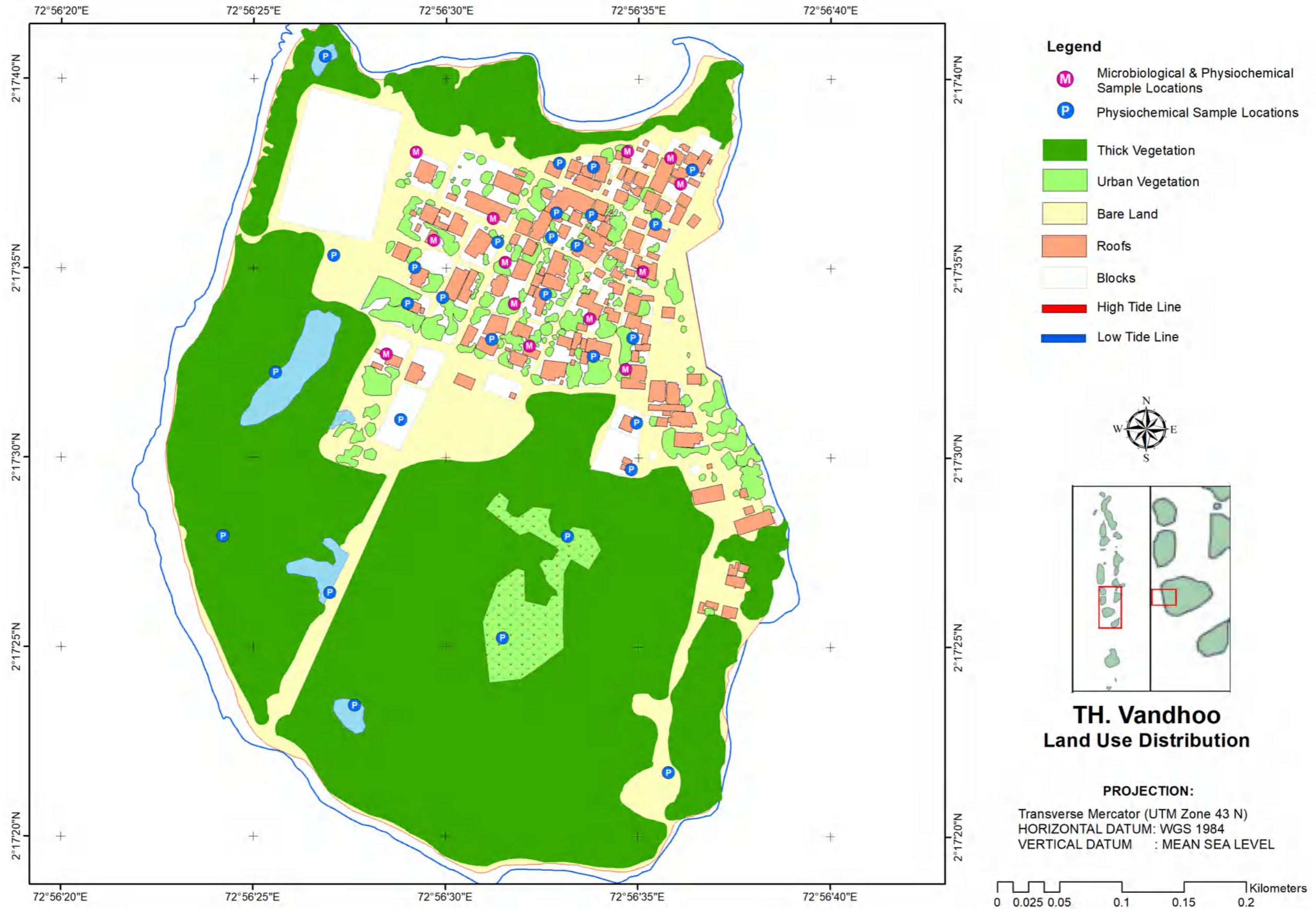


Figure 4-9: Location of groundwater sampling points in Vandhoo Island

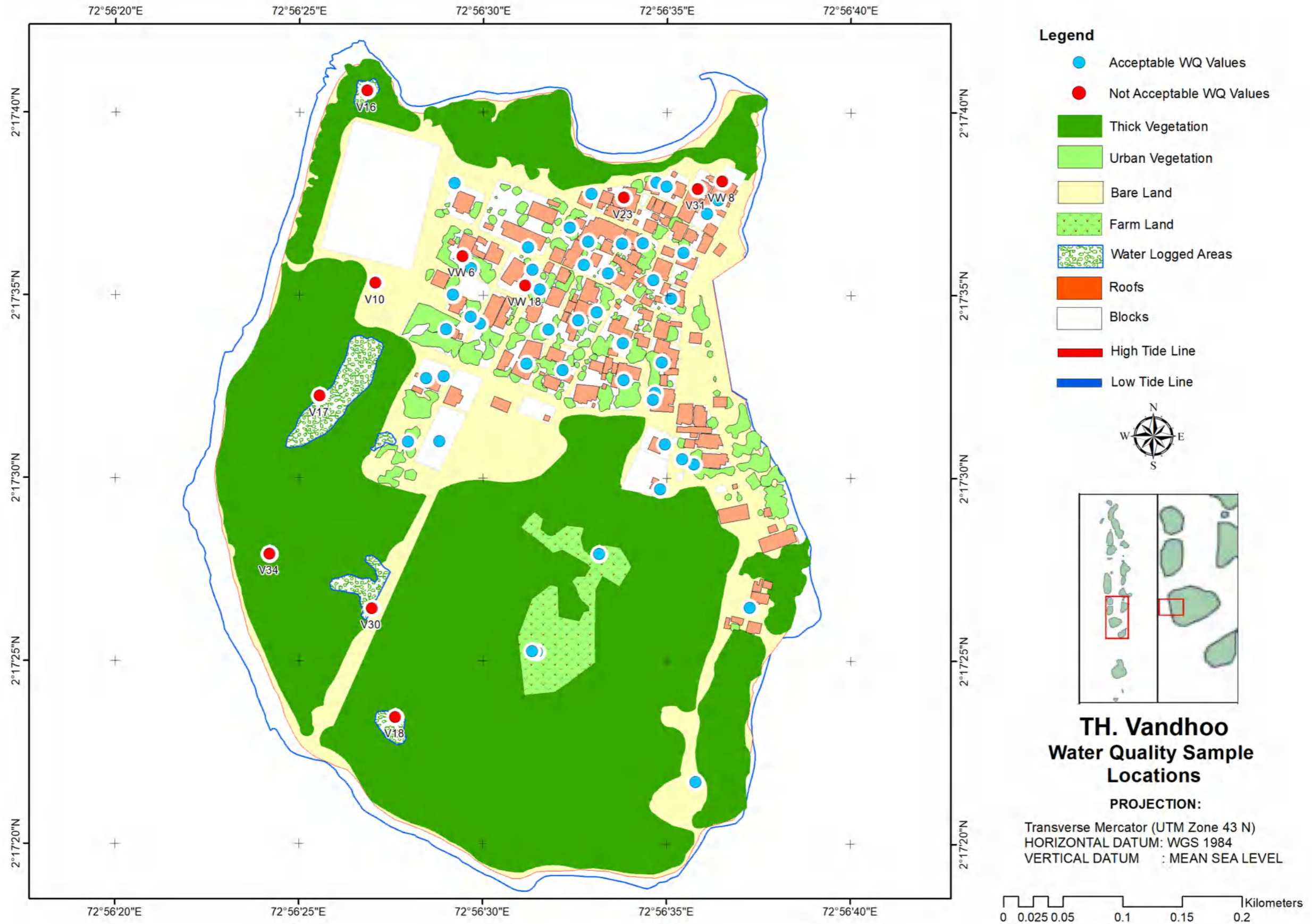


Figure 4-10: Location of groundwater sampling points with critical WQ values in Vandhoo Island

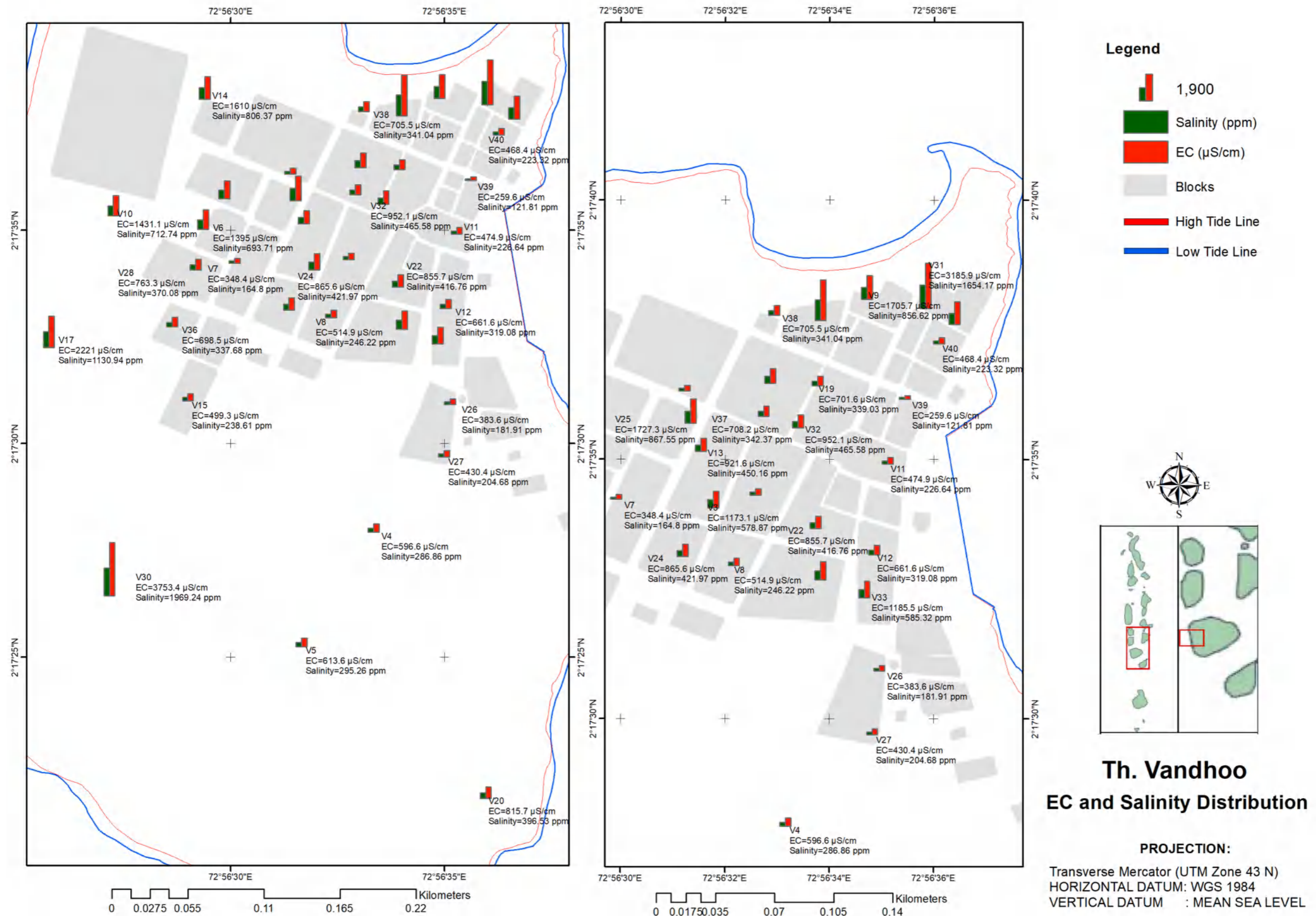


Figure 4-11: EC and Salinity Distribution in Th. Vandhoo Island

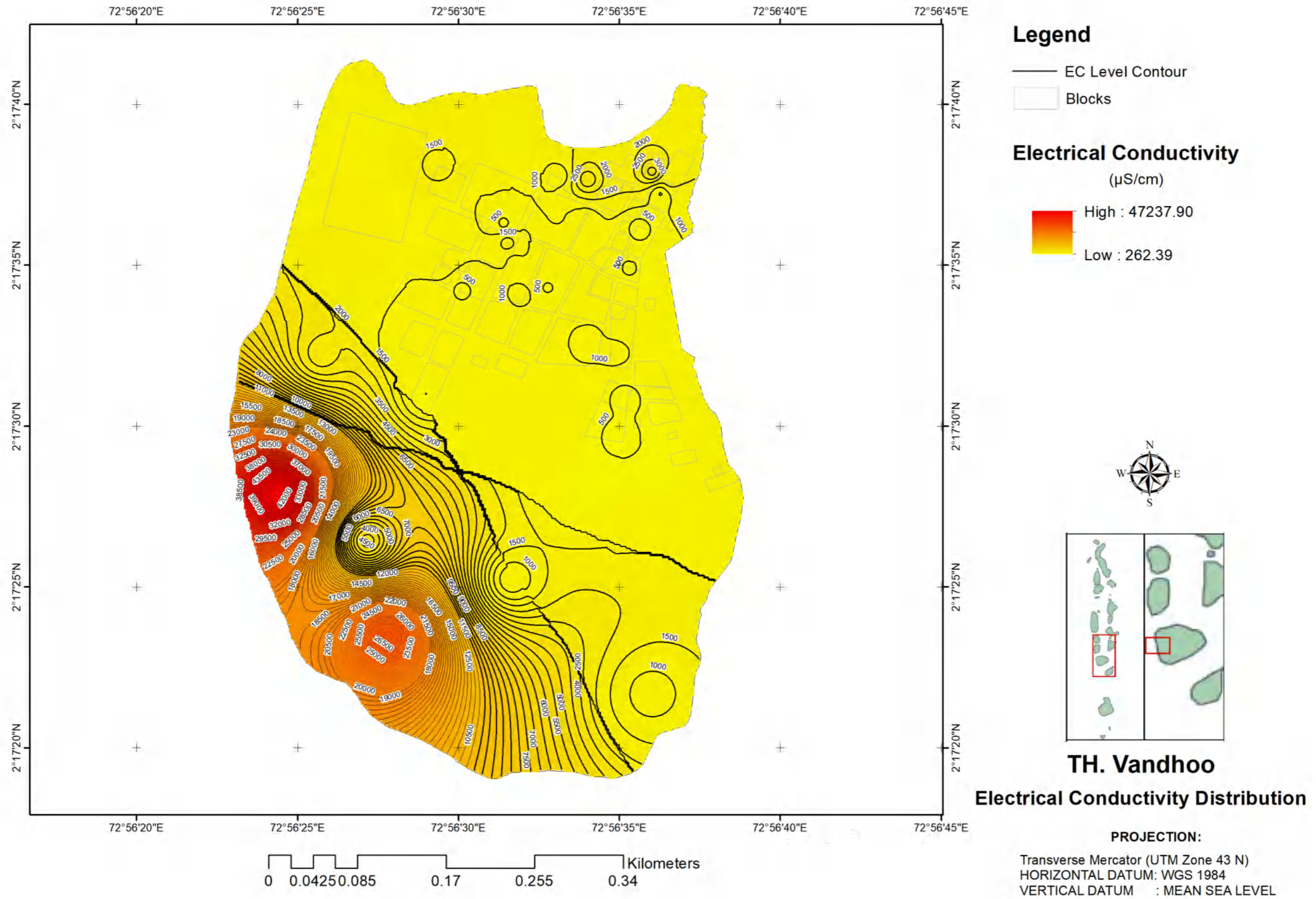


Figure 4-12: EC Distribution in Th. Vandhoo Island

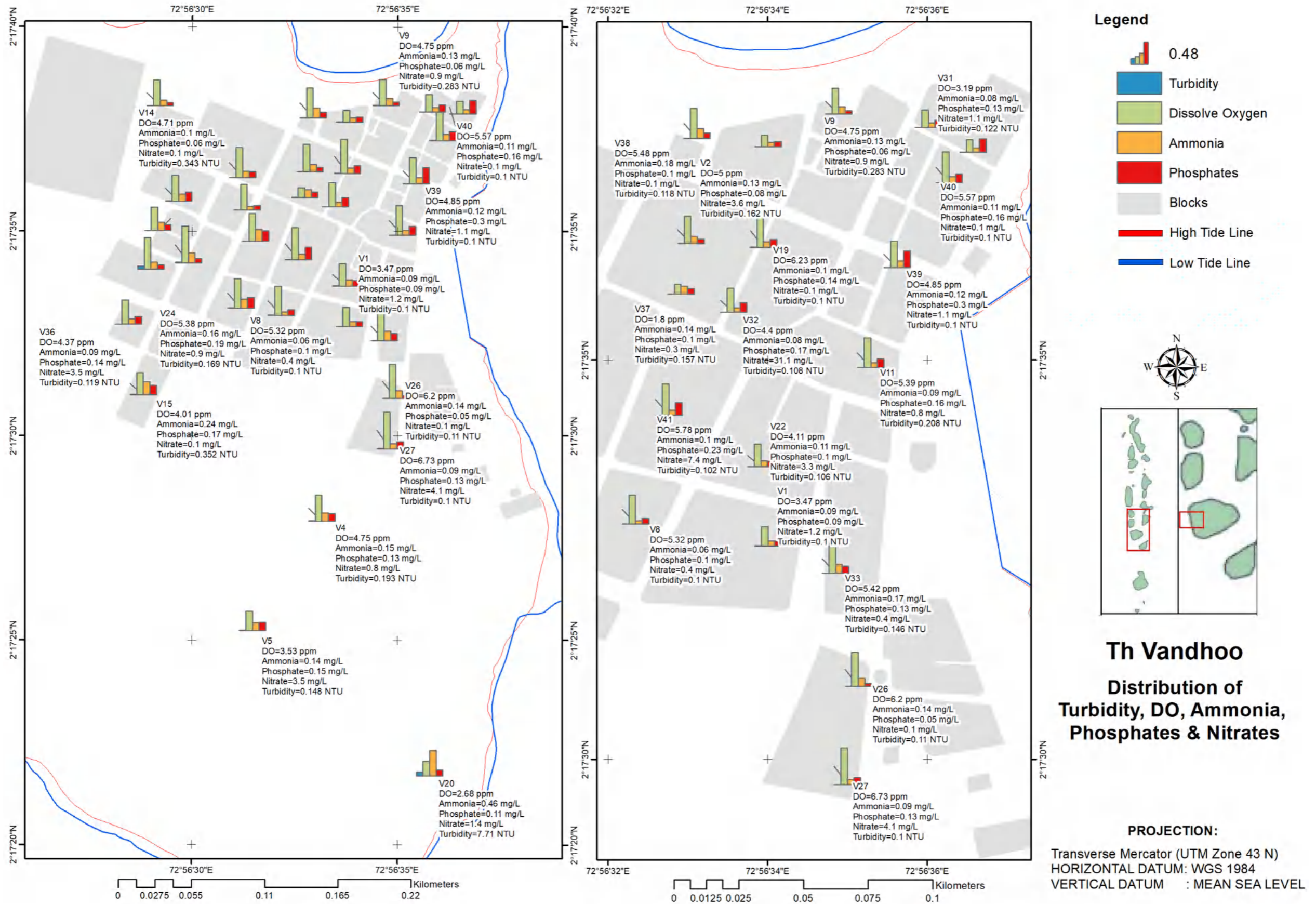


Figure 4-13: Distribution of Turbidity, DO, Ammonia, Phosphates and Nitrates in Th. Vandhoo Island

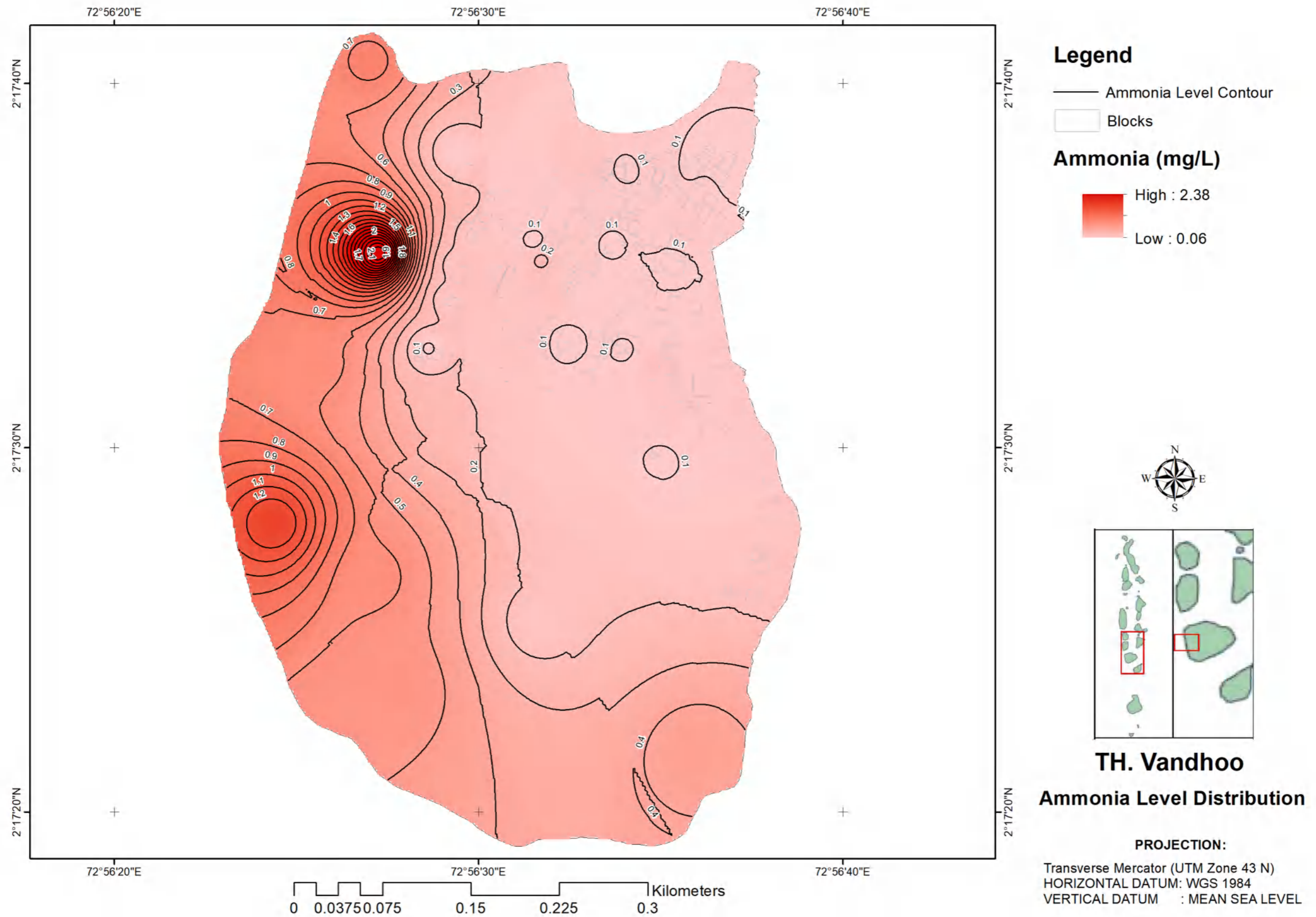


Figure 4-14: Ammonia Level Distribution in Th. Vandhoo Island

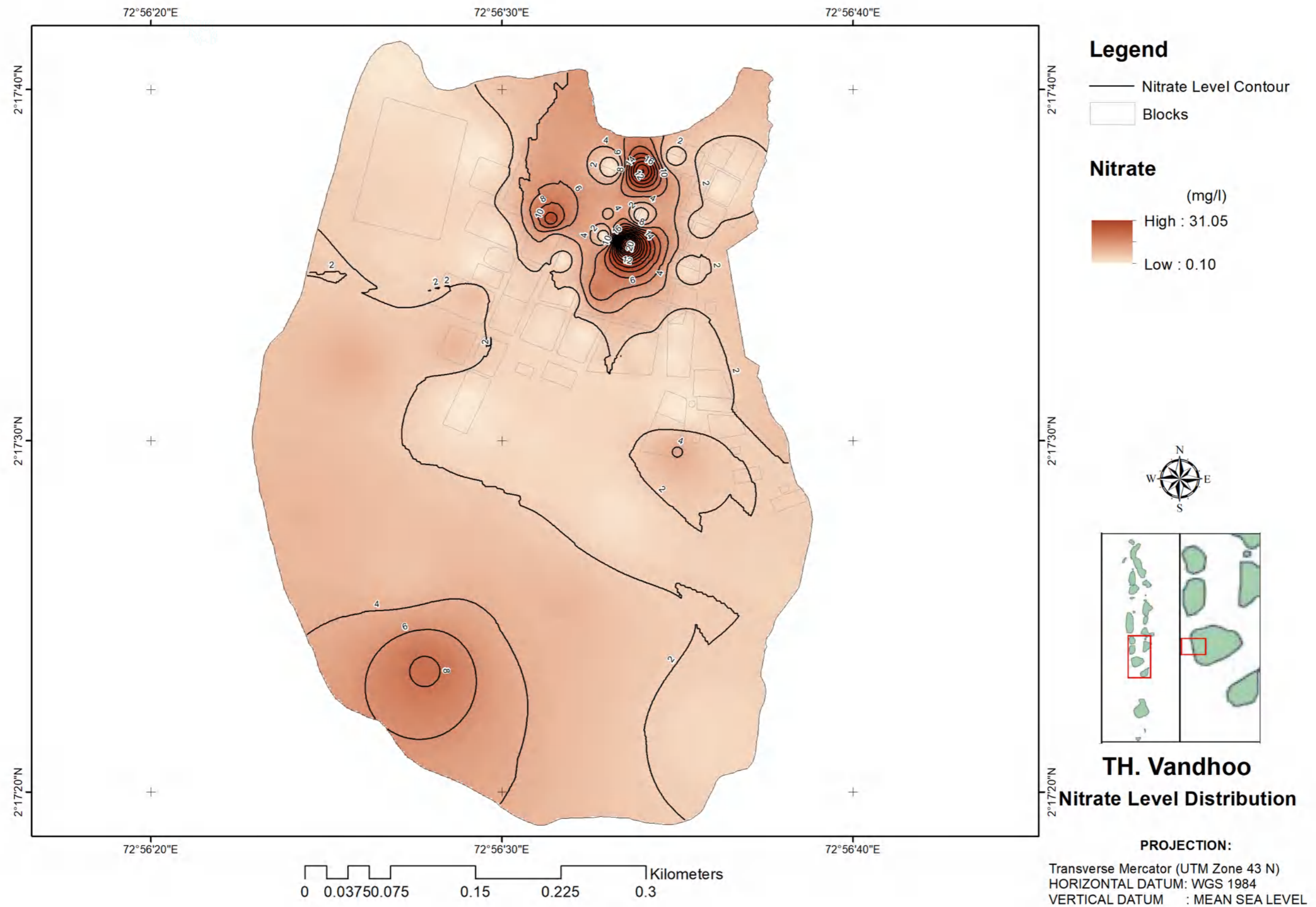


Figure 4-15: Nitrate Level Distribution in Th. Vandhoo Island

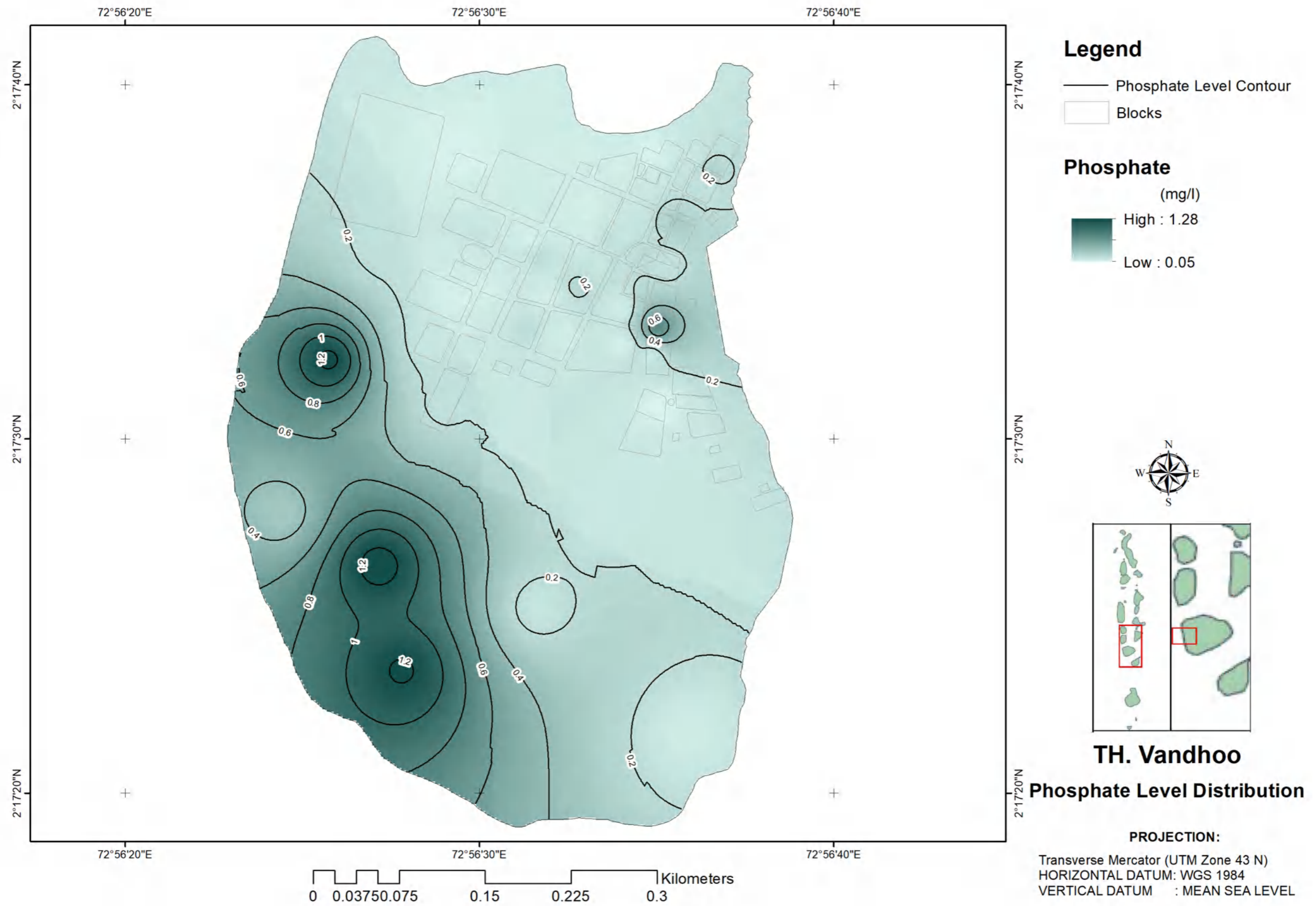


Figure 4-16: Phosphate Level Distribution in Th. Vandhoo Island

4.7.8 Geophysical survey

The Electrical Resistivity (ER) tests were carried out in the locations as outlined in Figure 4-17 below. The ER survey included test points along 6 transects selected representatively based on reconnaissance surveys to adequately characterise different land uses and island cross-sections. The main transects were aligned along existing roads to maintain consistency and uniformity.

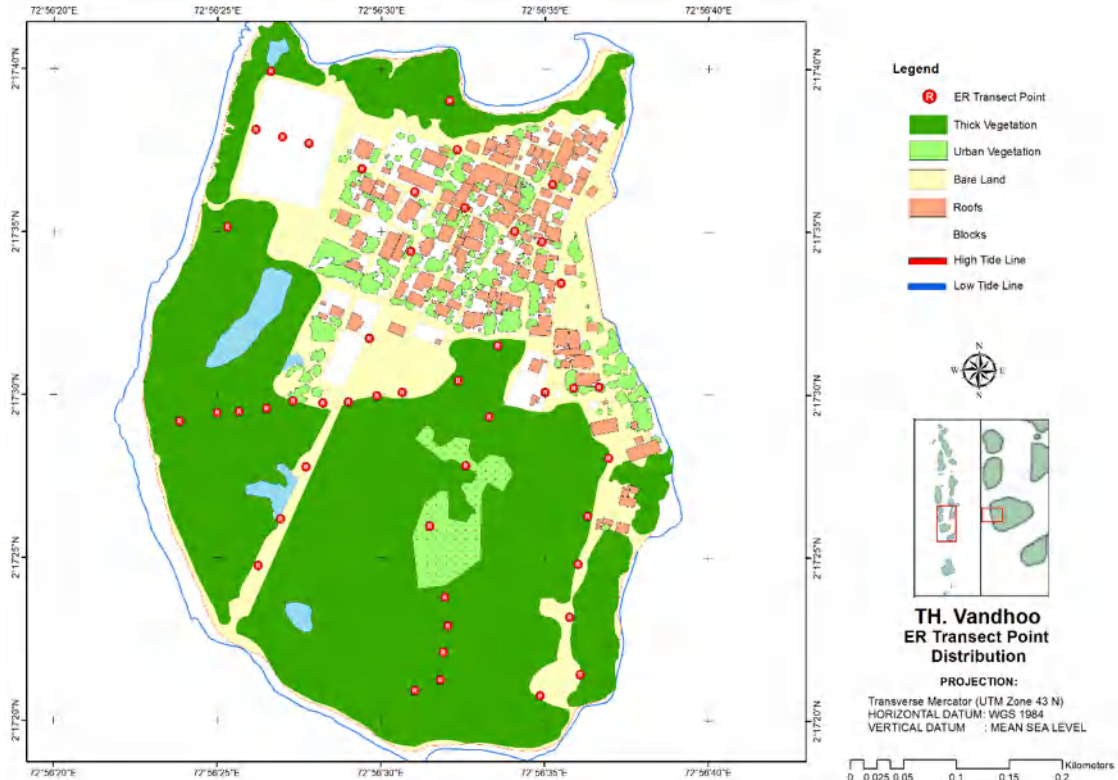


Figure 4-17: Location of ER points in Vandhoo Island

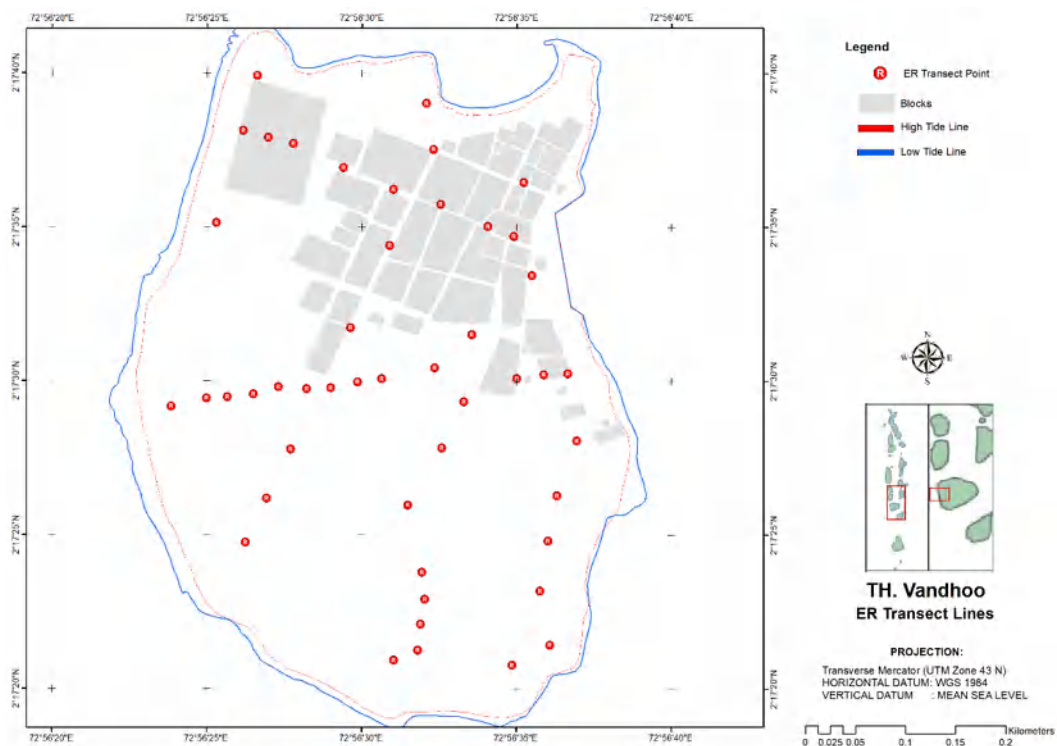


Figure 4-18: ER Test Points and Transect Lines in Vandhoo Island

4.7.9 Aerial surveys

Based on the aerial survey, a multiple data set consisting of buildings, roof cover, land cover, change detection and shoreline were extracted. This data is shown in the following Figure 4-19. The total roof cover for this island is 16,027 m².

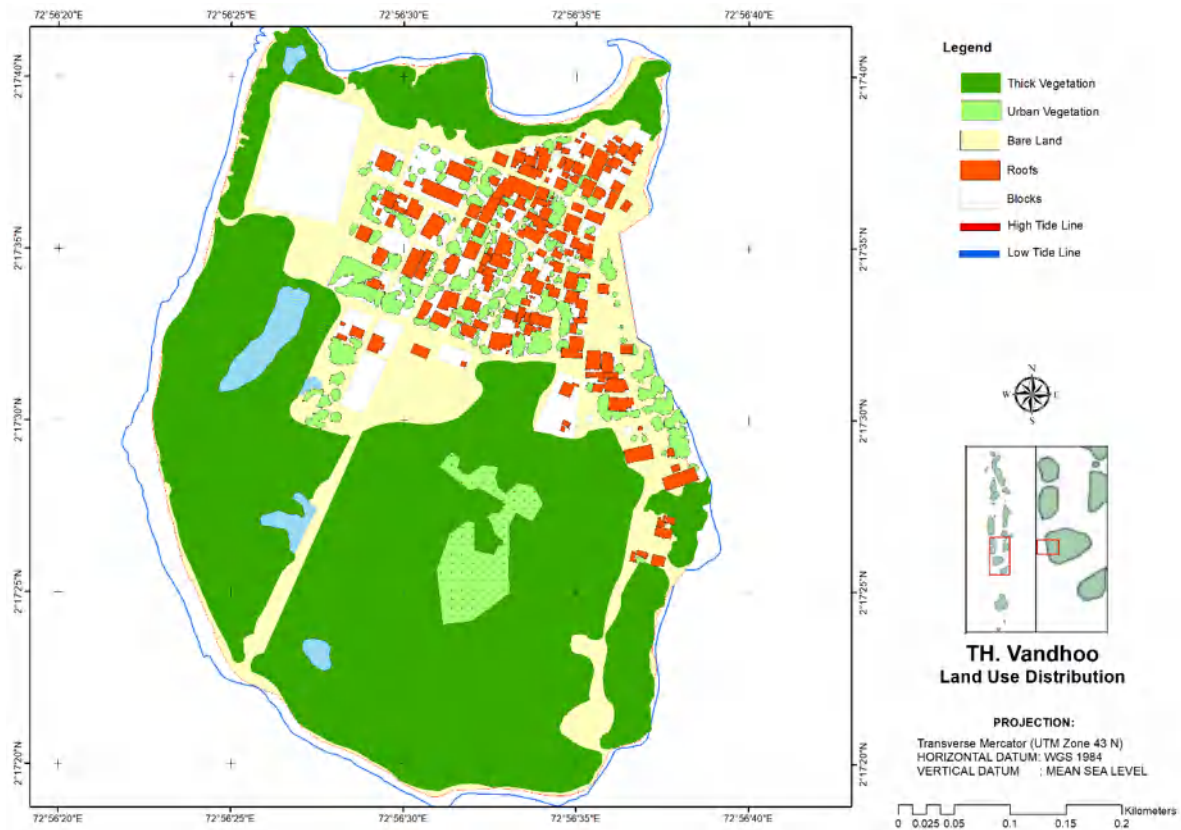


Figure 4-19: Roof Cover in Vandhoo Island based on UAV Survey

4.7.10 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 yards, road surfaces, etc., is not usable as there is no mechanism for its collection and treatment.

4.7.11 Freshwater lens

Based on the Electrical Resistivity (ER) surveys, the depth to groundwater level and the freshwater-saline water interface were determined for a set of transverse transects as shown in Figure 4-2. Plots in show the main two cross-sections of the island. The dotted lines in the plots indicate a simple interpolation of levels to mean sea level in the island boundaries.

Volume of the lens has been calculated with aid of ArcGIS and Surfer Software.

$$\text{Volume of lens} = 208,801 \text{ m}^3$$

$$\text{Groundwater Storage} = \text{Porosity (15\%)} \times \text{Lens volume (m}^3\text{)} = 31,320 \text{ m}^3$$

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented below in Figure 4-20 to Figure 4-22.

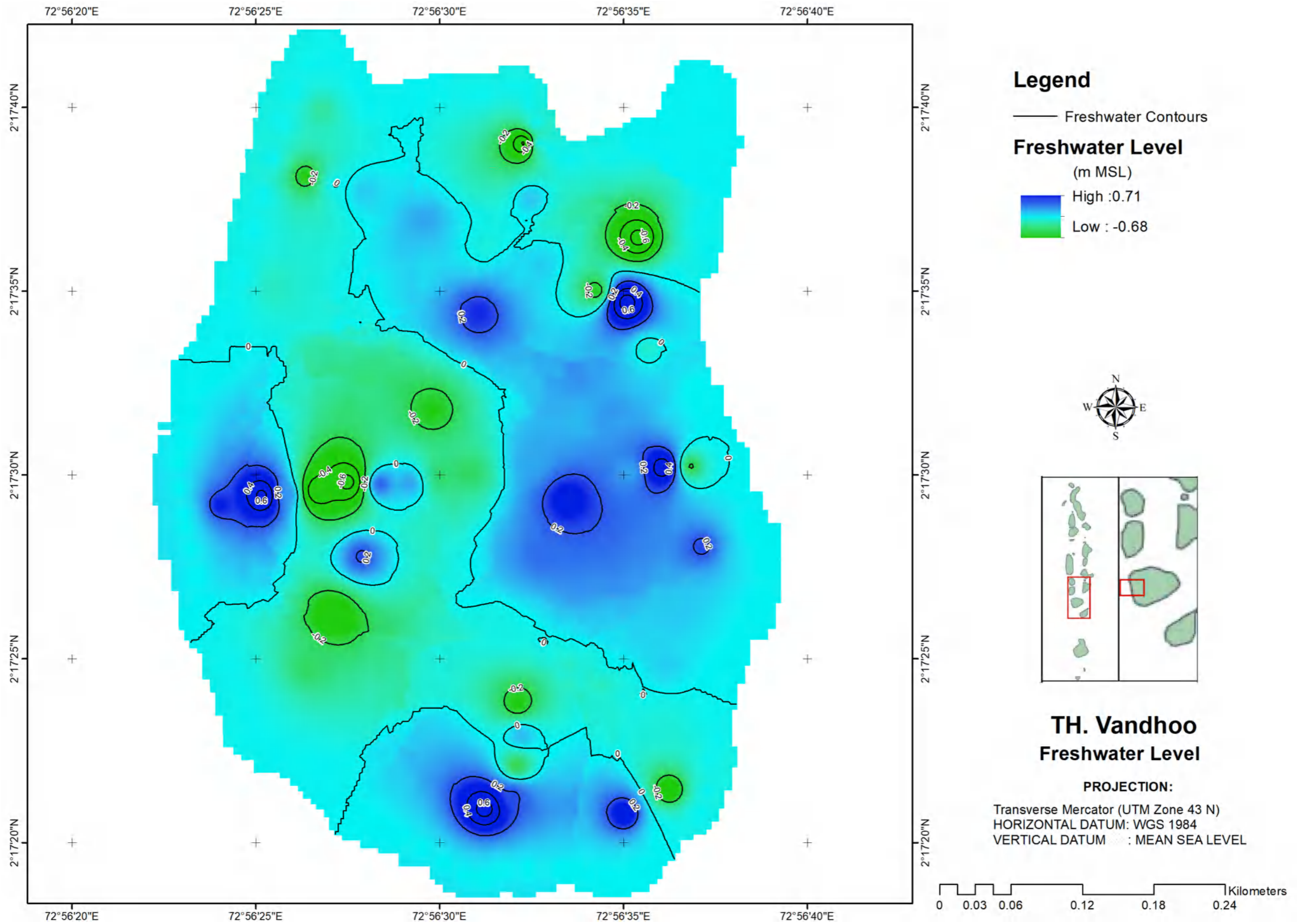


Figure 4-20: Freshwater Level in Vandhoo Island

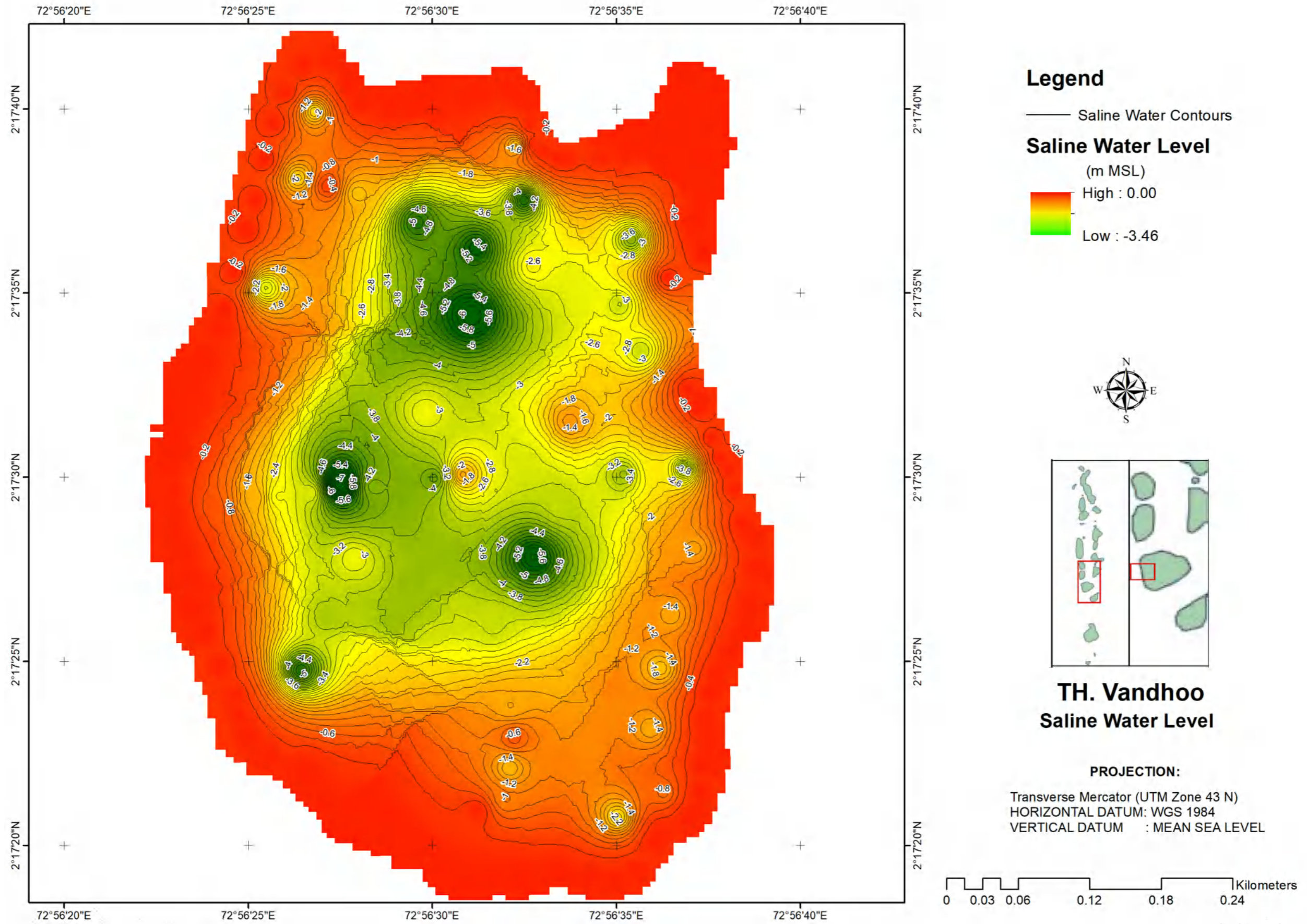


Figure 4-21: Saline water Level in Vandhoo Island

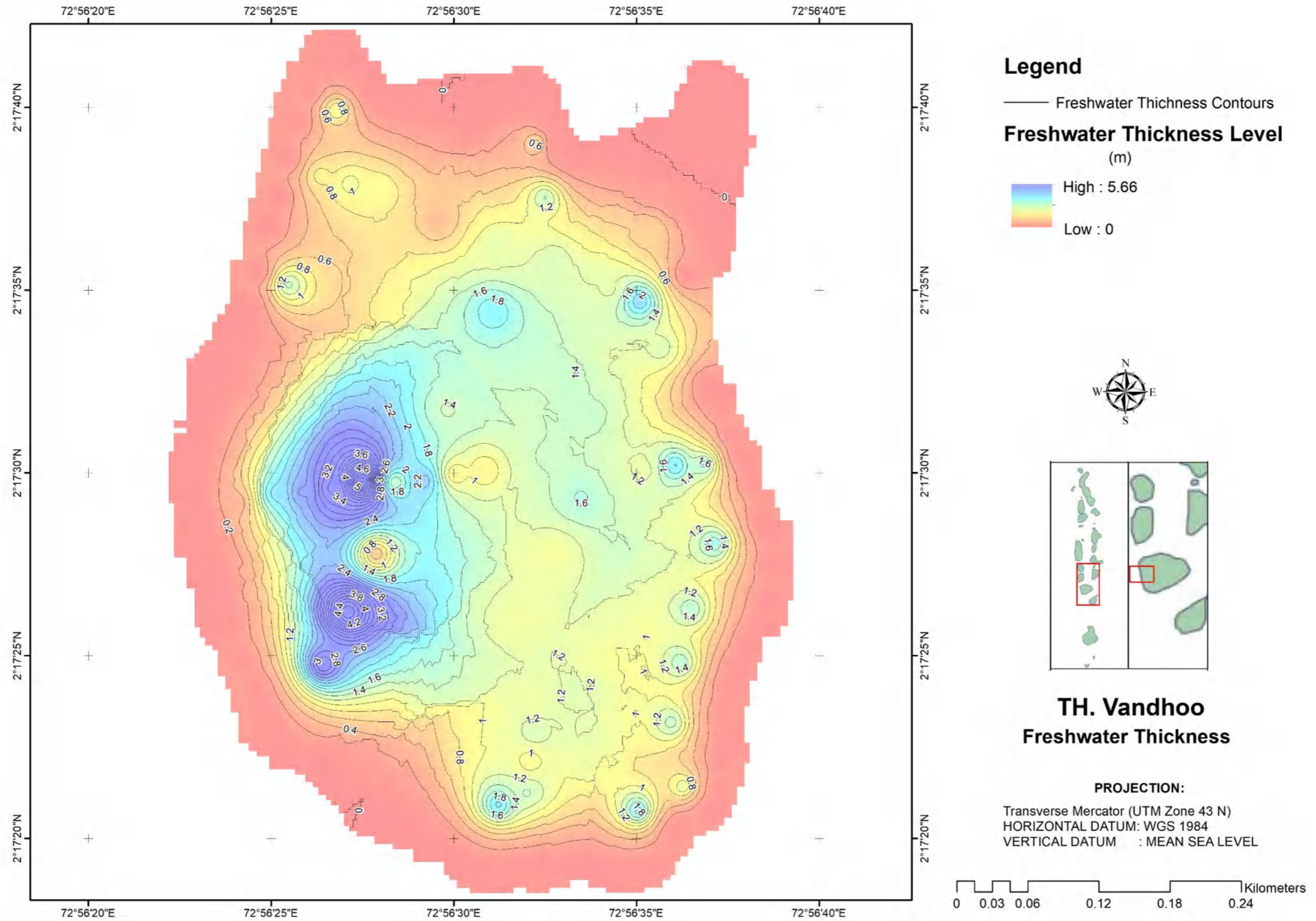


Figure 4-22: Freshwater thickness in Vandhoo Island

The maximum freshwater thickness of the island is 5.67 m (It is noted here that these readings were taken in September/October, which is the wet season and the with a reasonably higher number of wet days per month of the year).

4.7.12 Water balance and recharge

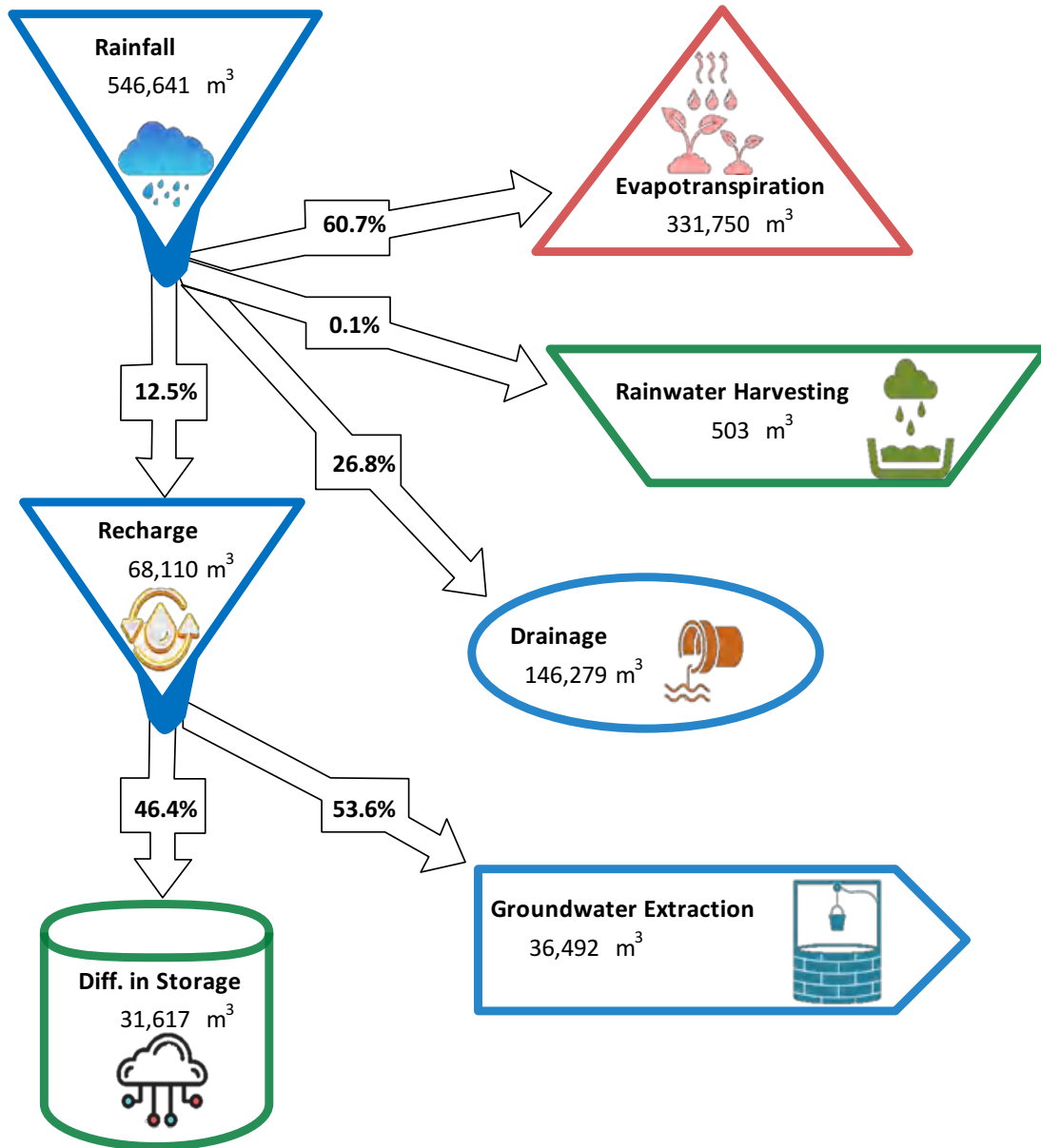


Figure 4-23: Schematic of water balance in Vandhoo Island

An annual estimation is carried out based on the water balance method (Falkland, 2000). Rainwater harvesting is calculated using the number of rainwater harvesting units on the island. According to the spatial mean annual rainfall of the Maldives, the annual average rainfall of Vandhoo Island is reported as 2,175 mm/year. Evapotranspiration was estimated using crop water requirements for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. Drainage or the surface runoff was calculated by considering an aggregate runoff coefficient for the island based on the land usage (roof cover, bare land, farmland, roads, playgrounds, wetlands). 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 the difference in storage.

4.7.13 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 301 m³ per day which was calculated by subtracting groundwater extraction from recharge volume derived from the schematic water balance model in Figure 4-23.

4.7.14 Permeability test

Permeability tests were carried out in the selected locations as outlined in the following Figure 4-24.

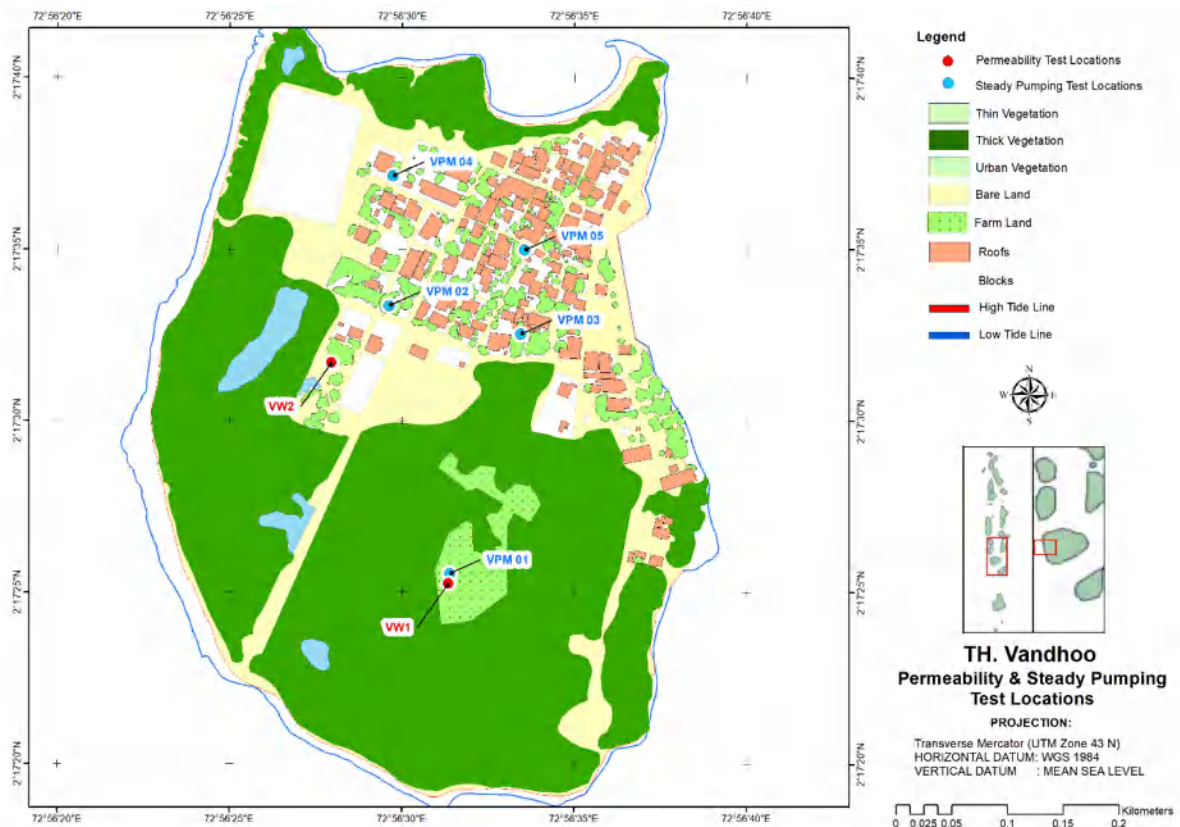


Figure 4-24: Locations of permeability and steady pumping tests in Vandhoo Island

The estimated permeability values for the above test locations are presented below in Table 4.11. The data will be comparatively verified and interpreted when additional data is acquired and calculations for other islands are completed.

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m³/s), H = Height of water in well (m), l = length of the perforated section (m), r_1 = outside radius of the casing (radius of the 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 the casing to water table (m).

Table 4.11: The Estimated Soil Permeability Values in Vandhoo Island

Point	VPM 01	VPM 02	VPM 03	VPM 04	VPM 05
D (m)	0.500	0.500	0.680	0.600	0.550
H (m)	0.500	0.500	0.680	0.600	0.550
l (m)	0.500	0.500	0.680	0.600	0.550
U (m)	0.600	0.600	0.850	0.760	0.750
T _u (m)	0.600	0.600	0.850	0.760	0.750
r (m)	0.076	0.076	0.076	0.076	0.076
Q (m ³ /s)	5.89E-06	9.22E-05	5.67E-06	5.44E-06	1.17E-04
r ₁ (m)	0.076	0.076	0.076	0.076	0.076
r _e (m)	0.010	0.010	0.010	0.010	0.010
T _u /ℓ	1.200	1.200	1.250	1.267	1.364
X = (H/T _u × 100)	83%	83%	80%	79%	73%
Section	Zone 2	Zone 2	Zone 2	Zone 2	Zone 2
ℓ/r _e	48.12	48.12	65.44	57.74	52.93
C _s	73	73	95	90	77
K (m/s)	1.85E-05	2.89E-04	1.03E-05	1.16E-05	2.82E-04
K (m/day)	1.59	24.98	0.89	1.00	24.33

4.7.15 Steady Pumping Test

Pumping tests were conducted in two existing wells to estimate the aquifer properties of unconfined water bearing formation and transmissivity of the water bearing formation was estimated using Muskat's Method.

Table 4.12: Selected Steady State Pumping Test Locations in Vandhoo Island

Well No.	C'	A (m ²)	t' (s)	ln($\frac{s_1}{s_2}$)	T (m ² /s)
VW1	4.3	2.24	2700	3.26	0.0016
VW2	4.0	4.52	4200	3.62	0.0025

The measured transmissivity (m²/s) values ranged from a minimum of 0.0016 m²/s to a maximum of 0.0025 m²/s., with an average of 0.00205 m²/s. During the testing period, EC (Electrical conductivity) of both wells was increased as below.

- For OW 1, EC (Electrical conductivity) increases from 810 µs/cm to 1010 µs/cm.
- For OW 2, EC (Electrical conductivity) increases from 800 µs/cm to 810 µs/cm

4.7.16 Status of groundwater availability in Vandhoo Island

- 1). The selected Vandhoo island has dimensions of width = 500 m and length = 670 m, with a total land area of 25.13 ha, a population of 610 persons, and a land use of Roof cover (Built up area) 1.60 ha (6.4%), Vegetation (Thick) 15.33 ha (61.0%), Vegetation (Light) 1.29 ha (5.1%), and Wetlands (Inland) 5.81 ha (23.1%).
- 2). In order to recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of the freshwater lens (FWL) and its associated recharge-discharge characteristics, 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 while steady-state pumping tests were conducted at 02 locations. In addition, the 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 1.02 m/day to a maximum of 50.92 m/day, with an average of 25.35 ± 18.71 m/day (Mean \pm Standard Deviation).
- 5). The ground elevation values ranged from a minimum of 0.00 m MSL to a maximum of 2.27 m MSL, with an average of 0.71 ± 0.34 m MSL (Mean \pm Standard Deviation).
- 6). The upper boundary of the freshwater lens (FWL) varied from a minimum of -0.68 m MSL to a maximum of 0.71 m MSL, with an average of 0.00 ± 0.11 m MSL (Mean \pm Standard Deviation).
- 7). The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -7.49 m MSL to a maximum of 0.00 m MSL, with an average of -1.67 ± 1.50 m MSL (Mean \pm Standard Deviation).
- 8). Accordingly, the freshwater lens (FWL) volumetric values ranged from a minimum of 0.00 m to a maximum of 5.67 m, with an average of 0.89 ± 0.77 m (Mean \pm Standard Deviation).
- 9). The groundwater profile in the island is characterised by a relatively Low (0.09%) Rainwater Harvesting (%) relatively Low (26.76%) Drainage (%) relatively Very Low (12.46%) Recharge (%) while the water use shows relatively Very High (53.58%) Groundwater extraction (%) leading to relatively Low (46.42%) Difference in Balance Storage (%).
- 10). The freshwater lens (FWL) volume calculated based on ER transect test data is 208,801 m³ with a maximum FWL thickness of 5.67 m and a steady state groundwater storage of 31,320 m³.

4.8 Conclusion

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 301 m³ per day, while it is 150 m³ per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 100 m³ per day and this exceeds the allowable Safe Yield in the island by 115% (moderately stressed). At present, there exists no water supply network island wide and the sewerage network is under construction.

Relative hydraulic condition of the island lies in 'Semi-pervious' state while present aquifer condition remains at 'Poor' – 'Good' state based on the hydraulic conductivity estimation carried out as per Bear (1972) and transmissivity of the formation was compared as per Krany (1993). Moreover, general status based on transmissivity ranged 'High' and potential for groundwater recharge remains 'Low' – 'Moderate' as per the estimations.

5 TH. OMADHOO ISLAND

5.1 General overview of the island

The island of Omadhoo (Figure 5-1) is located on the southern periphery of Thaa Atoll at coordinates 73° 1'28"E and 2° 10'5"N. The island has an area of about 0.4 km² and measures about 0.73 km in width and 1.08 km in length. The population of the island was found to be about 1,157 residents as of December 2021. The island has a harbour on the Northern side of the island. The following table outlines some basic information about the island and the following map outlines the location of Omadhoo.

Table 5.1: Basic statistical information on Omadhoo island in Thaa Atoll.

Name of the island	Th. Omadhoo
Longitude and Latitude	73° 1'28"E, 2° 10'5"N
Area	40.05 ha (0.4 km ²)
Population (Dec 2021)	1,157
Distance from Male'	228 km
Harbour	Present
Island sewerage network	Under Construction
Water supply network	No
Other infrastructure	RO Plant is under tender process

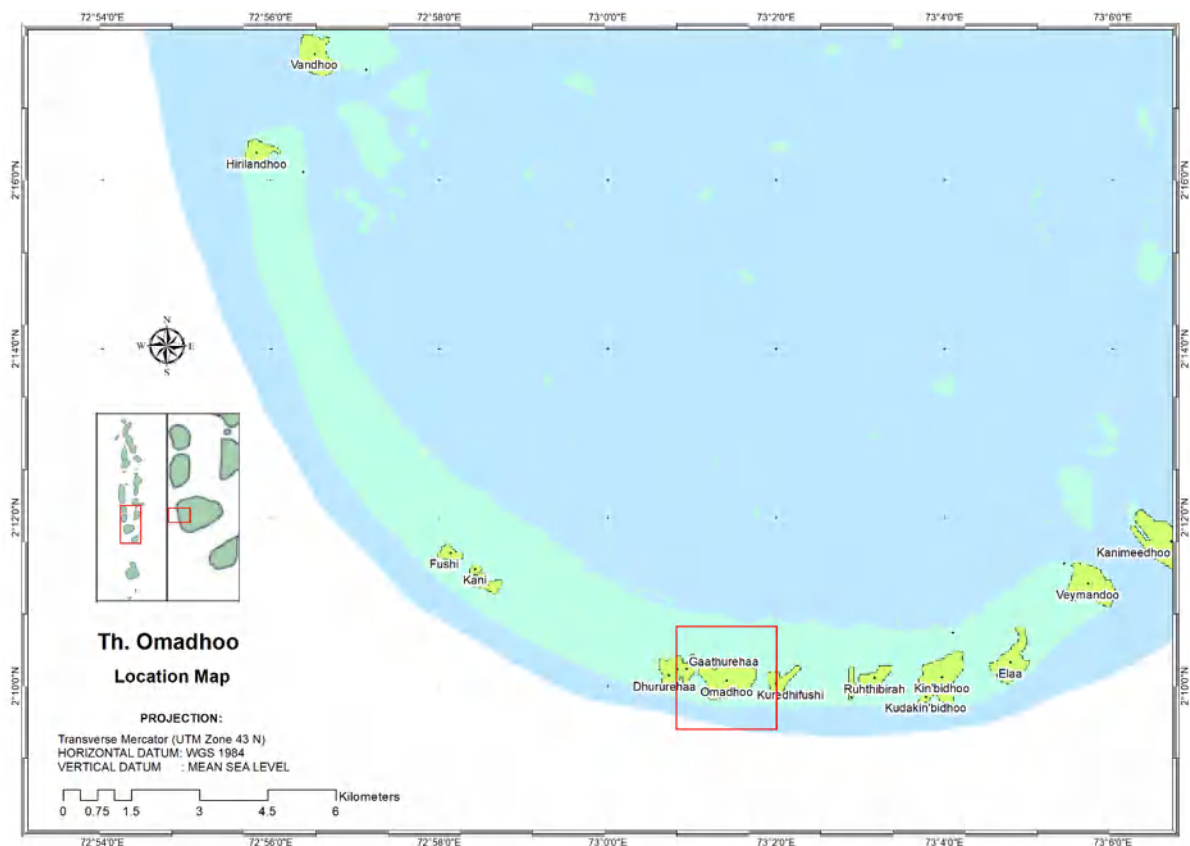


Figure 5-1: Location map for Omadhoo Island, Thaa Atoll.

5.2 Topography and Geology

Omadhoo island is in the South end of the Thaa Atoll. The Omadhoo island is located in the middle of the long E – W trending submerged coral reef which is extending about 25 km. Omadhoo island is roughly T shape and extends about 900 m in length (AB) and about 325 m in width (CD). Here, basic topography and the geological setting is mostly based on the properties of the underground coral beds and actions of ocean waves and currents. The elevation of the island varies from 0 m to 2 m and generally flatland through the island. General geological profile in the island is composed of topsoil and beach coral sand deposits underlain by sandy coral rock. The sandy coral rock consists of a weathered coral rock layer and hard fresh coral rock. From the cross-section A to B show a thin topsoil layer (0-0.5 m) and beach coral sand deposit layer about 0.2 m thickness in beach areas and about 1.0 m thickness in the middle of the island. In beach areas mostly beach coral sand exists as the top layer. Coral sand deposit layer is mostly unconsolidated and permeable layer. Weathered coral rock depth is varying between 0.5m (coastal area) to 2m (middle of the island) from MSL. and it is a semi permeable layer. Fresh groundwater lens occupied both coral sand layer and weathered coral rock. Hard coral layer is mostly unconsolidated and impermeable and present as a fresh rock. As the compositional and structural differences of coral formation, differential weathering could be observed in the cross section A-B. Profile 1 A-B indicates Western part of the island where the weathered coral rock thickness (about 9 m) is high compared to the eastern side (about 4-5 m) of the island. However, in the cross-section C-D in the island, it shows a uniform weathering and the general trend in the central part of the island shows a higher weathering compared to the coastal area. However, A-B cross section clearly shows several deep weathered zones in the eastern part of the island.

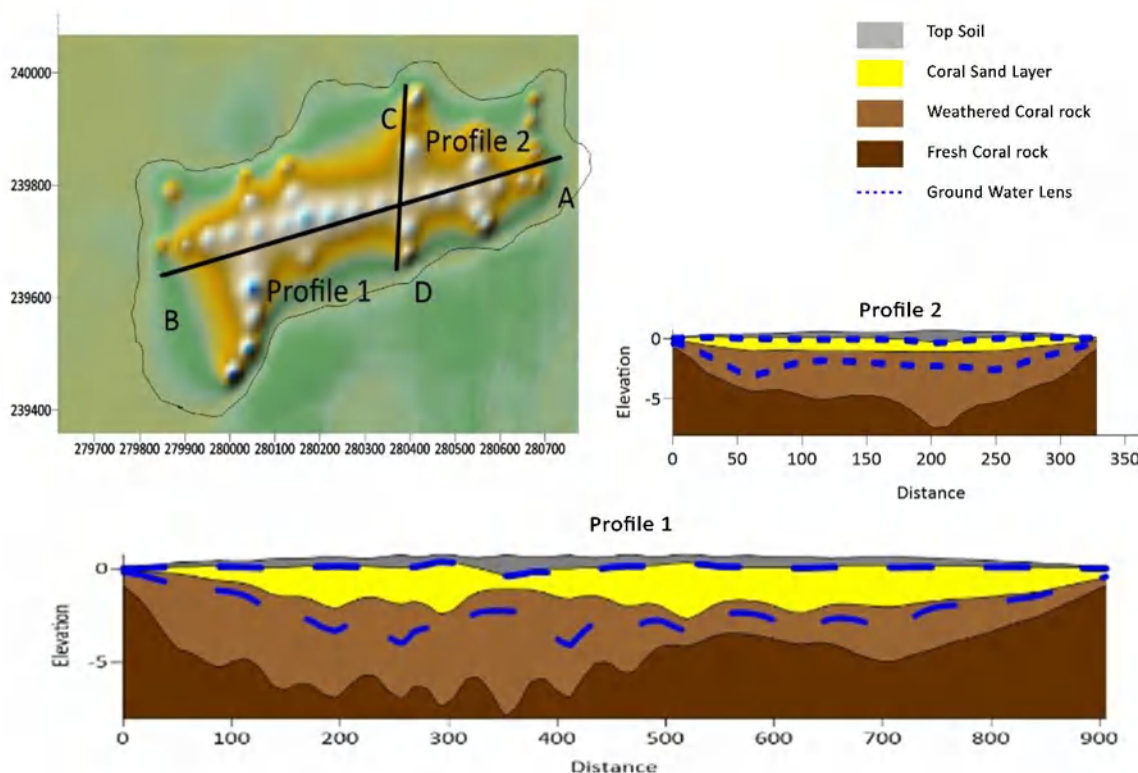


Figure 5-2: Geological sections of the island showing subsurface geological characteristics

5.3 Climate

Omadhoo experiences the typical two monsoons in the Maldives namely, the North-east monsoon from December/January to March/April and the South-west monsoon from Mid-May to November. There are no specific wind and rainfall data available for Omadhoo as there are no weather monitoring stations on the island itself. Based on the rainfall data of the nearest weather monitoring station, it shows a declining trend in rainfall for the past 30 years (Inception Report, 2021).

The historical rainfall data records from Kadhdhoo Island (not included in the 6 selected islands in Lot 2) located in the Laamu atoll (66 km to the southeast from Omadhoo Island) has an annual average rainfall of 2,242 mm with a standard deviation of 370.4 mm and the trend and the decadal means were shown in the following graph. (MEE, 2021).

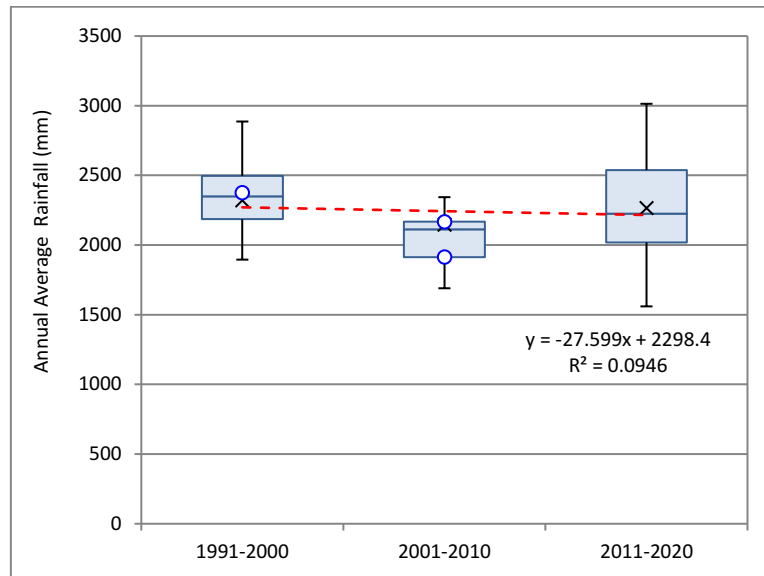


Figure 5-3: Decadal means and trend for rainfall in Kadhdhoo (1990 - 2020).

5.4 Demography

The total registered population of the island is reported by the island council as 1,157 at present, with 578 males and 579 females. The resident population of Omadhoo is not available at the preparation of this report. The following Table 5.2 shows the population breakdown for Omadhoo.

Table 5.2: Demographic Breakdown of Omadhoo Island as of December 2021

Registered Population (locals)		
Both	Male	Female
1157	581	579

5.5 Socio-economic condition

5.5.1 Natural resources and land uses

Th. Omadhoo has an area of 40.05 ha of which approximately 54% is occupied. There is no formal land use plan though one is being prepared at present. The island council now has the authority to allocate lands for different purposes with an approved land use plan.



Figure 5-4: Summary of household and socio-economic activities

5.5.2 Economic Activities

The main economic activity of the island is fisheries with an approximate number of 25 people involved in the sector. Additional economic activities include employment in different areas of the civil service sector and tourism sector, businesses and construction / carpentry industries.

5.5.3 Accessibility and Transport

The only direct mean of access to the island is via sea transport by speed boats or Dhonis'. It can be private hire or by ferries. Other means of transport is via air to the domestic airport at Thimarafushi of the same atoll and launch transfer from the airport to Omadhoo.

A harbour with quay walls located at the Northern side of the island is used to access the island. It was noted that after the construction of the harbour, the rate of erosion increased. The island experience severe erosion and coastal protection measures are under way to reduce the rate of erosion and its impact on the island.

5.5.4 Services and Infrastructures

The island is equipped with the basic services and supporting infrastructures.

5.5.4.1 Public Facilities and Amenities

The public facilities available in the island include:

- Power House
- Health Center
- Preschool
- Primary/Secondary School
- Mosques
- Government institutions (Office for Island Council, Island Court)
- Postal service
- Cable TV

5.5.4.2 Water supply

Currently, rainwater is used for drinking and cooking when needed, although bottled water sourced from Male' is also used. Groundwater is used for other purposes such as bathing and washing. This is further discussed in Section 5.6 and 5.7.

5.5.4.3 Energy supply

The island community has access to power 24 hours a day.

5.5.4.4 Waste and Wastewater disposal

Solid Waste: They do not have a waste management plan yet though a plan is under formulation. Currently, all HHs are required to take the waste to the waste dumping area. Within the area, all waste is segregated and managed by a group hired by the island council. They have a different area proposed for the waste management center but no ground works have been done yet.

Sewage Disposal: Main method of sewerage disposal at Omadhoo is by means of septic tanks. Each household has a septic tank within close proximity and is infiltrated into the ground. There are a couple of households which use pipes as waste outlets through a septic tank system from where the effluent is disposed to sea. This is further discussed in Section 5.6.

5.5.5 Sites with historical significance and cultural interests

The “*Hukuru Miskiy*” and “*Kuda miskiy*” on the island are 2 of the historical sites, in addition to the island cemetery.

5.6 Existing Water and Sanitation Situation

5.6.1 Water

Groundwater is the main source of water for all uses except drinking and cooking. The groundwater quality of the island is observed to be in bad condition in all areas of the island. It was noted that the groundwater is mainly affected due to the current sewage management practices. Discolouration and odour indicate the pollution level.

Currently, the island does not have piped drinking water system though it is being established.

Rainwater and bottled water are mainly used for drinking and cooking. Rainwater is harvested at both the household level and island level. At the household level, each household has at least one water tank with a capacity of 2,500 L. The council have established 10 community tanks of 5,000L for rainwater harvesting. All tanks are used by the community.

The general practice of rainwater harvesting at the island level is to clean the roofs thoroughly and letting the first flush pass to the roads which would eventually seep into the ground. Excess rainwater is also discharged to the roads in a similar manner. This sometimes causes flooding as well.

The establishment of an RO Plant is under tender process.

5.6.2 Wastewater and Sewage Disposal

A sewerage system with pump stations and a proper outfall has been installed in Omadhoo since 2020 although the service has not been started due to some technical issues. It was informed by the council that the utility company, STELCO will be starting to provide the service soon.

Currently, the main method of sewerage disposal at Omadhoo is by means of septic tanks. Each household has a septic tank within close proximity and is infiltrated into the ground. There are a couple of households which uses pipes as waste outlets through a septic tank system from where the effluent is disposed to the sea.

Once they start to use the new sewerage facility the existing system will be abandoned. The septic tank inflows from the pipes will be ceased by disconnecting the inflow pipes. The remaining sludge in the pipes and septic tanks will then be removed by sewer jetting and released to the sea via outfall pipe.

5.7 Results of the Baseline Surveys: Water Usage

5.7.1 Summary of socio-economic surveys

As detailed in the methodology section of this report, a social survey was carried out to determine the water usage at households (HHs), commercial entities (cafés/restaurants), institutions and places with industrial uses (agricultural lands, fish processing). The survey was carried out from 18th May to 20th May 2021 with the help of local enumerators. The following Table 5.3: summarizes samples taken for each sector at a 95% confidence interval and the total number of completed surveys for each.

Table 5.3: Population and Sample taken for the social survey

Categories	Population	Sample	Forms Completed
Households	115	89	94
Farmers	3	3	2
Fishermen	24	23	0
Fish Processing	22	21	9
Institutions	4	4	2
Guest houses	0	0	0
Café/Restaurants	2	2	2

Note: A number of mitigation measures were adopted to ensure to achieve the 95% confidence level sample size. The challenges and limitations and the measures undertaken to mitigate the challenges are listed in Section 1.4.3.3.

The key findings from this survey show that a total of 500.7 liters of groundwater are estimated to be used per capita per day for various domestic uses. The respective water use situations including domestic, commercial and institutional uses are illustrated in the following sections.

5.7.2 Water usage for domestic purposes

5.7.2.1 Domestic Water Usage

A household survey was carried out at a 95% confidence interval. A total of 98 HHs were surveyed of which 94HHs responded. As presented in Table 5.3.; 84% of HHs have at least one of 2,500 L capacity HDPE rainwater tanks at their homes to collect rainwater for daily uses. Among the 94 HHs, 56% uses rainwater for drinking while 97% also uses it for cooking.

Groundwater is mainly used for non-potable use in all the households surveyed.

Table 5.4: Groundwater and rainwater use data for Omadhoo

Rainwater	Per cent (%)
Households with rainwater tanks	84%
Rainwater use for drinking	56%
Rainwater use for cooking	97%
Groundwater	Per cent (%)
Groundwater as a drinking source	3%
Groundwater for cooking	22%
Groundwater for non-potable use	93%
Total number of household wells surveyed	94
Percentage of wells surveyed fitted with pumps	98%

Based on the survey carried out, the average daily groundwater demand per capita for domestic non-potable 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 5.5:. The total domestic groundwater use is estimated to be 369.28 liters per capita per day.

Table 5.5: Domestic Ground Water Usage in Omadhoo

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
99.4	45.0	18.0	136.0	298.4

5.7.2.2 Perception on Groundwater

The HHs were also asked about their perception on groundwater, if it is safe to use for daily purposes and whether the quality of groundwater is good or bad.

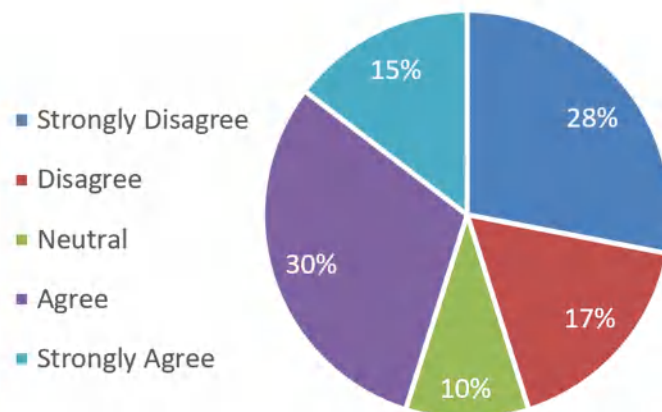


Figure 5-5: Perception of HHs of Th Omadhoo on safety of Groundwater

As it can be seen from Figure 5-5, while a total of 45% agreed that groundwater of Omadhoo is safe to use for non-potable uses the other 45% disagreed that groundwater is safe and 10% noted it as neutral.

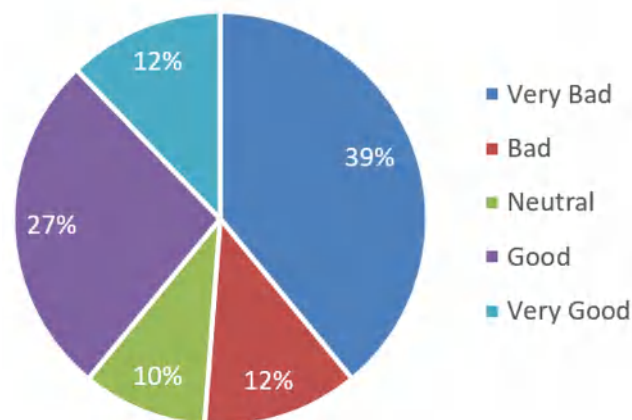


Figure 5-6: Perception of HHs of Th. Omadhoo on quality of groundwater

Furthermore, the HHs were asked about the quality of groundwater with regard to their experience. A total of 51% of the respondents said the quality is bad among which 39% considered it as very bad

quality. Similarly, another 39% considers the quality of water they use as good of which 12% thinks it is very good. The varying opinion on groundwater quality is because in Omadhoo, in different parts of the island water quality is different. During the consultations with the island council, it was noted that the quality is really bad and the main reason for groundwater contamination is the mismanagement of sewage. It was noted that the practice of using septic tanks and sewage infiltration to the ground is having a huge negative impact on the groundwater quality.

5.7.3 Water Usage by Commercial Activities

Omadhoo has 2 cafés. The 2 cafés were surveyed. There were no guesthouses.

The table below presents a summary of water usage by the cafés.

Table 5.6: Water Usage by commercial activities in Omadhoo

Cafés	Total Volume of water per day (Liters)
1	863
2	45

For the cafés, while 1 café used groundwater for all purposes, the other café used it dishwashing and cleaning. From the total 2 cafés that were surveyed, the total groundwater consumption for these Cafés was estimated to be 908 liters.

5.7.4 Water Usage by Institutions

Based on the survey carried out to collect data on water consumption by institutions, although the island has four places that can be considered as institutions which are in the island, i.e. powerhouse, island court, school and health center, response was received only from the powerhouse and school.

As per the respondents, groundwater in the institutions in Omadhoo are mainly used for mopping floors, flushing toilets and to some extent gardening. A total of approximately 4,467 liters of groundwater are estimated to be used per day by the institutions. As the use of each institution is different, to generalize the water consumption of institutions to an average figure may not be accurate in this situation as well. However, it can be deduced that based on the data, 93.06 liters of groundwater are estimated to be used per staff per day at the institutions of Omadhoo (Table 5.7).

Table 5.7 Water Usage by commercial activities in Omadhoo

	Water Flushed(Liters)	Gardening(Liters)	Mopping(Liters)	Sub-Total Water Used (Liters)	Total Water Used (Liters)	Institutional Groundwater Usage (Liters Per Staff Per Day)
Power House	192	1,227	10	1,429	4,467	93.06
School	384	2,454	200	3,038		

5.7.5 Water Usage for Farming

A total of 2 out of the 3 farmers participated in the survey. Farmers mainly use groundwater for watering the plants. 100% of the surveyed farmers use groundwater extracted from wells using pumps to water their plants. Table 5.8: below summarizes the water usage to water the plants every day.

Table 5.8: Water Usage by Farmers in Omadhoo

Farmlands	Area of farmland	Volume of water used per day (Liters)	Total volume of water used per day (Liters) per sqft
1	5,000	1,227	0.25
2	NA	50	NA
Total		1,277	

From the total two (2) farmers that were surveyed, a total of approximately 1,277 liters of groundwater is estimated to be used per day by the farmers. However, due to missing data, an average usage of water per sqft cannot be determined. As per the finding, 1 farmer uses 0.25 liters per day per sqft in Omadhoo to water his farmland.

5.7.6 Water Usage for Fisheries Activities

In Omadhoo, we were only able to survey the fish processing groups. They commonly use groundwater for cleaning or gutting of fish. Rainwater is used for the cooking of fish. Out of the 22 registered fish processors in the list provided by the Council, only 11 were active at the time of data collection.

Table 5.9: Water Usage by Fisheries activities in Omadhoo

Fishing Processors	Total Volume of groundwater used per day (Liters)
1	1,780
2	1,755
3	2,680
4	2,620
5	1,140
6	8,360
7	2,620
8	2,590
9	6,503
Total	30,048

As per the findings, a total of approximately 30,048 liters of groundwater are estimated to be used per day for fish processing. As this is not a statistically significant sample, a generalization of water usage per unit of fish processing cannot be deduced from the findings. Hence, water usage per unit is presented in Table 5.9.

5.7.7 Groundwater quality

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

The following Table 5.10 summarizes the water quality results.

Table 5.10: Summary of groundwater quality tests from Omadhoo Island in 2021

Sample No	EC (µS/cm)	pH	Turbidity (NTU)	DO (ppm)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
Samples in Residential Areas											
O1	529.70	7.40	0.00	2.52	28	0.25	0.70	0.25	0.15		
O3	598.50	7.21	0.13	1.99	28	0.29	8.80	0.51	0.12		
O4	566.60	7.20	0.00	2.63	28	0.27	6.60	0.18	0.60		
O5	499.10	7.82	0.00	5.41	28	0.24	19.20	0.16	0.15	2420	24
O6	626.60	8.07	0.05	5.24	28	0.30	0.60	0.08	0.25		
O7	675.50	7.38	1.82	3.04	28	0.33	1.20	0.14	0.31		
O8	534.00	7.22	3.19	1.86	28	0.26	1.10	0.21	0.33		
O9	530.20	7.30	0.19	1.91	28	0.25	1.60	0.14	0.21	1733	37
O10	497.70	7.51	0.00	1.41	28	0.24	5.30	0.09	0.29	2420	58
O11	717.40	7.56	0.45	1.78	28	0.35	14.70	8.25	0.14		
O12	574.70	7.28	0.00	1.99	28	0.28	3.80	0.04	0.34		
O13	667.40	7.66	0.00	2.55	28	0.32	0.80	0.23	0.48		
O14	636.70	7.37	0.12	1.69	28	0.31	4.70	0.23	0.17		
O15	716.80	7.70	3.92	2.79	28	0.35	0.50	0.14	0.55		
O16	230.20	7.77	0.00	3.73	28	0.11	2.60	0.13	0.16	2420	236
O17	323.40	7.85	0.00	3.89	28	0.15	0.50	0.43	0.17		
O18	394.00	7.58	0.00	2.39	28	0.19	0.80	0.13	0.05		
O19	351.70	7.91	0.00	3.09	28	0.17	1.00	0.14	0.17	2420	2
O20	787.60	7.30	0.23	1.53	28	0.38	18.20	0.17	0.13	1986	6
O21	414.60	7.60	0.00	2.69	28	0.20	0.50	0.08	0.11		
O22	672.90		1.34	1.74	28	0.32					
O26	562.30	7.72	0.00	6.43	28	0.27	0.70	0.20	0.07	488	64
O27	450.00	7.53	0.00	2.69	28	0.21	0.90	0.02	0.80		
O28	562.00	7.35	5.14	0.86	28	0.27	0.90	0.15	0.12	435	44
O30	675.30	7.70	0.05	6.18	28	0.33	12.10	0.11	0.39		
O31	328.30	7.78	0.00	5.27	28	0.15	0.40	0.11	0.06		
O32	315.00	7.48	0.00	4.67	28	0.15	0.80	0.14	0.35		
O33	646.30	7.36	0.00	1.74	28	0.31	1.30	0.23	0.15		
O34	313.50	7.69	0.00	2.53	28	0.15	9.80	0.16	0.36	2420	144
O35	643.60	7.10	0.00	2.54	28	0.31	43.40	0.10	0.84	2420	2420
O36	432.30	8.10	0.20	9.05	28	0.21	6.10	0.07	0.14		
O37	327.60	7.26	0.00	2.41	28	0.15	1.10	0.86	0.05	2420	2420
O38	534.60	7.31	0.00	2.37	28	0.26	1.70	0.20	0.29		
O39	414.40	7.95	0.00	4.36	28	0.20	0.50	0.13	0.24		
O40	342.40	8.98	0.21	9.39	28	0.16	3.00	0.11	0.55		

Sample No	EC ($\mu\text{S/cm}$)	pH	Turbidity (NTU)	DO (ppm)	Temp ($^{\circ}\text{C}$)	Salinity (PSU)	Nitrates (mg/L)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
Samples in Industrial Areas											
O2	1060.20	7.10	0.00	6.62	28	0.52	1.30	0.55	0.08	>2420	687
Samples in Other Areas											
O29	531.60	7.57	0.00	3.20	28	0.25	0.80	0.13	0.11	2420	40
O23	262.40	7.68	0.00	5.34	28	0.12	0.80	0.15	0.05	1986	249
O24	292.80	7.66	0.00	6.36	28	0.14	1.50	0.43	0.10		
O25	726.00	7.74	0.00	5.05	28	0.35	0.90	0.26	0.06		

Based on the full results and the summary shown in Table 5.10, the following can be summarized for Omadhoo Island:

- The EC of the groundwater is generally low, with an average of 524.15 $\mu\text{S/cm}$ which is below an acceptable limit for potable water of 1500 $\mu\text{S/cm}$. The electrical conductivity readings range from 230.2 to 1,060.2 $\mu\text{S/cm}$. All the samples fall within the acceptable limit.
- The pH of groundwater ranged from 7.1 to 8.98 with an average of 7.58. The pH values of all samples were within the WHO permissible limits of 6.5-8.5.
- Turbidity ranged from the lowest of 0 NTU to 5.14 NTU with an average of 0.43 NTU.
- Dissolved oxygen levels were low to moderate, with values varying from 0.862 mg/L to 9.386 mg/L with an average of 3.57 mg/L.
- The salinity of groundwater ranged from 0.11 PSU to 0.52 PSU with an average of 0.25 PSU. Salinity is expressed in Practical Salinity Units (PSU) which is equivalent to PPT.
- The average Nitrate concentration was 4.65 mg/L and therefore it does not exceed the WHO guideline limit of 5.09 mg/L. But 10 of the 39 tested water samples exceeded this limit of 5.09 mg/L. The Nitrate concentrations ranged from 0.4 mg/L to 43.4 mg/L.
- Ammonia concentrations were generally low. The average ammonia concentration was 0.78 mg/L. This is within the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. Only 1 of the tested water samples exceeded this limit (ranged from 0.02 to 8.25 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 were within the range 0.05-0.84 mg/L with an average of 0.25 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). There were 7 samples tested below 0.1 mg/L.
- Total coliform levels were also found to be significant and ranged from the lowest count of 435 MPN/100 mL to the highest count of more than 2420 MPN/100 mL, with an average count of 2029.14 MPN/100 mL. Faecal Coliform levels were found to be less significant and ranged from the lowest count of 2 MPN/100 mL to the highest count of 2420 MPN/100 mL.

EC values of the selected wells were collected at the start of wet period (September – October) and following table show the summary of all the result collected during dry and wet periods based on the land use distribution.

Table 5.11: Comparison of WQ results based on land usage

Land Use	Number of samples	Results are lined with conditions	Enrichment of measured parameters	Remark
Residential area	53	50	O3, O11, and O37	Enrichment of Ammonia in three wells are due to anthropogenic activities.
Industrial area	1	0	O2	Enrichment of Ammonia is due to anthropogenic activities.
Fish huts	7	6	OW 13	OW13-Enrichment of EC due to higher groundwater extraction from thin fresh water lens.
Total	61	56	5	

Considered desirable water quality limits:

- 1) EC < 2500 $\mu\text{s}/\text{cm}$ (water could be used for potable and non-potable use depending of EC).
- 2) Nitrate (<50 mg/l), Phosphate (<5 mg/l), and ammonia (<0.5 mg/l) as per WHO guideline.

Four (4) samples (O2, O3, O11, and O37) out of 53 analysed samples in residential area has recorded higher concentration of ammonia in groundwater. The enrichment of ammonia could be due to contamination of sewerage into groundwater.

An area close to sampling point (OW13) at fish hut area has recorded high EC and it could be due to higher groundwater extraction.

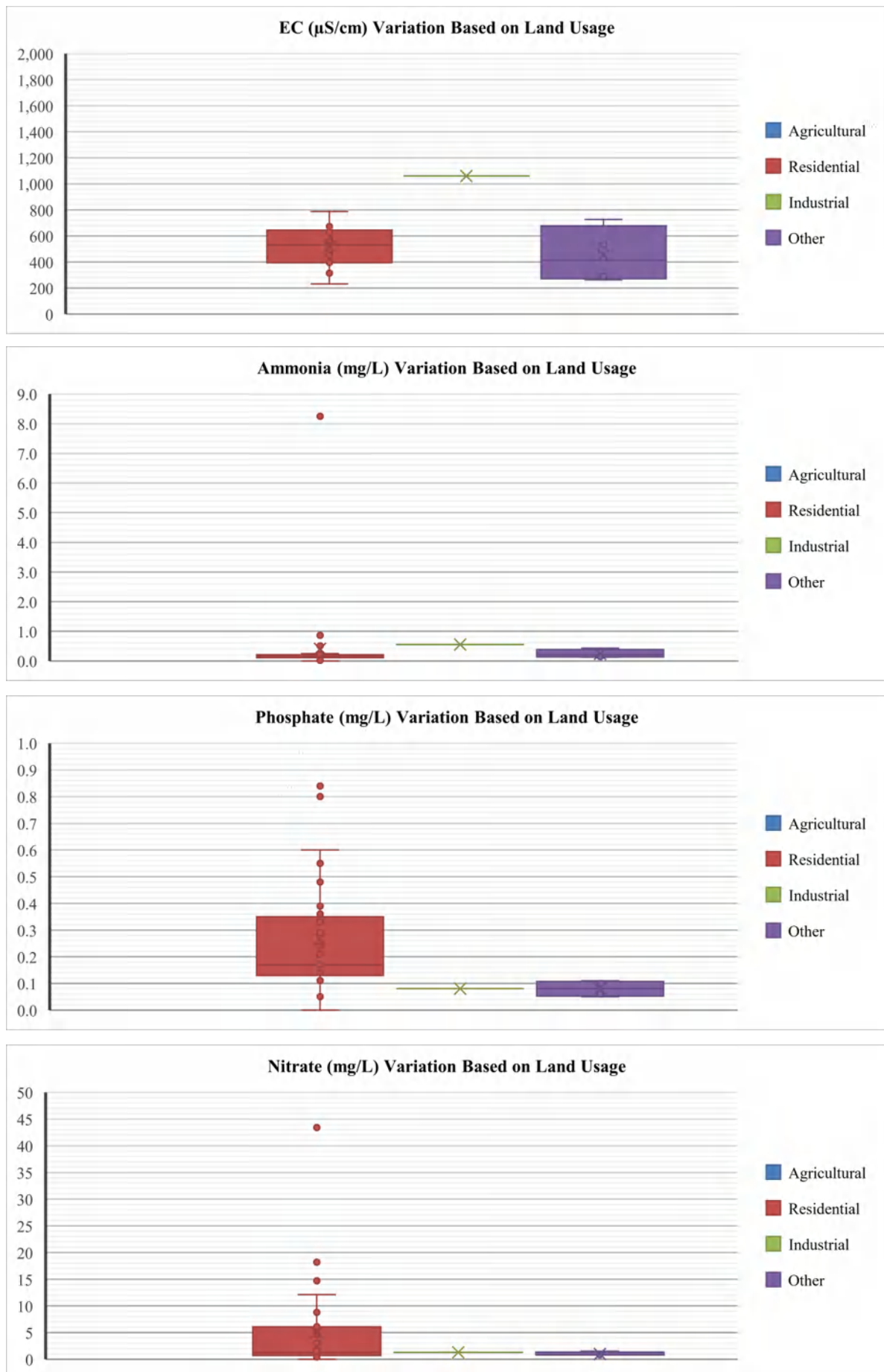


Figure 5-7: Variation of measured WQ parameters in Omadhoo Island

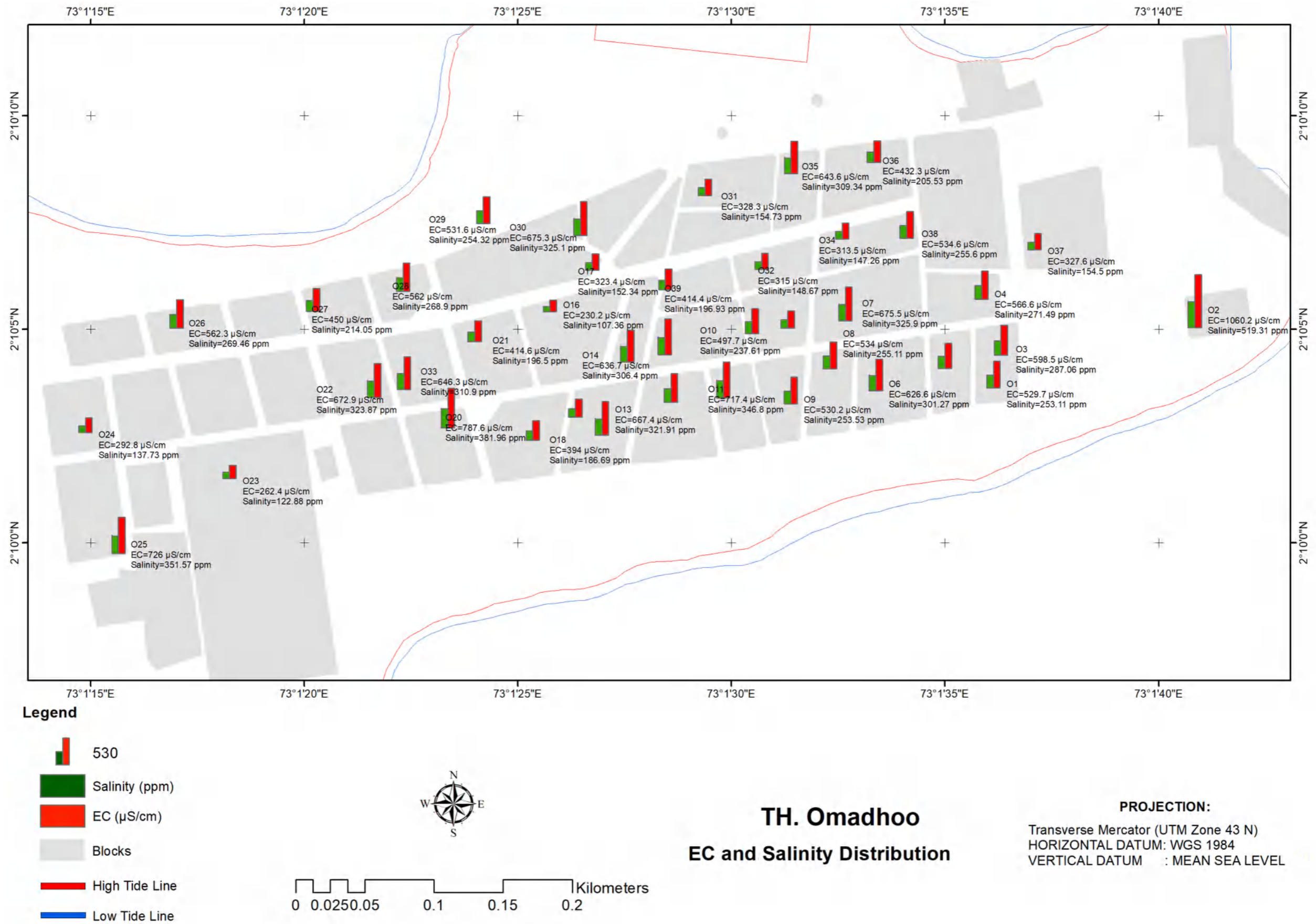


Figure 5-10: EC and Salinity Distribution in Th. Omadhoo Island

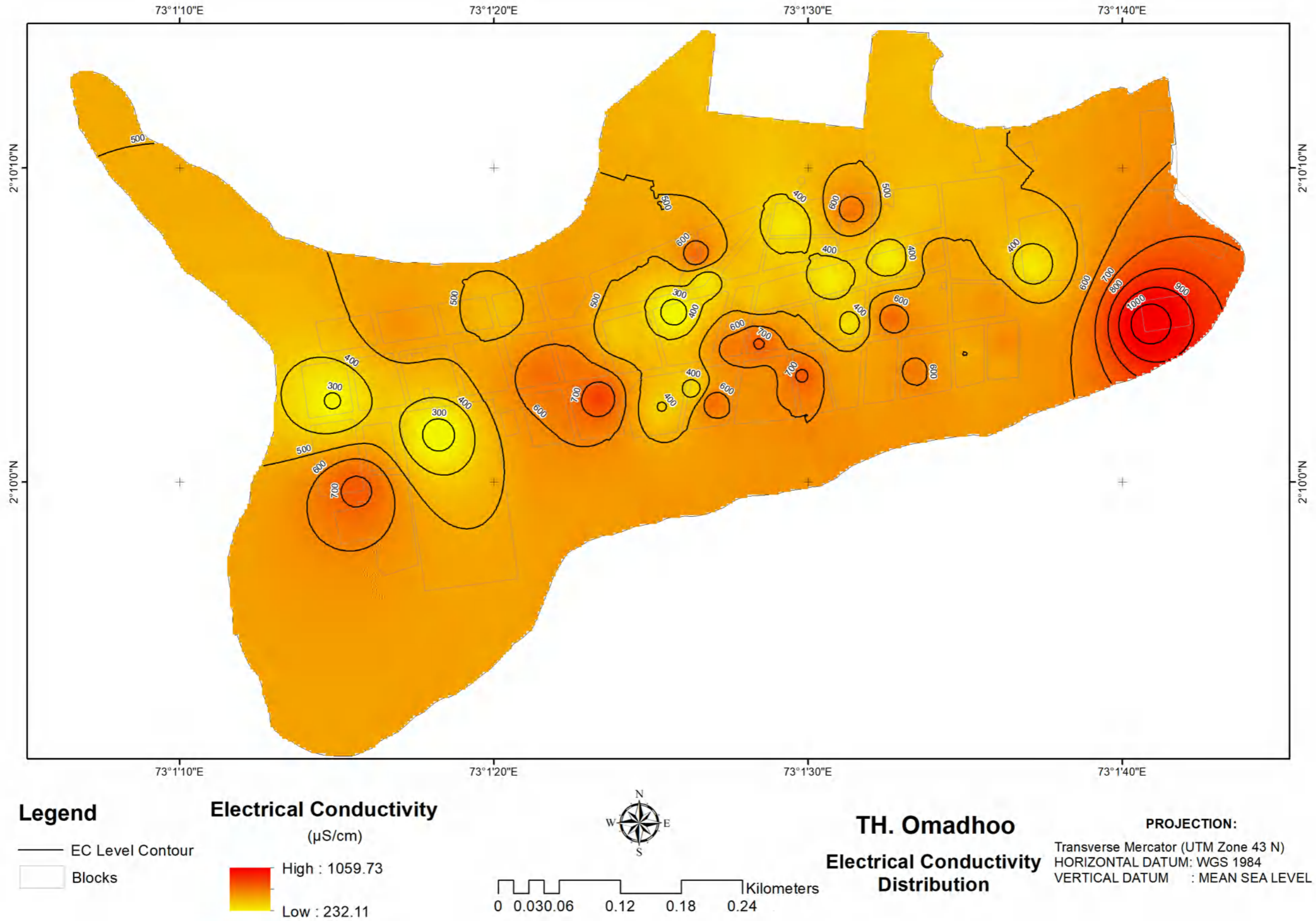


Figure 5-11: EC Distribution in Th. Omadhoo Island

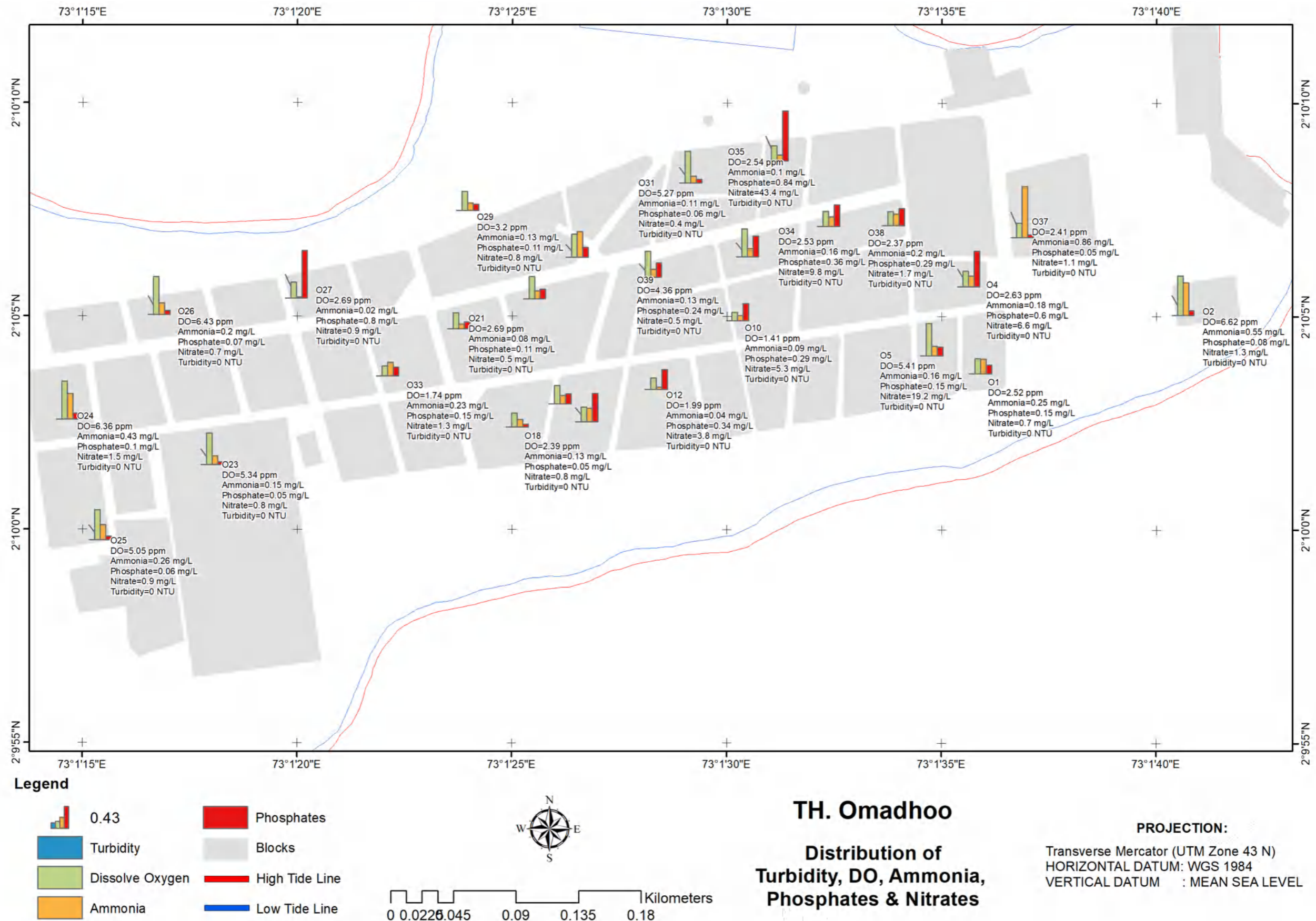


Figure 5-12: Distribution of Turbidity, DO, Ammonia, Phosphates and Nitrates in Th. Omadhoo Island

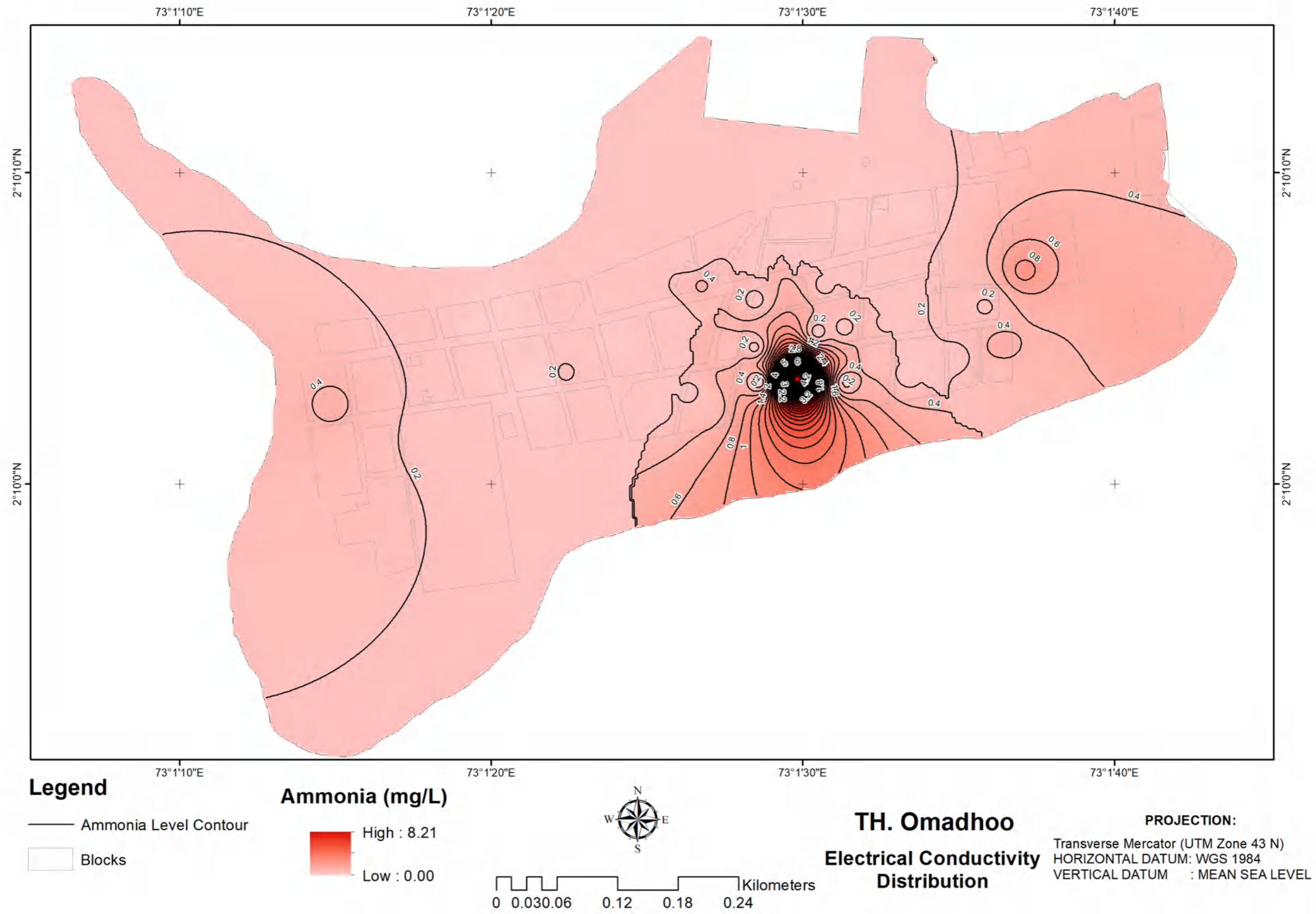


Figure 5-13: Ammonia Level Distribution in Th. Omadhoo Island

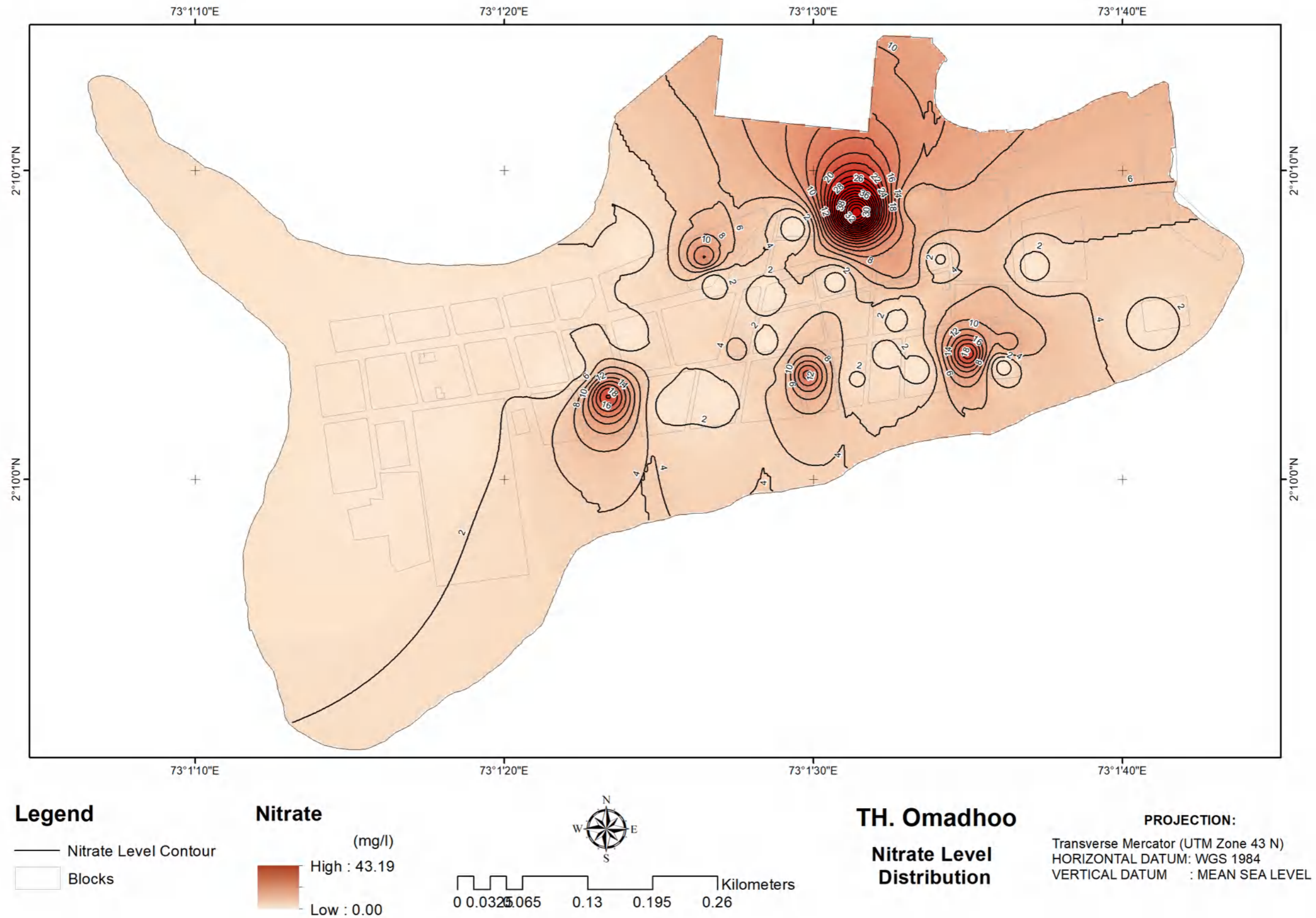


Figure 5-14: Nitrates Level Distribution in Th. Omadhoo Island

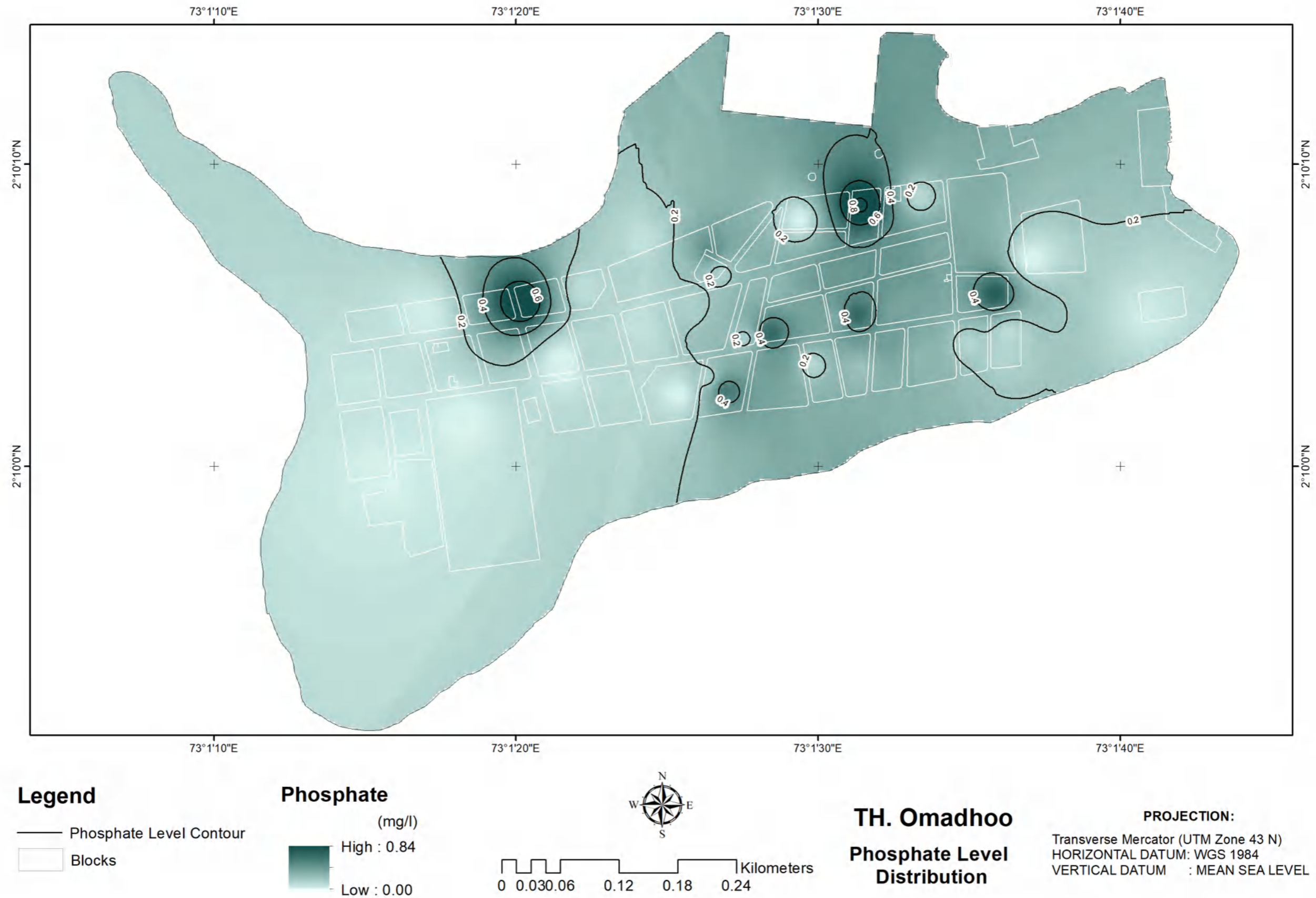


Figure 5-15: Phosphates Level Distribution in Th. Omadhoo Island

5.7.8 Geophysical survey

The Electrical Resistivity (ER) tests were carried out in the locations as outlined in Figure 5-16 below. The ER survey included test points along 9 transects selected representatively based on reconnaissance surveys to adequately characterise different land uses and island cross-sections. The main transects were aligned along existing roads to maintain consistency and uniformity.

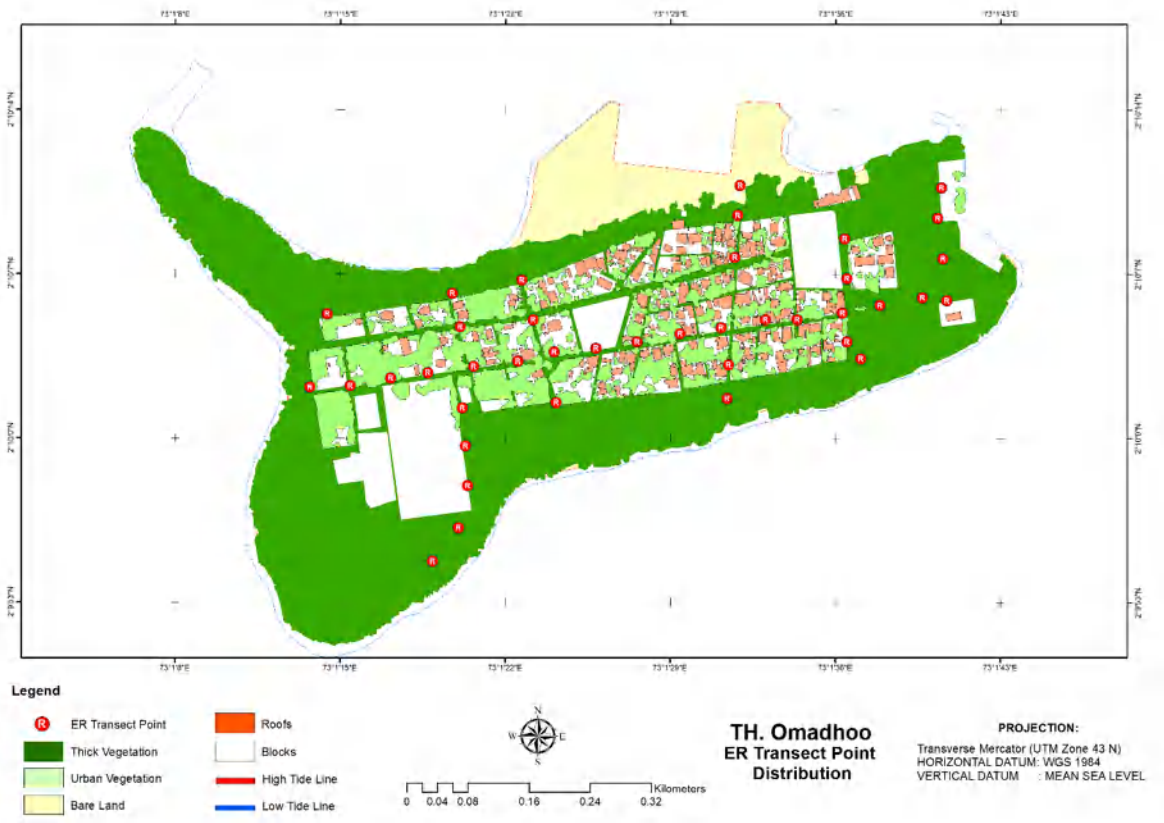


Figure 5-16: Location of ER points in Omadhoo Island

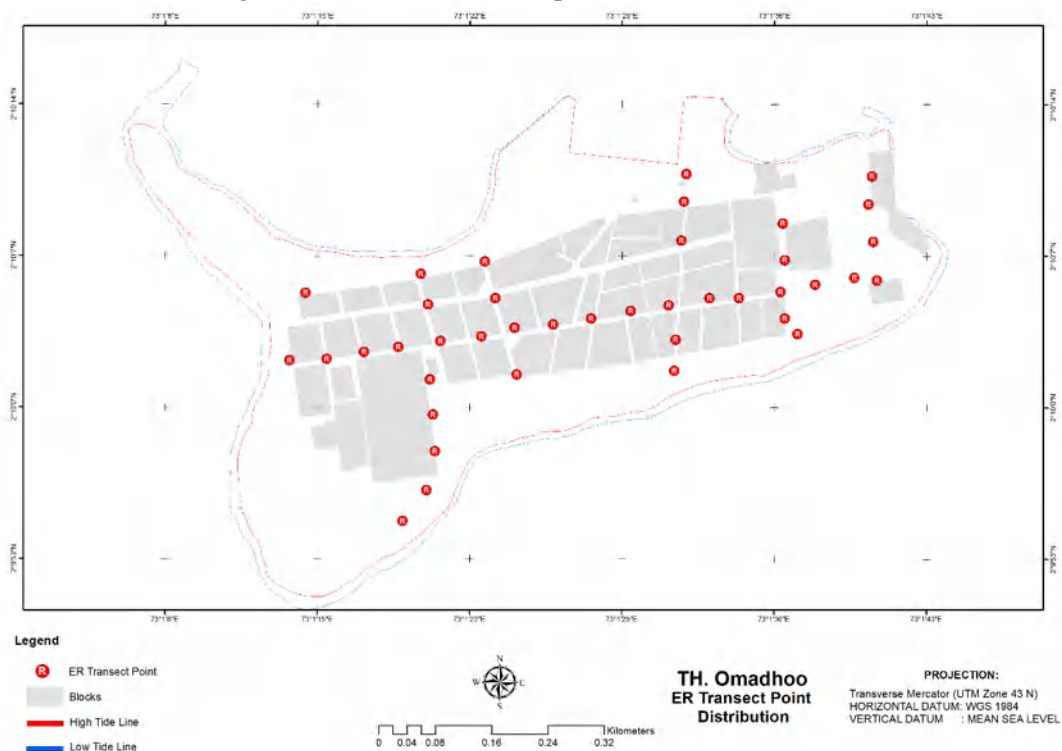


Figure 5-17: ER Test Points and Transect Lines in Omadhoo Island

5.7.9 Aerial surveys

Based on the aerial survey, a multiple data set consisting of buildings, roof cover, land cover, change detection and shoreline were extracted. This data is shown in the below Figure 5-18. The total roof cover for this island is 23,066 m².

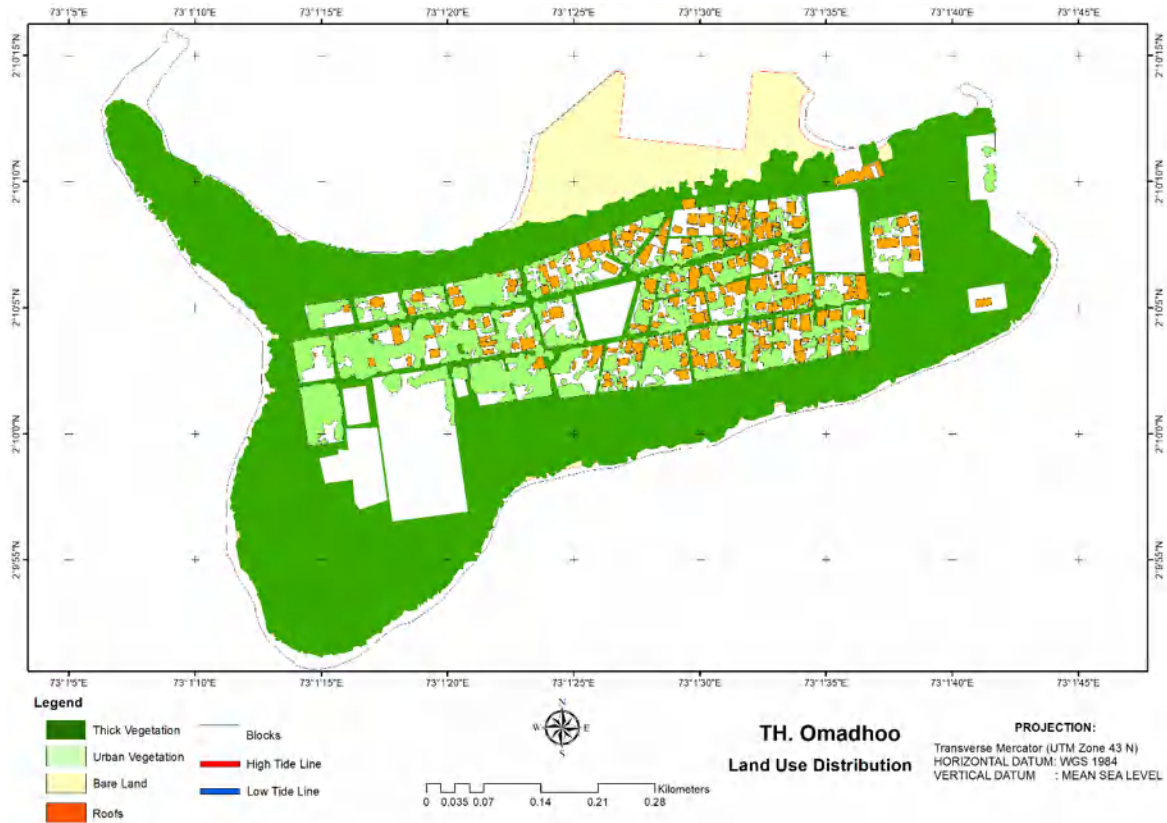


Figure 5-18: Roof Cover in Omadhoo Island based on UAV Survey

5.7.10 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 yards, road surfaces, etc., is not usable as there is no mechanism for its collection and treatment.

5.7.11 Freshwater lens

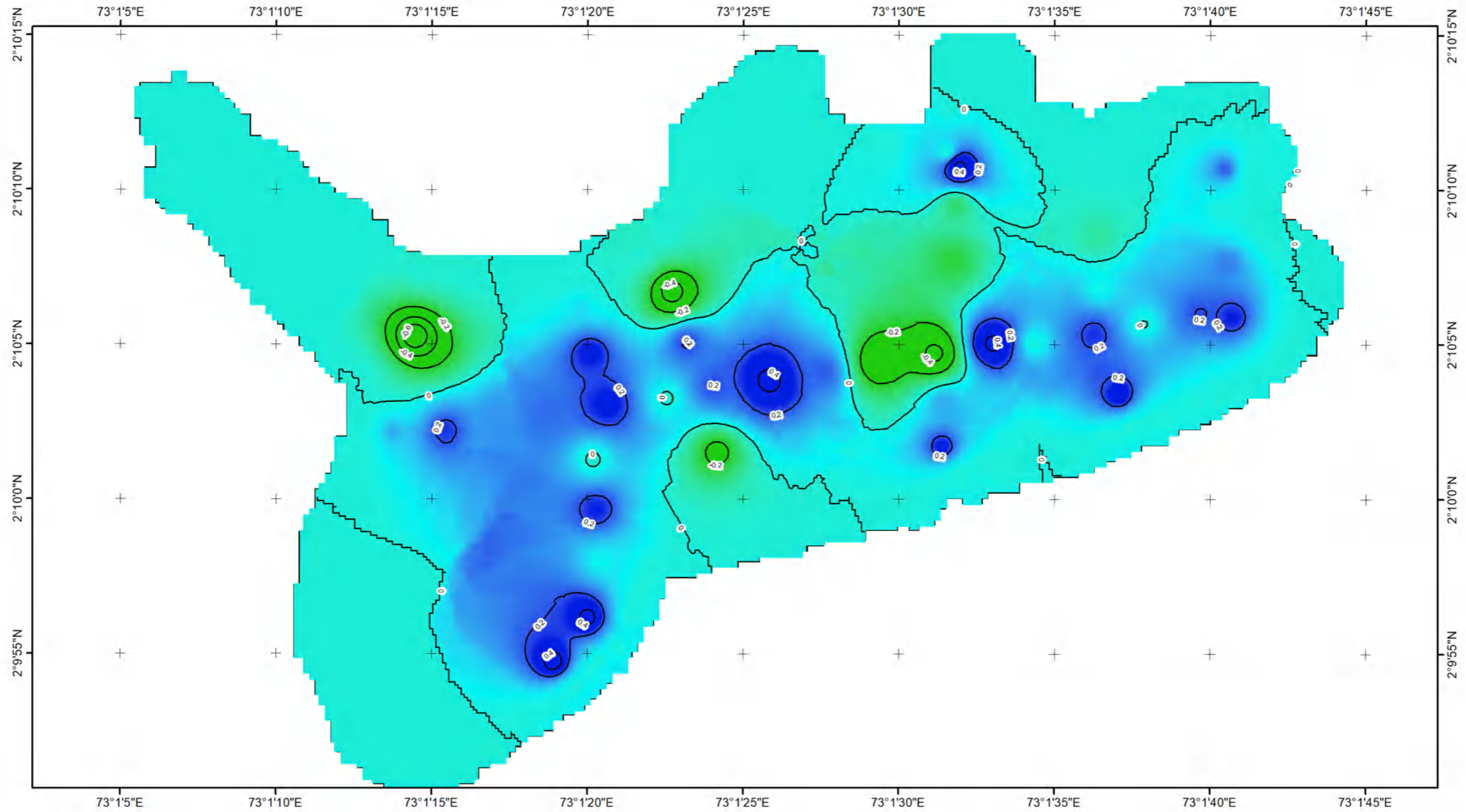
Based on the Electrical Resistivity (ER) surveys, the depth to groundwater level and the freshwater-saline water interface were determined for a set of transverse transects as shown in Figure 5-17. Plots in Figure 5-2 show the main two cross-sections of the island. The dotted lines in the plots indicate a simple interpolation of levels to mean sea level in the island boundaries.

Volume of the lens has been calculated with aid of ArcGIS and Surfer Software.

$$\text{Volume of lens} = 251,915 \text{ m}^3$$

$$\text{Groundwater Storage} = \text{Porosity (15\%)} \times \text{Lens volume (m}^3\text{)} = 37,787 \text{ m}^3$$

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented below in Figure 5-19 to Figure 5-21.

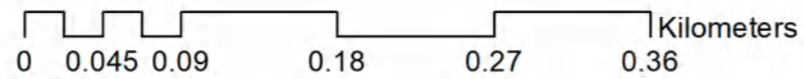
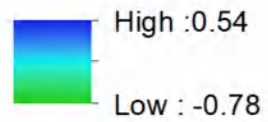


Legend

— Freshwater Contours

Freshwater Level

(m MSL)

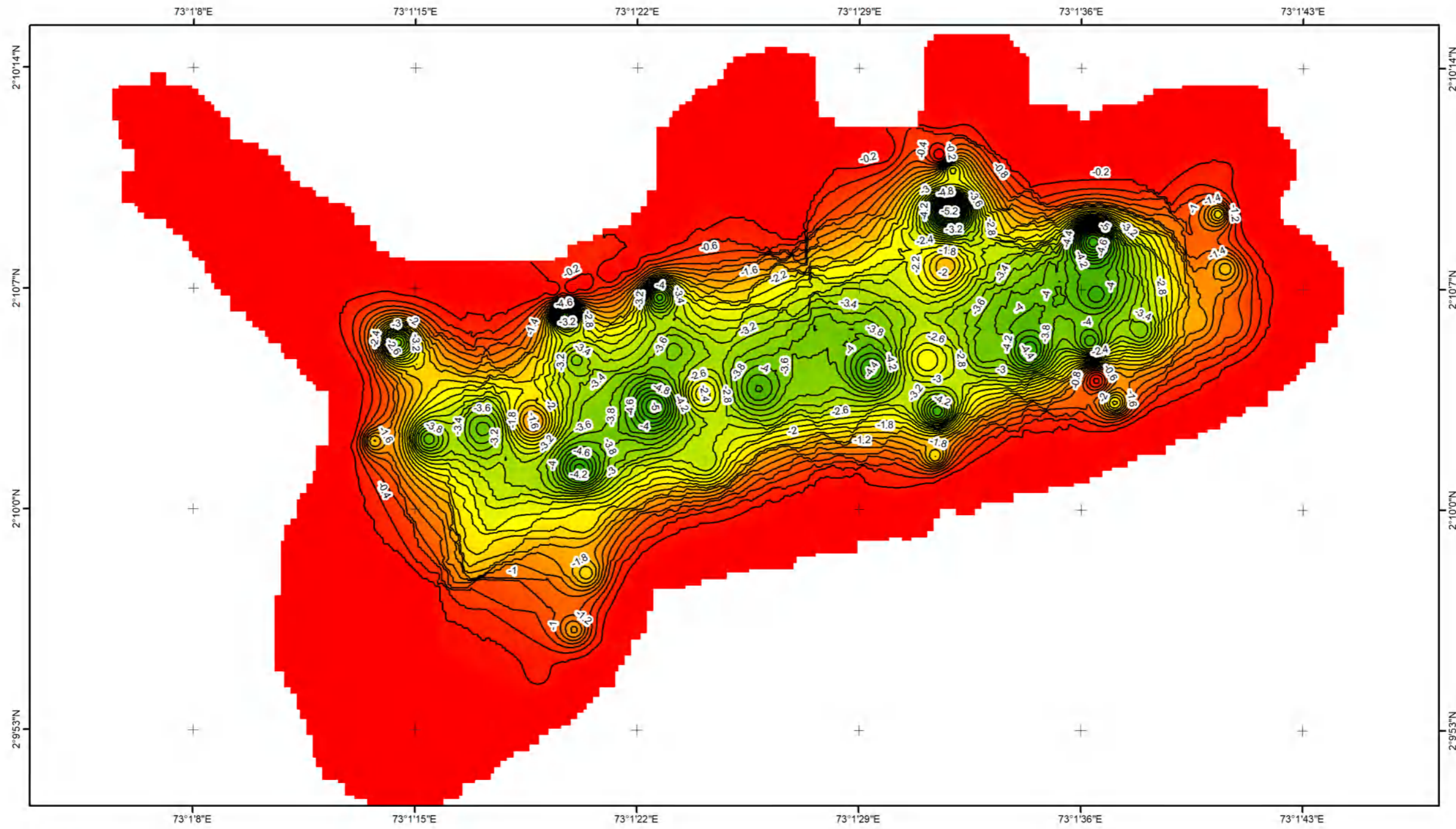


**TH. Omadhoo
Freshwater Level**

PROJECTION:

Transverse Mercator (UTM Zone 43 N)
HORIZONTAL DATUM: WGS 1984
VERTICAL DATUM : MEAN SEA LEVEL

Figure 5-19: Freshwater Level in Omadhoo Island

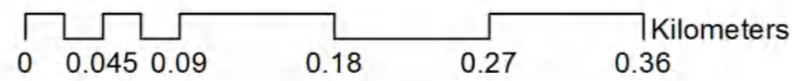


Legend

— Saline Water Contours

Saline Water Level

(m MSL)



**TH. Omadhoo
Saline Water Level**

PROJECTION:

Transverse Mercator (UTM Zone 43 N)
HORIZONTAL DATUM: WGS 1984
VERTICAL DATUM : MEAN SEA LEVEL

Figure 5-20: Saline water Level in Omadhoo Island

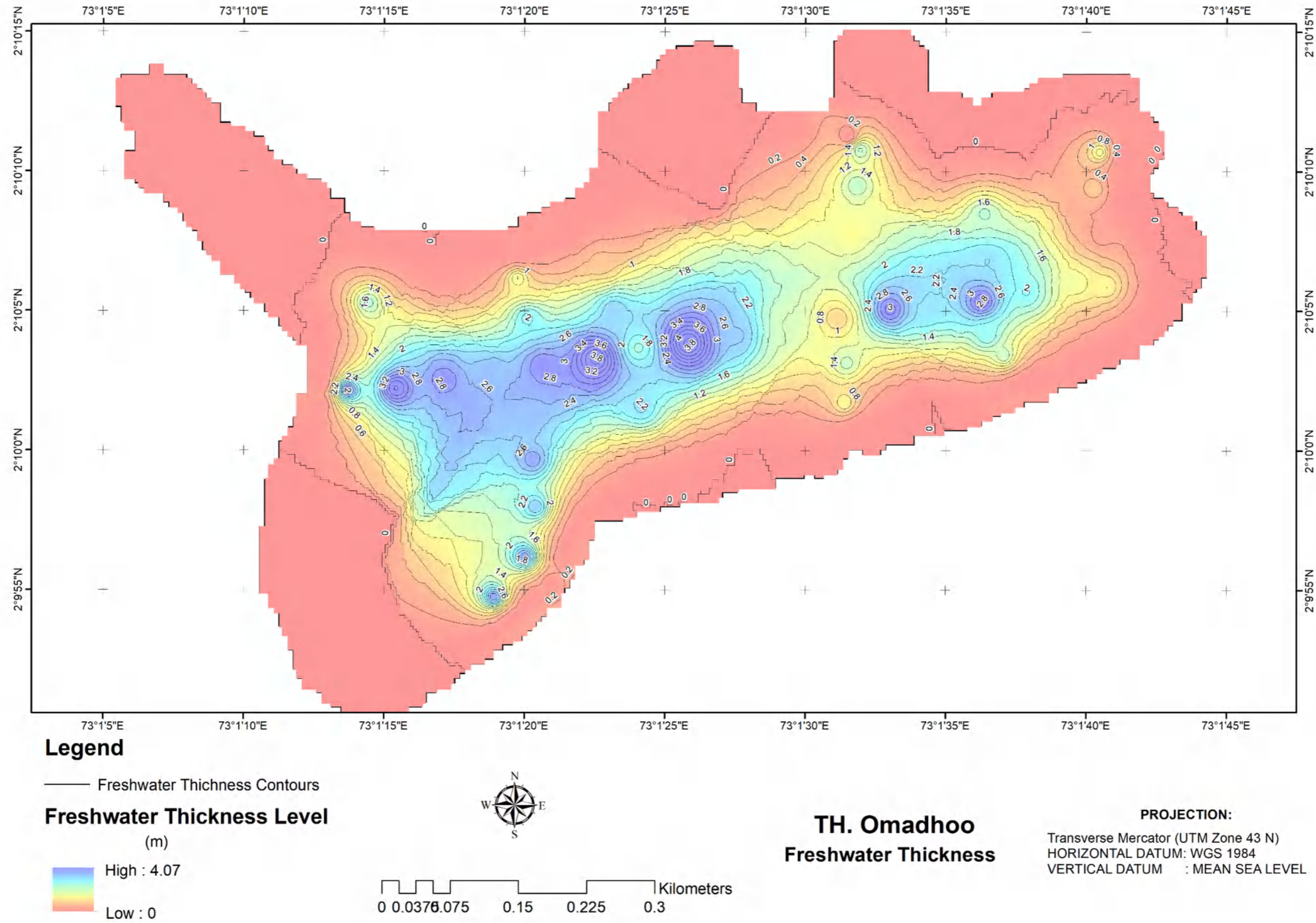


Figure 5-21: Freshwater thickness in Omadhoo Island

The maximum freshwater thickness of the island is 4.07 m (It is noted here that these readings were taken in September/October, which is the wet season and the with a reasonably higher number of wet days per month of the year).

5.7.12 Water balance and recharge

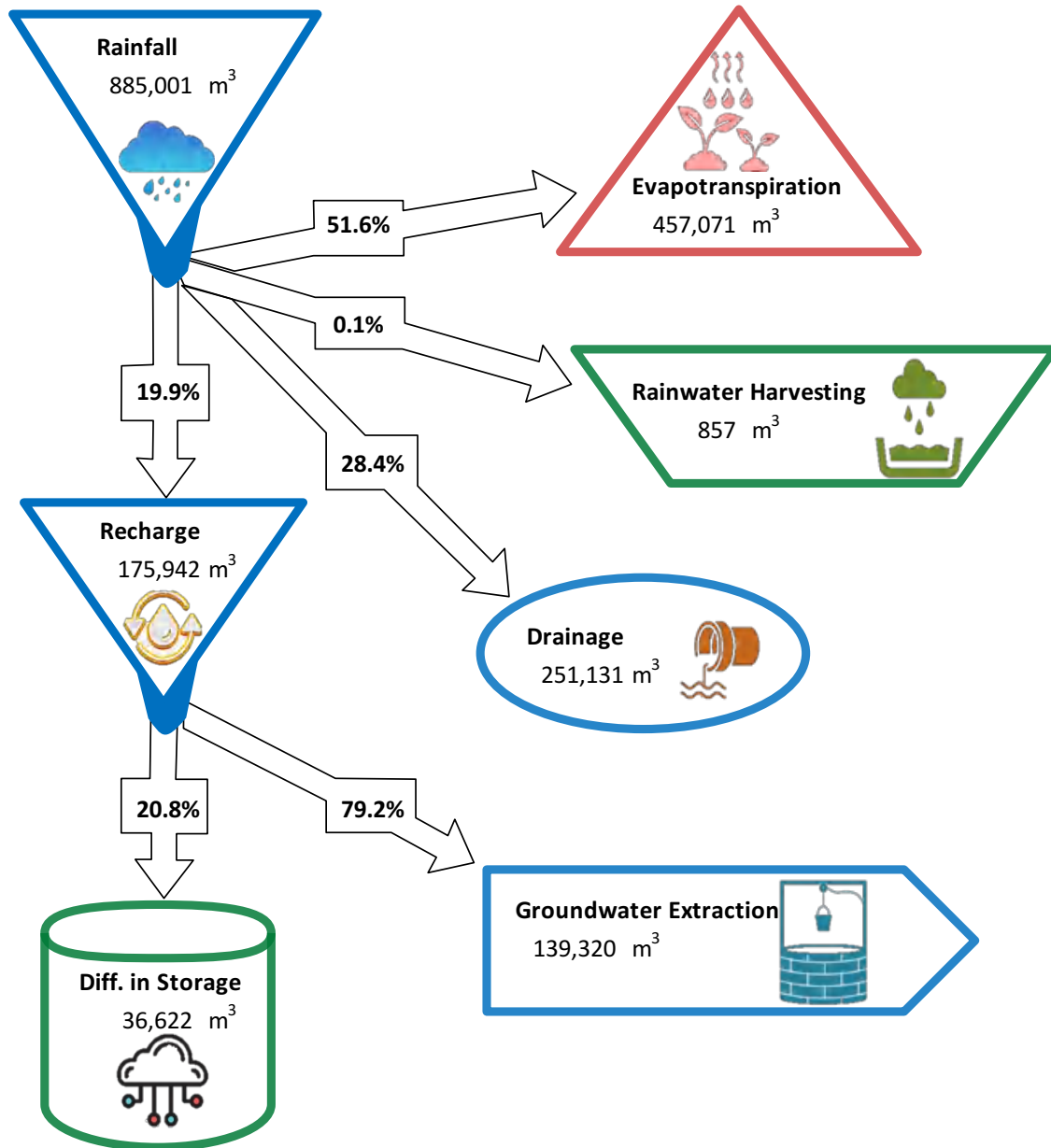


Figure 5-22: Schematic of water balance in Omadhoo Island

An annual estimation is carried out based on the water balance method (Falkland, 2000). Rainwater harvesting is calculated using the number of rainwater harvesting units on the island. According to the spatial mean annual rainfall of the Maldives, the annual average rainfall of Omadhoo Island is reported as 2,210 mm/year. Evapotranspiration was estimated using crop water requirements for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. Drainage or the surface runoff was calculated by considering an aggregate runoff coefficient for the island based on the land usage (roof cover, bare land, farmland, roads, playgrounds, wetlands). 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 the difference in storage.

5.7.13 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 483 m³ per day which was calculated by subtracting groundwater extraction from recharge volume derived from the schematic water balance model in Figure 5-22.

5.7.14 Permeability test

Permeability tests were carried out in the selected locations as outlined in the following Figure 5-23.

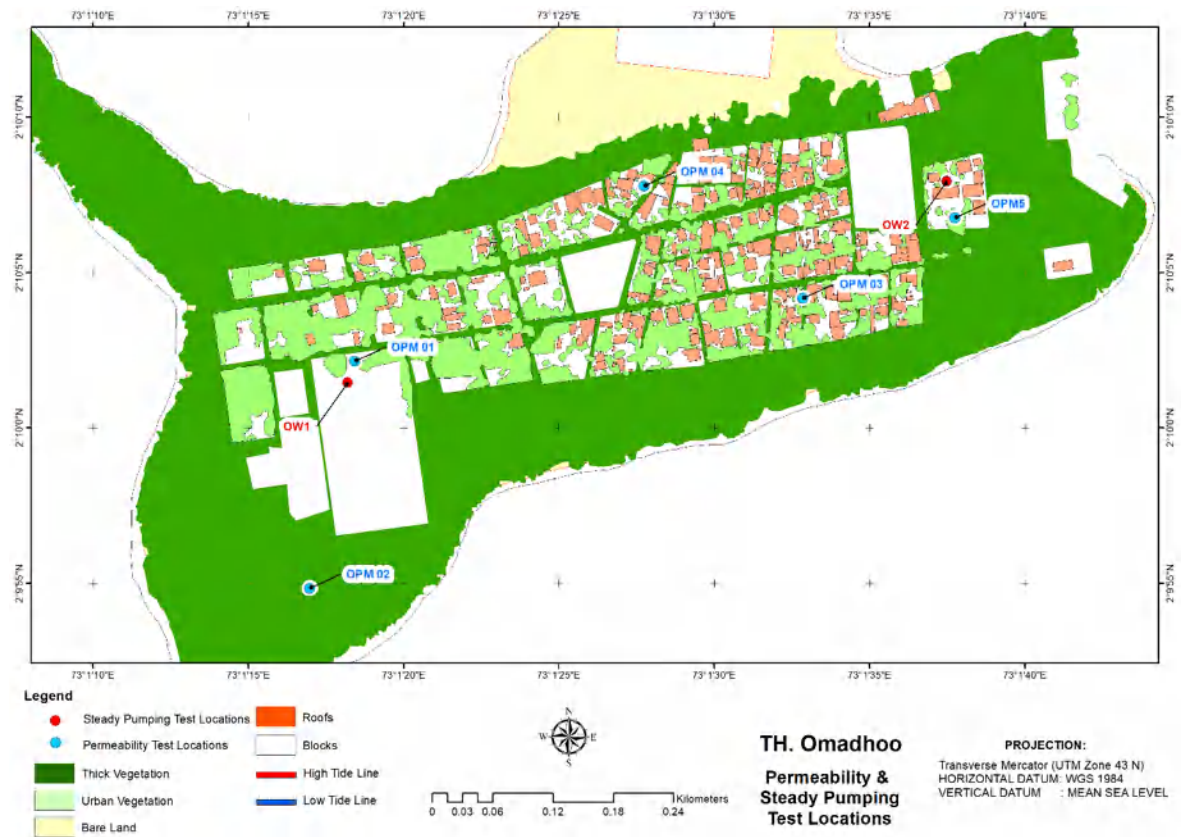


Figure 5-23: Locations of permeability and steady pumping tests in Omadhoo Island

The estimated permeability values for the above test locations are presented below in Table 5.12. The data will be comparatively verified and interpreted when additional data is acquired and calculations for other islands are completed.

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m³/s), H = Height of water in well (m), l = length of the perforated section (m), U = thickness of saturated permeability material above water table, r_1 = outside radius of the casing (radius of the 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_s = Conductivity Coefficients, and T_u = distance from water level in the casing to water table (m).

Table 5.12: The Estimated Soil Permeability Values in Omadhoo Island

Point	OPM 01	OPM 02	OPM 03	OPM 04	OPM 05
D (m)	0.680	0.580	0.500	0.680	0.650
H (m)	0.680	0.580	0.500	0.680	0.650
l (m)	0.680	0.580	0.500	0.680	0.650
U (m)	0.880	0.700	0.700	0.750	0.700
T _u (m)	0.880	0.700	0.700	0.750	0.700
r (m)	0.076	0.076	0.076	0.076	0.076
Q (m ³ /s)	1.37E-05	1.95E-05	2.53E-05	7.17E-06	6.89E-06
r ₁ (m)	0.076	0.076	0.076	0.076	0.076
r _e (m)	0.010	0.010	0.010	0.010	0.010
T _u /l	1.294	1.207	1.400	1.103	1.077
X = (H/T _u × 100)	77%	83%	71%	91%	93%
Section	Zone 2	Zone 2	Zone 2	Zone 2	Zone 2
l/r _e	65.44	55.82	48.12	65.44	62.55
C _s	95	80	73	95	92
K (m/s)	2.40E-05	4.90E-05	6.81E-05	1.48E-05	1.56E-05
K (m/day)	2.08	4.24	5.88	1.28	1.35

5.7.15 Steady Pumping Test

Pumping tests were conducted in two existing wells to estimate the aquifer properties of unconfined water bearing formation and transmissivity of the water bearing formation was estimated using Muskat's Method.

Table 5.13: Selected Steady State Pumping Test Locations in Omadhoo Island

Well No.	C'	A (m ²)	t' (s)	ln ($\frac{s_1}{s_2}$)	T (m ² /s)
OW1	4.6	1.91	1800	1.56	0.0012
OW2	4.4	5.2	1800	0.89	0.0018

The measured transmissivity (m²/s) values ranged from a minimum of 0.0012 m²/s to a maximum of 0.0018 m²/s., with an average of 0.0015 m²/s. During the testing period, EC (Electrical conductivity) of both wells was increased as below.

- For OW 1, EC (Electrical conductivity) increases from 490 µs/cm to 560 µs/cm.
- For OW 2, EC (Electrical conductivity) increases from 360 µs/cm to 390 µs/cm.

5.7.16 Status of groundwater availability in Omadhoo Island

- 1). The selected Omadhoo island has dimensions of width = 730 m and length = 1080 m, with a total land area of 40.05 ha, a population of 929 persons, and a land use of Roof cover (Built up area) 2.66 ha (6.6%), Vegetation (Thick) 18.91 ha (47.2%), Vegetation (Light) 5.77 ha (14.4%), and Bare lands 12.70 ha (31.7%).
- 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, Electrical Resistivity (ER) location readings along 09 representatively selected transects were collected.
- 3). Soil overburden permeability tests (constant head) were carried out at five (05) locations while steady-state pumping tests were conducted at 02 locations. In addition, the groundwater level was also recorded at 06 locations where groundwater water quality samples were tested.
- 4). Permeability tests were carried out at representatively selected five (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 \pm Standard Deviation).
- 5). The ground elevation values ranged from a minimum of 0 m MSL to a maximum of 2.00 m MSL, with an average of 0.69 ± 0.36 m MSL (Mean \pm Standard Deviation).
- 6). The upper boundary of the freshwater lens (FWL) varied from a minimum of -0.78 m MSL to a maximum of 0.54 m MSL, with an average of 0.03 ± 0.09 m MSL (Mean \pm Standard Deviation).
- 7). The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -6.10 m MSL to a maximum of 0.00 m MSL, with an average of -1.12 ± 1.37 m MSL (Mean \pm Standard Deviation).
- 8). Accordingly, the freshwater lens (FWL) volumetric values ranged from a minimum of 0.00 m to a maximum of 4.07 m, with an average of 1.50 ± 0.85 m (Mean \pm Standard Deviation).
- 9). The groundwater profile in the island is characterised by a relatively Low (0.10%) Rainwater Harvesting (%) relatively High (28.38%) Drainage (%) relatively Very Low (19.88%) Recharge (%) while the water use shows relatively Very High (79.19%) Groundwater extraction (%) leading to relatively Very Low (20.81%) Difference in Balance Storage (%).
- 10). The freshwater lens (FWL) volume calculated based on ER transect test data is 251,915 m³ with a maximum FWL thickness of 4.07 m and a steady state groundwater storage of 37,787 m³.

5.8 Conclusion

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 483 m³ per day, while it is 242 m³ per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 382 m³ per day and this exceeds the allowable Safe Yield in the island by 380% (Highly stressed). At present, there exists no island wide water supply network and sewerage network is under construction.

Relative hydraulic condition of the island lay in 'Semi-pervious' state while present aquifer condition remains at 'Poor' state based on the hydraulic conductivity estimation carried out as per Bear (1972) and transmissivity of the formation was compared as per Krany (1993). Moreover, general status based on transmissivity ranged 'High' and potential for groundwater recharge remains 'Low' – 'Moderate' as per the estimations.

6 TH. GAADHIFFUSHI ISLAND

6.1 General Overview of the Island

The island of Gaadhiffushi (Figure 6-1) is located on the south eastern periphery of Thaa Atoll at coordinates 73°12'45"E and 2°15'09"N. The island has an area of about 0.15 km² and measures about 0.4 km in width and 0.7 km in length. The population of the island was found to be about 712 residents as of December 2021. The island has a harbour on the North Western side of the island. The following table outlines some basic information about the island and the following map outlines the location of Gaadhiffushi.

Table 6.1: Basic statistical information on Gaadhiffushi island in Thaa Atoll.

Name of the island	Th. Gaadhiffushi
Longitude and Latitude	73°12'45"E, 2°15'09"N
Area	14.63 ha (0.15 km ²)
Population (Dec 2021)	712
Distance from Male'	215 km
Harbour	Present
Island sewerage network	Under Construction
Water supply network	No
Other infrastructure	RO Plant (Under Construction)

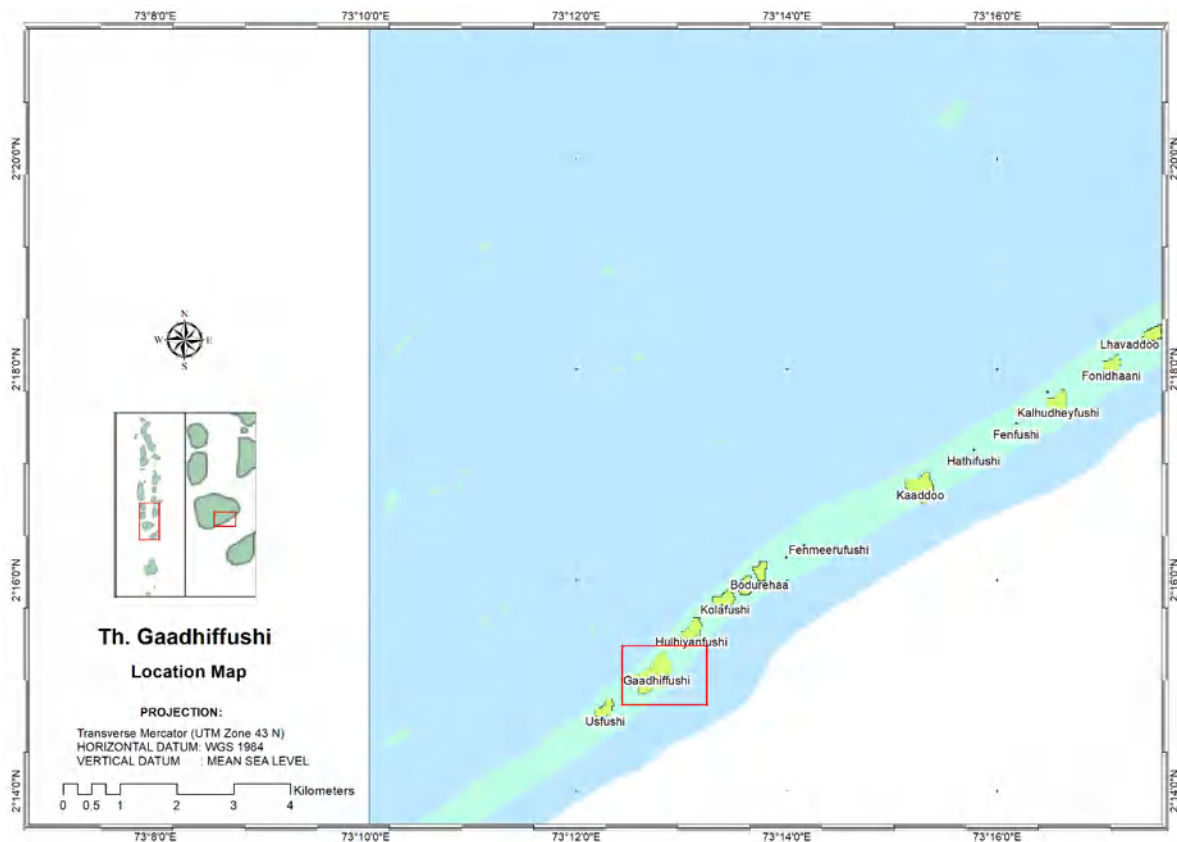


Figure 6-1: Location map for Gaadhiffushi Island, Thaa Atoll.

6.2 Topography and Geology

Gaadhiffushi Island is located in the South - Eastern side of the Thaa Atoll. The Gaadhiffushi Island is located middle of the long NE – SW trending submerged coral reef which is extending about 25 km. Gaadhiffushi Island is roughly L shape and extends about 620 m (NE-SW) in length (AB) and about 350 m (NW-SE) in width (CD). Here, basic topography and the geological setting is mostly based on the properties of the underground coral beds and actions of ocean waves and currents. The elevation of the island varies from -0.34 m to 1.89 m and generally flatland through the island. General geological profile in the island is composed of topsoil and beach coral sand deposits underlain by sandy coral rock. The sandy coral rock consists of a weathered coral rock layer and hard fresh coral rock. From the cross-section A to B shows a thin topsoil layer (0-0.5 m) and beach coral sand layer about 0.2m thickness in beach areas and about 1.0 m thickness in the middle of the island. In beach areas mostly beach coral sand exists as the top layer. Coral sand layer is mostly unconsolidated and permeable layer. Weathered coral rock depth is varying between 0.5m (coastal area) to 4m (middle of the island) from MSL. and it is a semi permeable layer. Groundwater lens occupied both the coral sand layer and weathered coral rock. Hard coral layer is mostly unconsolidated and impermeable and present as a fresh rock. As the compositional and structural differences of coral formation, differential weathering could be observed in cross section A-B. The cross-section C-D in the island shows uniform weathering and as a general trend in the central part of the island, it shows a higher weathering compared to the coastal area. However, A-B cross section clearly shows several deep weathered zones.

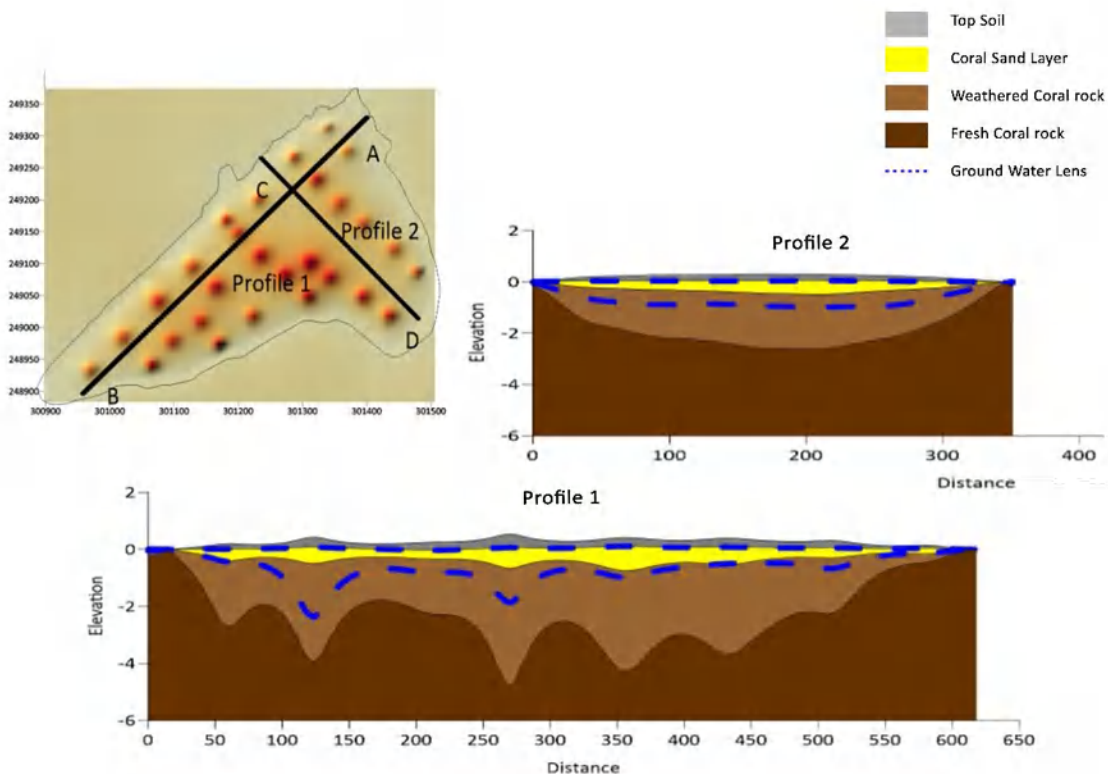


Figure 6-2: Geological sections of the island showing subsurface geological characteristics

6.3 Climate

Gaadhiffushi experiences the typical two monsoons in the Maldives namely, the North-east monsoon from December/January to March/April and the South-west monsoon from Mid-May to November. There are no specific wind and rainfall data available for Gaadhiffushi as there are no weather monitoring stations on the island itself. Based on the rainfall data of the nearest weather monitoring station, it shows a declining trend in rainfall for the past 30 years (Inception Report, 2021).

The historical rainfall data records from Kadhdhoo Island (not included in the 6 selected islands in Lot 2) located in the Laamu atoll (56 km to the southeast from Gaadhiffushi Island) has an annual average rainfall of 2,242 mm with a standard deviation of 370.4 mm and the trend and the decadal means were shown in the following graph (MEE, 2021).

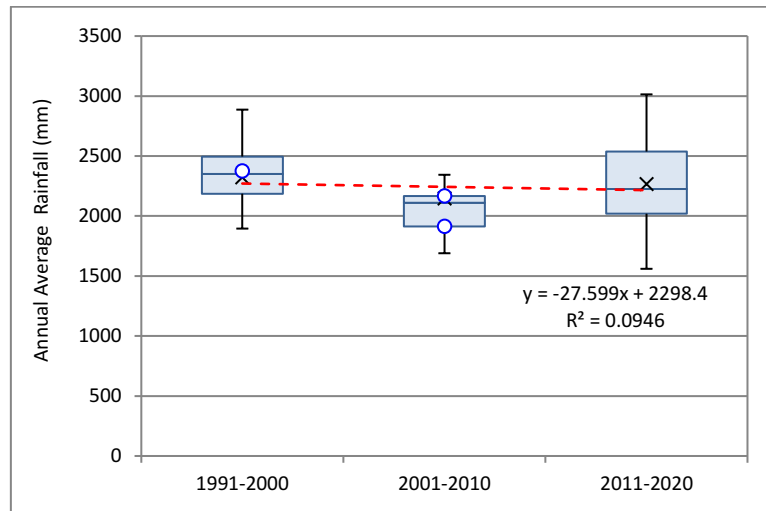


Figure 6-3: Decadal means and trend for rainfall in Kadhdhoo (1990 - 2020).

6.4 Demography

Gaadhiffushi has a registered population of 742 of which 372 are Male and 370 are Female. However, at present, the resident population is 652 with 600 locals and 52 foreigners. The following Table 6.2 and Figure 6-4 illustrates the population breakdown for Gaadhiffushi.

Table 6.2: Demographic Breakdown of Gaadhiffushi of December 2021

Registered Population (locals)			Resident population								
			Total			Maldivians			Foreigners		
Both	Male	Female	Both	Male	Female	Both	Male	Female	Both	Male	Female
742	372	370	857	489	368	739	380	359	118	109	9

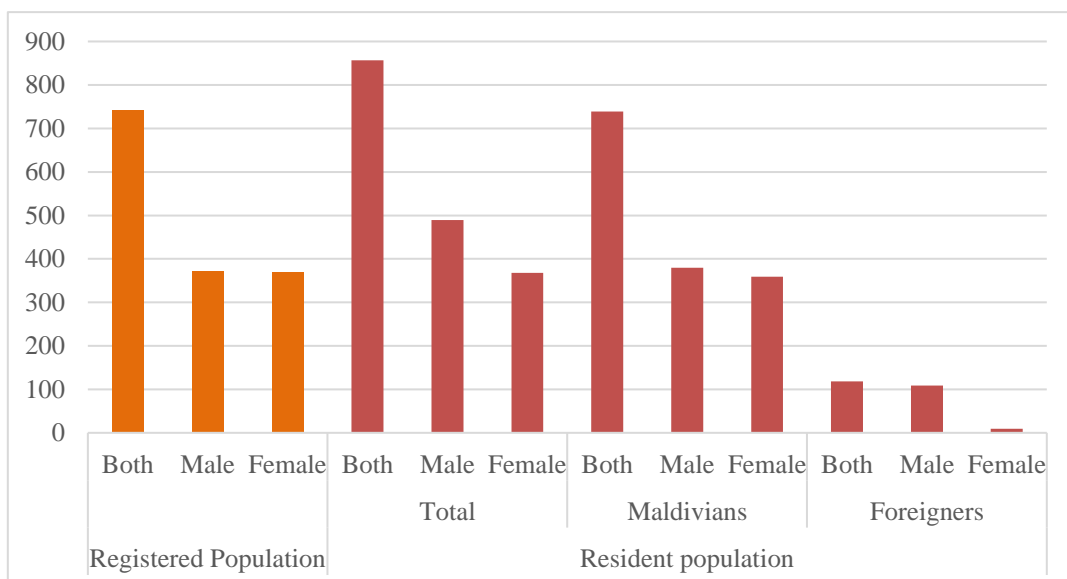


Figure 6-4: Population breakdown of Gaadhiffushi (Maldivians & Foreigners)

6.5 Socio-economic Condition

6.5.1 Natural Resources and Land Uses

With an area of 14.63 hectare, the island is considered to be one of the smallest inhabited islands of Thaa Atoll where a large percentage (more than 90%) is already full with different land uses mostly housing.

There is no formal land use plan prepared to date. The island council now has the authority to allocate lands for different purposes with an approved land use plan.

6.5.2 Economic Activities



Figure 6-5: Summary of household and socio-economic activities

The main economic activities of the island are Reef Fishery and Sea Cucumber Fishery. Other income earning activities practiced in the island include employment in service provision sectors such as teaching, health sector and tourism sector. Women are involved in Thatching and weaving ropes which are supplied to tourist resorts. There are three (3) cafés operational in the island. No farming is done in Gaadhiffushi due to lack of space. Home gardening is practiced to some extent, that also very minimal hence use of fertilisers and chemicals are not very common.

6.5.3 Accessibility and Transport

The only direct mean of access to the island is via sea transport by speed boats or Dhonis. It can be private hire or by ferries. Other means of transport is via air to the domestic airport at Thimarafushi of the same atoll and launch transfer from airport to Gaadhiffushi.

A harbour with quay walls located at the north west side of the island is used to access the island. It was noted that after the construction of the harbour, the rate of erosion increased especially at the northern side and other areas as well.

6.5.4 Services and Infrastructures

The island is equipped with the basic services and supporting infrastructures.

6.5.4.1 Public Facilities and Amenities

The public facilities available in the island include:

- Health Center
- Primary/Secondary School
- Government institutions (Office for Island Council, Island Court)
- Mosques
- Power House

6.5.4.2 Water supply

Currently, rainwater is used for drinking and cooking when needed, although bottled water sourced from Male' is also used. Groundwater is used for other purposes such as bathing and washing. This is further discussed in Section 6.6 and 6.7.

6.5.4.3 Energy supply

Gaadhiffushi has electricity for 24 hours generated from island powerhouse operated by Fenaka.

6.5.4.4 Waste and Wastewater disposal

Solid Waste: Households segregate waste at the household level (plastics, organic (food) waste, other waste). They have to take the waste to the waste dumping area allocated at the north eastern tip of the island. Waste within the site is managed by the Council. Although they have a waste management plan, they are not able to fully implement it due to the lack of resources. During the time of data collection for this project, it was noted that the current waste disposal area is not an approved land and there is no space in the island to allocate an area that would fulfill the regulations of EPA and MNPHI.

Sewage Disposal: Main method of sewerage disposal at Gaadhiffushi is by means of septic tanks. Each household has a septic tank within close proximity and is infiltrated into the ground. This is further discussed in Section 6.6.

6.6 Existing Water and Sanitation Situation

6.6.1 Water

Currently, the island does not have piped drinking water system though it is being established.

Groundwater is the main source of water for all uses except drinking and cooking. The groundwater quality of the island is observed to be in bad condition especially in areas at the periphery of the island than the areas at the central part where the water lens is thicker. It was noted that the groundwater is mainly affected due to the current sewage management practices. Discolouration and odour indicate the pollution level.

Rainwater and bottled water are mainly used for drinking and cooking. Rainwater is harvested at both the household level and island level. At the household level, each household has at least one water tank with a capacity of 2,500 L. The council have established 8 community tanks of 5,000L for rainwater harvesting. However, at present none are being used for drinking purposes as the tanks are not well maintained hence it is not safe for drinking. Nevertheless, it was noted that during dry seasons, some use it for drinking after boiling.

The general practice of rainwater harvesting at the island level is to clean the roofs thoroughly and letting the first flush pass to the roads which would eventually seep into the ground. Excess rainwater is also discharged to the roads in a similar manner. This sometimes causes flooding as well.

A rainwater harvesting system is also underway where roofs of all government institutions buildings/offices (council, mosque, health center, school, etc) will be used to collect rainwater into public tanks which will then be filtered and distributed to 3 different areas of the island through common water taps to be used by the public.

In addition, the establishment of an RO Plant with household connection is ongoing and is expected to be completed and ready to use by the early next year 2022.

6.6.2 Wastewater and Sewage Disposal

Currently, sewage is disposed by means of septic tanks. Each household has a septic tank within close proximity and is infiltrated into the ground. It was noted that most of the households keep the soakage pits outside the house, away from the groundwater wells although the septic tank is inside the house, to reduce the impact of sewage to the groundwater. According to the social survey that was carried out under this study, about 63% of the respondents kept the septic tanks 15 ft or more away from the well.

Establishment of a proper sewerage system with household connections is currently ongoing. It is expected to be completed by end of this year or early next year 2022. Once the new sewerage facility has been established, the existing facility will be abandoned. The septic tank inflows from the pipes will be ceased by disconnecting the inflow pipes. The remaining sludge in the pipes and septic tanks will then be removed by sewer jetting and released to the sea via an outfall pipe.

6.7 Results of the Baseline Surveys: Water Usage

6.7.1 Summary of socio-economic surveys

As detailed in the methodology section of this report (Section 1.4.3.2) a social survey was carried out to determine the water usage at households (HHs), commercial entities (cafés/restaurants), institutions and places with industrial uses (agricultural lands, fish processing). The survey was carried out from 20th May to 22nd May 2021 with the help of local enumerators. As in Gaadhiffushi, there were no significant groups involved in industrial activities that use water, the survey was carried out for households, cafés and institutions only.

The following Table 6.3 summarizes samples taken for each sector at a 95% confidence interval and the total number of completed surveys for each.

Table 6.3: Population and Sample taken for the social survey

Categories	Population	Sample	Forms Completed
Households	73	60	60
Institutions	4	3	3
Café/restaurants	3	3	

Note: A number of mitigation measures were adopted to ensure to achieve the 95% confidence level sample size. The challenges and limitations and the measures undertaken to mitigate the challenges are listed in Section 1.4.3.3.

The key findings from this survey show that a total of 695.56 liters of groundwater are estimated to be used per capita per day for various domestic uses. The respective water use situations including domestic, commercial and institutional uses are illustrated in the following sections.

6.7.2 Water usage for domestic purposes

6.7.2.1 Domestic Water Usage

A household survey was carried out at a 95% confidence interval. A total of 60 HHs were surveyed. As presented in Table 6.4, 97% of HHs have at least one of 2,500L capacity HDPE rainwater tanks at their homes to collect rainwater for daily uses. Among the 60 HHs, 77% uses rainwater for drinking while 97% also uses it for cooking.

Groundwater is mainly used for non-potable use in all the households surveyed.

Table 6.4: Groundwater and rainwater use data for Gaadhiffushi

Rainwater	Per cent (%)
Households with rainwater tanks	97%
Rainwater use for drinking	77%
Rainwater use for cooking	97%
Groundwater	Per cent (%)
Groundwater as a drinking source	0%
Groundwater for cooking	3%
Groundwater for non-potable use	90%
Total number of household wells surveyed	60
Percentage of wells surveyed fitted with pumps	95%

Based on the survey carried out, an 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 6.5. The total domestic water use is estimated to be 421.27 liters per capita per day.

Table 6.5: Domestic Water Usage in Gaadhifushi

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
103.9	45.0	27.7	172.7	349.3

6.7.2.2 Perception on Groundwater

The HHs were also asked about their perception on groundwater, if it is safe to use for daily purposes and whether the quality of groundwater is good or bad.

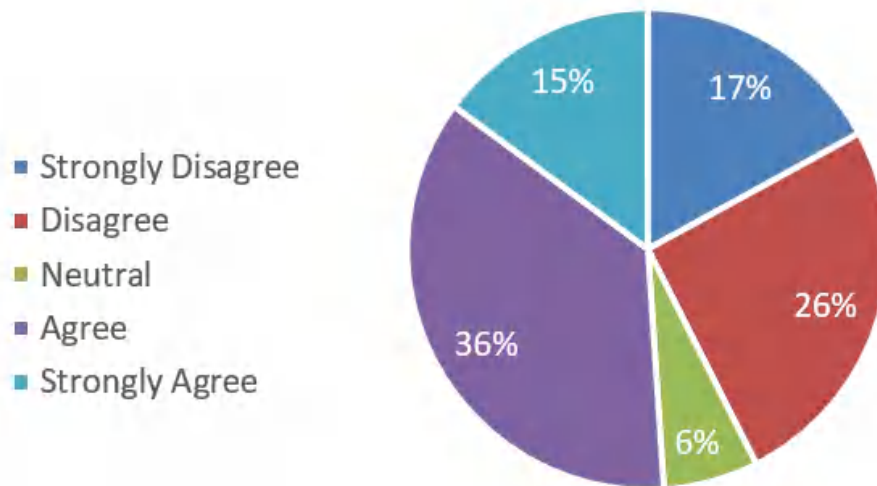


Figure 6-6: Perception of HHs on safety of Groundwater

As it can be seen from Figure 6-6, a total of 51% agreed that the groundwater of Gaadhiffushi is safe to use for non-potable uses. Among this 51%, only 15% strongly agreed that it is safe.

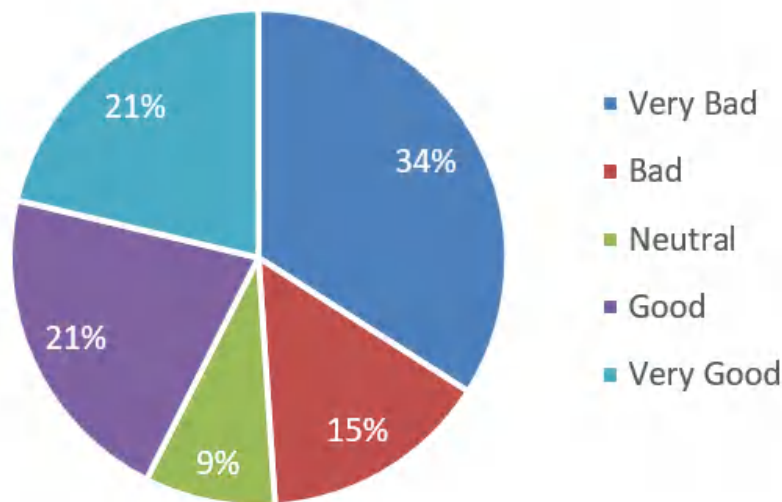


Figure 6-7: Perception of HHs on quality of groundwater

Furthermore, the HHs were asked about the quality of groundwater with regard to their experience. A total of 49% of the respondents said the quality is not good (34% said very bad, 15% said bad). But it is important to note that a total of 42% thought the groundwater quality is good. The varying opinion on groundwater quality is because in Gaadhiffushi, in different parts of the island water quality is different. While in general it was noted even by the island council that groundwater quality is not good in most parts of the island, they also noted that at the central area where the water lens is thick, the groundwater seems to be good in quality.

6.7.3 Water Usage by Commercial Activities

Gaadhiffushi has three (3) cafés considered as commercial entities. The three (3) cafes were surveyed. There were no guesthouses in Gaadhiffushi.

The table below presents a summary of water usage by the cafés.

Table 6.6: Water Usage by commercial activities in Gaadhiffushi

Cafés	Total Volume of water per day (Liters)
1	1,272
2	1,227
3	50
Total	2,549

For the cafés, the main use of groundwater was for dishwashing. From the total three (3) cafés that were surveyed, the total groundwater consumption for these Cafés was estimated to be 2,549 liters.

6.7.4 Water Usage by Institutions

Based on the survey carried out to collect data on water consumption by institutions, four institutions were surveyed for this study which are the island powerhouse, island court, school and health center.

Groundwater in the institutions in Gaadhiffushi is mainly used for mopping floors, flushing toilets and to some extent gardening. A total of approximately 4,699.5 liters of groundwater are estimated to be used per day by the institutions surveyed. As the use of each institution is different, to generalize the water consumption of institutions to an average figure will not be accurate. However, it can be deduced that based on the data, 203.17 liters of groundwater are estimated to be used per staff per day by the institutions of Gaadhiffushi (Table 6.7).

Table 6.7 Water Usage by commercial activities in Gaadhiffushi

	Water Flushed (Liters)	Gardening (Liters)	Mopping (Liters)	Sub-Total Water Used (Liters)	Total Water Used (Liters)	Institutional Groundwater Usage (Liters Per Staff Per Day)
Power House	216	204.5	N/A	420.5	4,699.5	203.17
Court	36	0	5	41		
School	336	2,454	24	2,814		
Health Center	192	1,227	5	1,424		

6.7.5 Groundwater quality

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

The following Table 6.8 summarizes the water quality results.

Table 6.8: Summary of groundwater quality tests from Gaadhiffushi Island in 2021

Sample No	EC ($\mu\text{S}/\text{cm}$)	pH	Turbidity (NTU)	DO (ppm)	Temp ($^{\circ}\text{C}$)	Salinity (PSU)	Nitrates (mg/L)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
Samples in Residential Areas											
G1	693.90	7.47	0.05	0.33	29.33	0.00	24.30	0.07	0.22		
G2	411.40	7.92	0.00	1.81	30.52	0.19	0.60	0.06	0.11	>2420	1415
G3	651.10	7.43	21.29	3.67	31.85	0.31	1.10	0.22	0.14		
G4	494.00	7.92	0.00	5.37	29.97	0.24	0.80	0.08	0.12	91	3
G5	547.50	7.76	0.00	2.86	28.59	0.26	0.50	0.06	0.15	488	102
G6	1073.40	7.02	0.00	1.15	29.83	0.53	92.40	0.05	0.36		
G7	718.00	7.51	0.09	0.61	29.53	0.35	1.50	0.06	0.21	1120	16
G8	494.10	7.43	0.00	1.40	29.20	0.24	3.70	0.05	0.13		
G9	511.60	7.57	0.00	2.44	28.89	0.24	4.60	0.05	0.13	2420	4
G10	517.20	7.09	0.00	1.84	29.98	0.25	39.90	0.09	0.45	>2420	5
G11	614.10	7.36	0.00	3.74	28.90	0.29	11.40	0.08	0.20		
G12	275.30	7.61	0.00	2.59	28.15	0.13	1.40	0.05	0.43	>2420	54
G13	579.50	7.09	3.77	3.05	30.50	0.28	113.60	0.71	2.20		
G14	1450.30	7.66	0.00	2.43	28.79	0.72	1.20	0.08	1.32		
G15	402.00	7.82	0.00	1.60	29.02	0.19	1.20	0.02	0.31	>2420	>2420
G16	711.10	7.42	0.00	1.44	28.00	0.34	8.50	0.14	0.14		
G17	513.30	7.08	0.00	3.41	29.69	0.25	0.80	0.05	0.15	579	2
G18	437.30	7.81	0.01	2.72	28.25	0.21	11.90	0.05	0.28		
G19	329.70	7.82	0.00	1.77	28.59	0.16	5.80	<0.02	0.21		
G20	766.40	7.16	0.00	1.38	30.21	0.37	130.30	0.08	0.23		
G21	295.50	8.06	0.00	4.57	29.13	0.14	3.60	0.17	0.07		
G22	1233.30	7.56	1.30	4.35	29.72	0.61	11.40	0.08	0.14		
G23	464.50	7.66	0.00	1.95	29.58	0.22	1.50	0.06	0.15	1203	0
G24	703.60	7.11	10.21	1.63	29.37	0.34	75.40	0.13	0.14		
G25	261.90	7.66	0.00	5.03	28.18	0.12	0.40	0.07	0.14	1414	45
G26	318.00	7.74	0.00	2.05	29.14	0.15	5.30	0.07	0.16		
G27	257.60	8.28	0.00	6.00	28.91	0.12	0.90	0.03	0.14		
G28	441.60	7.86	0.00	4.23	29.11	0.21	0.60	<0.02	0.13		
G29	346.30	8.16	0.00	4.42	28.36	0.16	0.30	0.06	0.17		
G30	1099.00	7.37	17.72	4.28	29.54	0.54	3.60	0.09	0.13		
G31	1182.70	7.10	2.85	1.26	29.33	0.58	112.00	2.44	0.12		
G32	700.00	7.49	0.00	1.52	29.03	0.34	32.90	0.16	0.18	387	96
G33	586.60	7.47	0.00	4.01	30.53	0.28	4.70	<0.02	0.14		
G35	474.00	7.36	0.00	1.92	28.74	0.23	19.40	4.75	0.11		
G36	1029.80	7.30	3.54	0.51	28.51	0.50	11.70	0.08	0.12	>2420	130
G37	809.70	7.24	0.00	0.93	29.96	0.39	31.70	0.08	0.18		
G38	693.70	7.82	4.82	63.06	29.53	0.33	0.90	0.09	0.22	1986	1414
G39	715.90	7.74	0.00	2.59	29.07	0.35	0.60	0.10	0.17		
G40	1152.60	7.61	0.00	1.37	28.53	0.57	0.70	0.12	0.10	>4840	59
Samples in Industrial Areas											
G34	694.90	7.66	0.30	4.81	33.17	0.33	2.10	0.07	0.10	488	10

Based on the full results and the summary shown in Table 6.8, the following can be summarized for Gaadhiffushi Island:

- The EC of the groundwater is generally low, with an average of 641.31 $\mu\text{S}/\text{cm}$ which is below an acceptable limit for potable water of 1500 $\mu\text{S}/\text{cm}$. The electrical conductivity readings range from 257.6 to 1450.3 $\mu\text{S}/\text{cm}$. All the samples were fallen within the acceptable limit.
- The pH of groundwater ranged from 7.02 to 8.28 with an average of 7.56. The pH values of all samples were within the WHO permissible limits of 6.5-8.5.
- Turbidity ranged from the lowest of 0 NTU to 21.29 NTU with an average of 1.65 NTU.
- Dissolved oxygen levels were low to moderate, with values varying from 0.33 mg/L to 63.06 mg/L with an average of 4.15 mg/L.
- The salinity of groundwater ranged from 0.12 PSU to 0.72 PSU with an average of 0.31 PSU. Salinity is expressed in Practical Salinity Units (PSU) which is equivalent to PPT.
- The average Nitrate concentration was 19.38 mg/L and therefore it exceed the WHO guideline limit of 5.09 mg/L. But only 17 of the 40 tested water samples exceeded this limit of 5.09 mg/L. The Nitrate concentrations ranged from 0.3 mg/L to 130.3 mg/L.
- Ammonia concentrations were generally low. The average ammonia concentration was 0.78 mg/L. This is within the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. Only 2 tested water samples exceeded this limit (ranged from 0.02 to 4.75 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 were within the range 0.07-2.2 mg/L with an average of 0.26 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). There were 1 samples tested below 0.1 mg/L.
- Total coliform levels were also found to be significant and ranged from the lowest count of 91 MPN/100 mL to the highest count of more than 4840 MPN/100 mL, with an average count of 1694.75 MPN/100 mL. Faecal Coliform levels were found to be less significant and ranged from the lowest count of 0 MPN/100 mL to the highest count of 2420 MPN/100 mL.

EC values of the selected wells were collected at the start of wet period (September – October) and following table show the summary of all the result collected during dry and wet periods based on the land use distribution.

Table 6.9: Comparison of WQ results based on land usage

Land Use	Number of samples	Results are lined with conditions	Enrichment of measured parameters	Remark
Residential area	59	52	G6, G13, G20, G24, G31, G35, GW14	G6,G13,G20,G24,G31,G35- indicate the pollution due to anthropogenic activities.

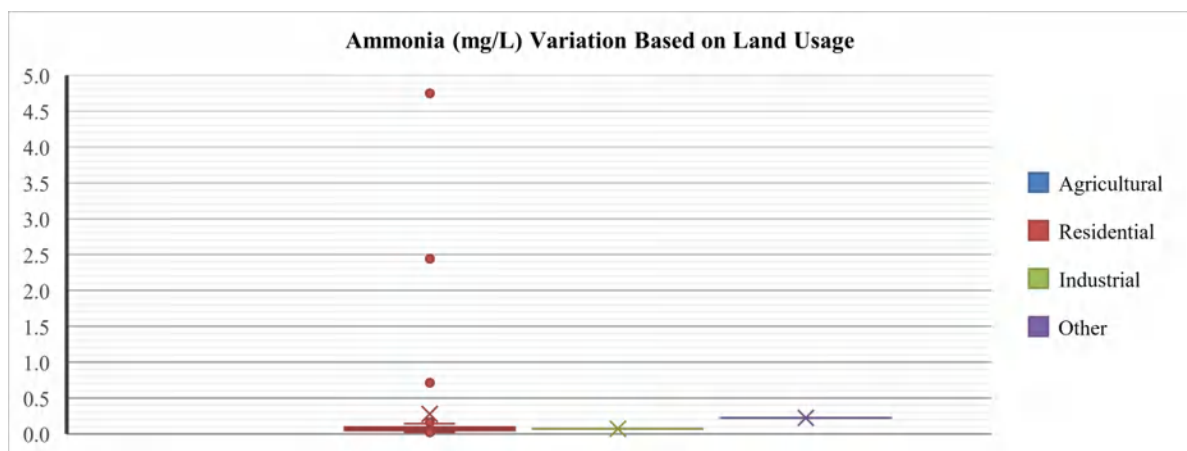
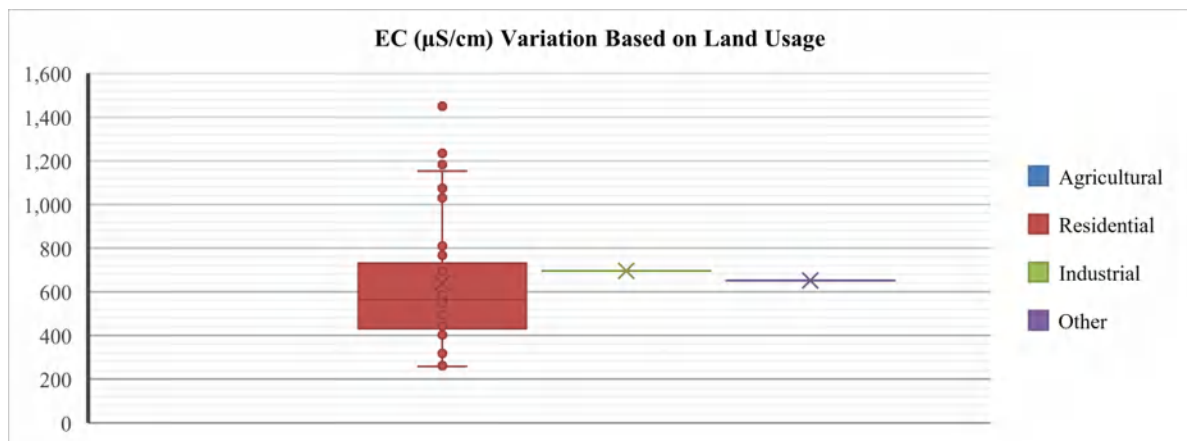
Land Use	Number of samples	Results are lined with conditions	Enrichment of measured parameters	Remark
				GW 14-This site is located at beach line.
Industrial Areas	1	1		
Total	60	53	7	

Considered desirable water quality limits:

- 1) EC < 2500 $\mu\text{s/cm}$ (water could be used for potable and non-potable use depending of EC).
- 2) Nitrate (<50 mg/l), Phosphate (<5 mg/l), and ammonia (<0.5 mg/l) as per WHO guideline.

Six (6) samples (G6, G13, G20, G24, G31, and G3) out of 59 analysed samples in resident area has recorded higher concentration of ammonia and nitrate in groundwater. The enrichment of ammonia and nitrate could be due to contamination of sewerage into ground water.

An area close to sampling point (GW 14) at abandoned coffee shop has recorded high EC and it could be due to previous groundwater extraction activities. Also, GW 14 is located at beach line.



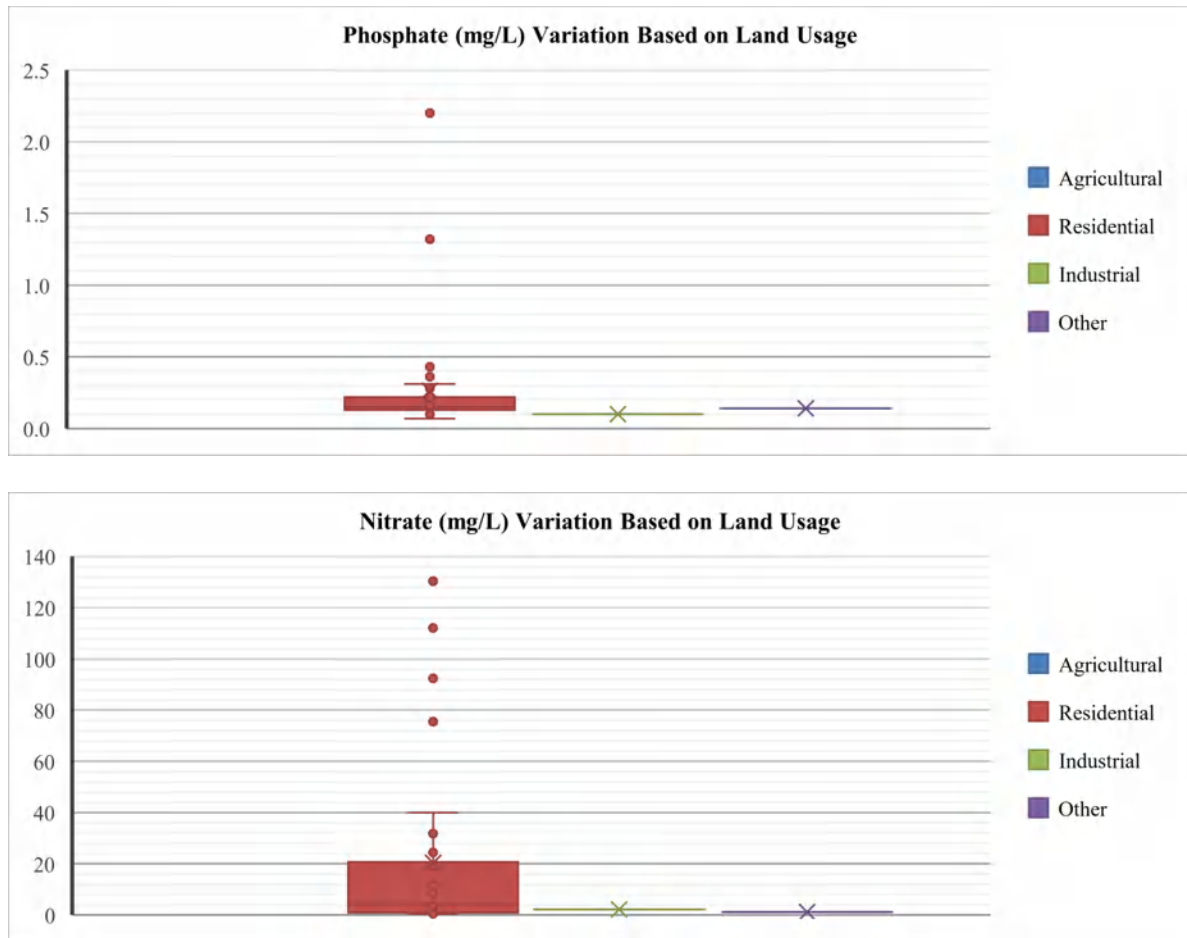


Figure 6-8: Variation of measured WQ parameters in Gaadhiffushi Island

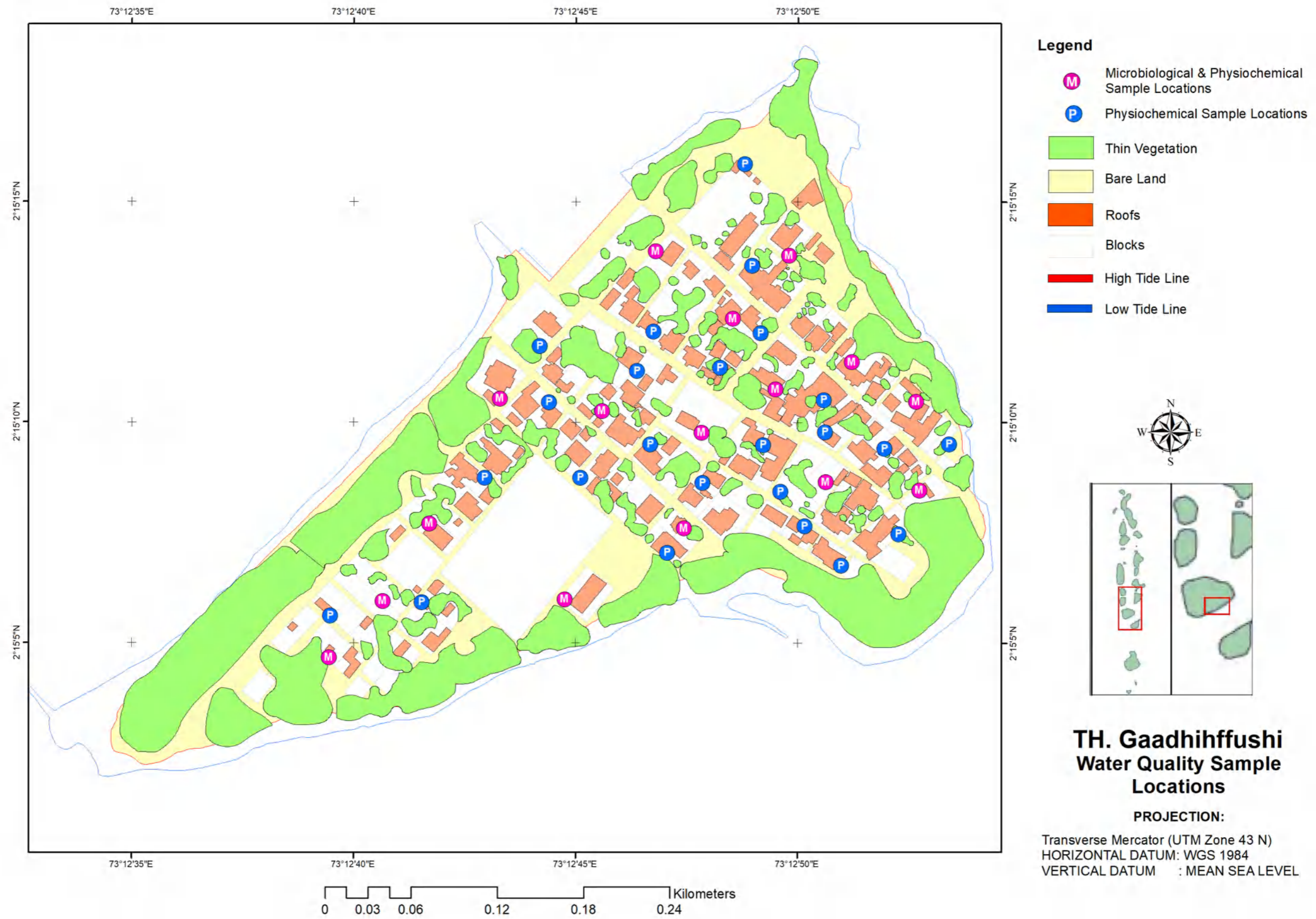


Figure 6-9: Location of groundwater sampling points in Gaadhiffushi Island

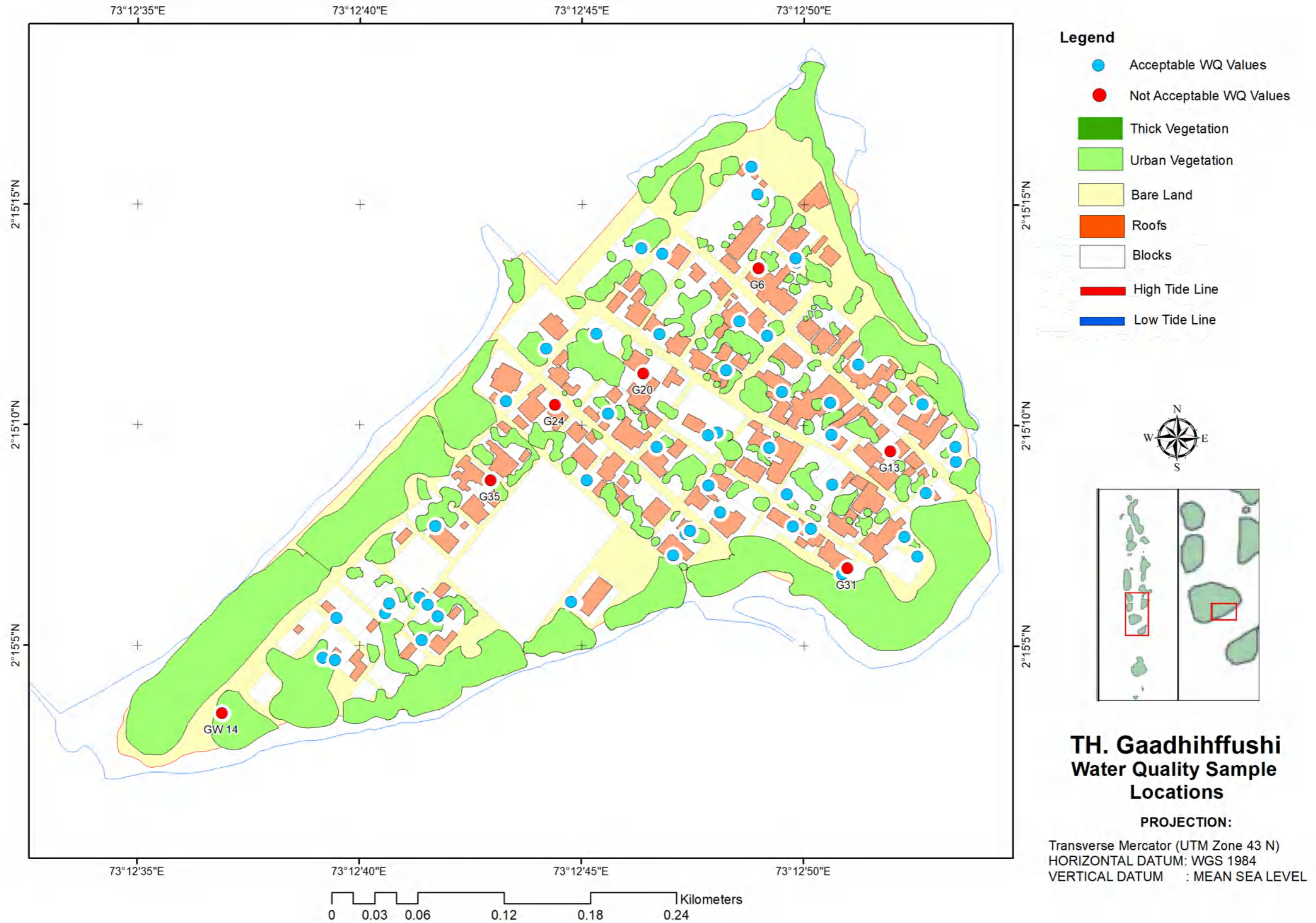


Figure 6-10: Location of groundwater sampling points with critical WQ values in Gaadhiffushi Island

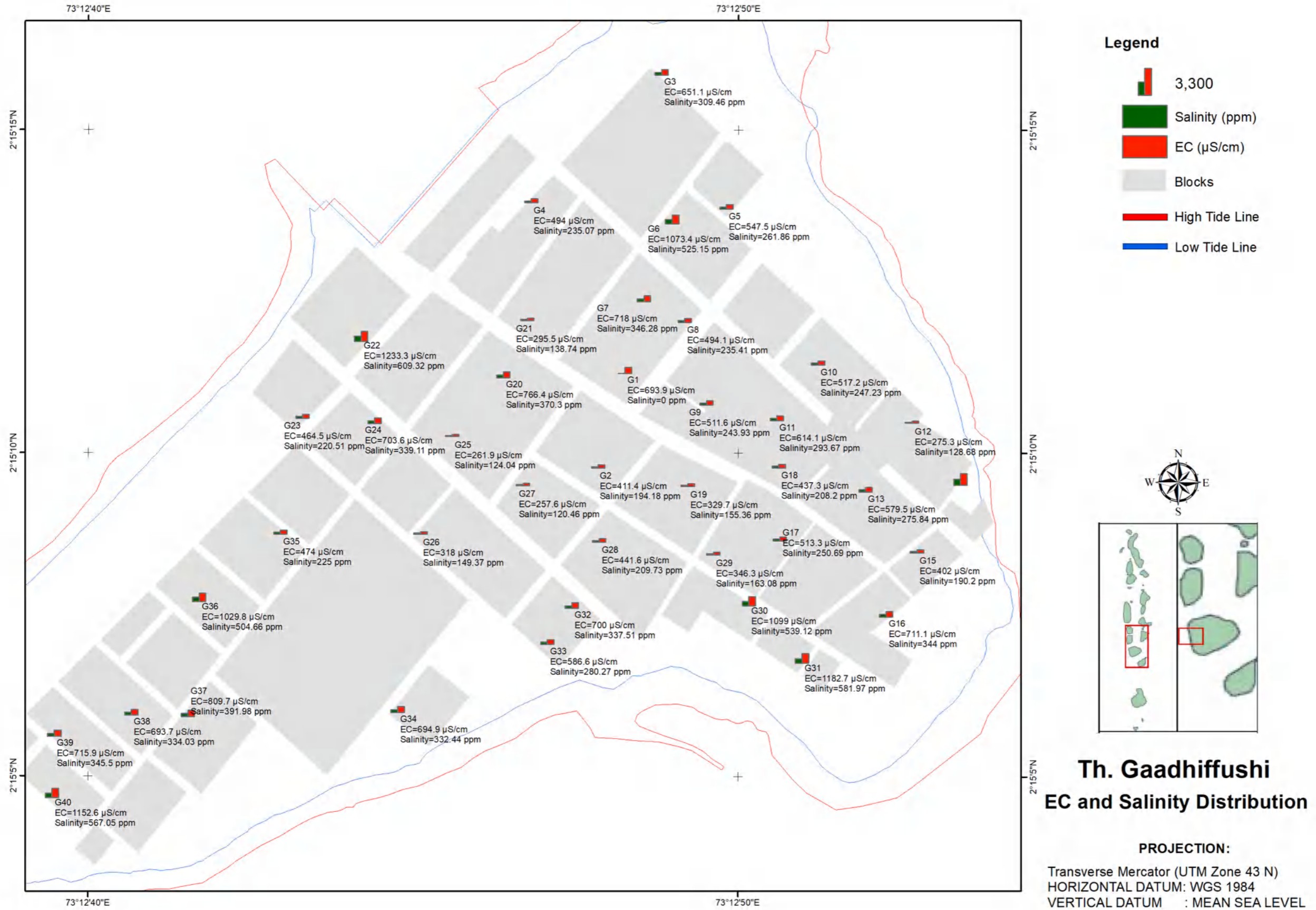


Figure 6-11: EC and Salinity Distribution in Th. Gaadhiffushi Island

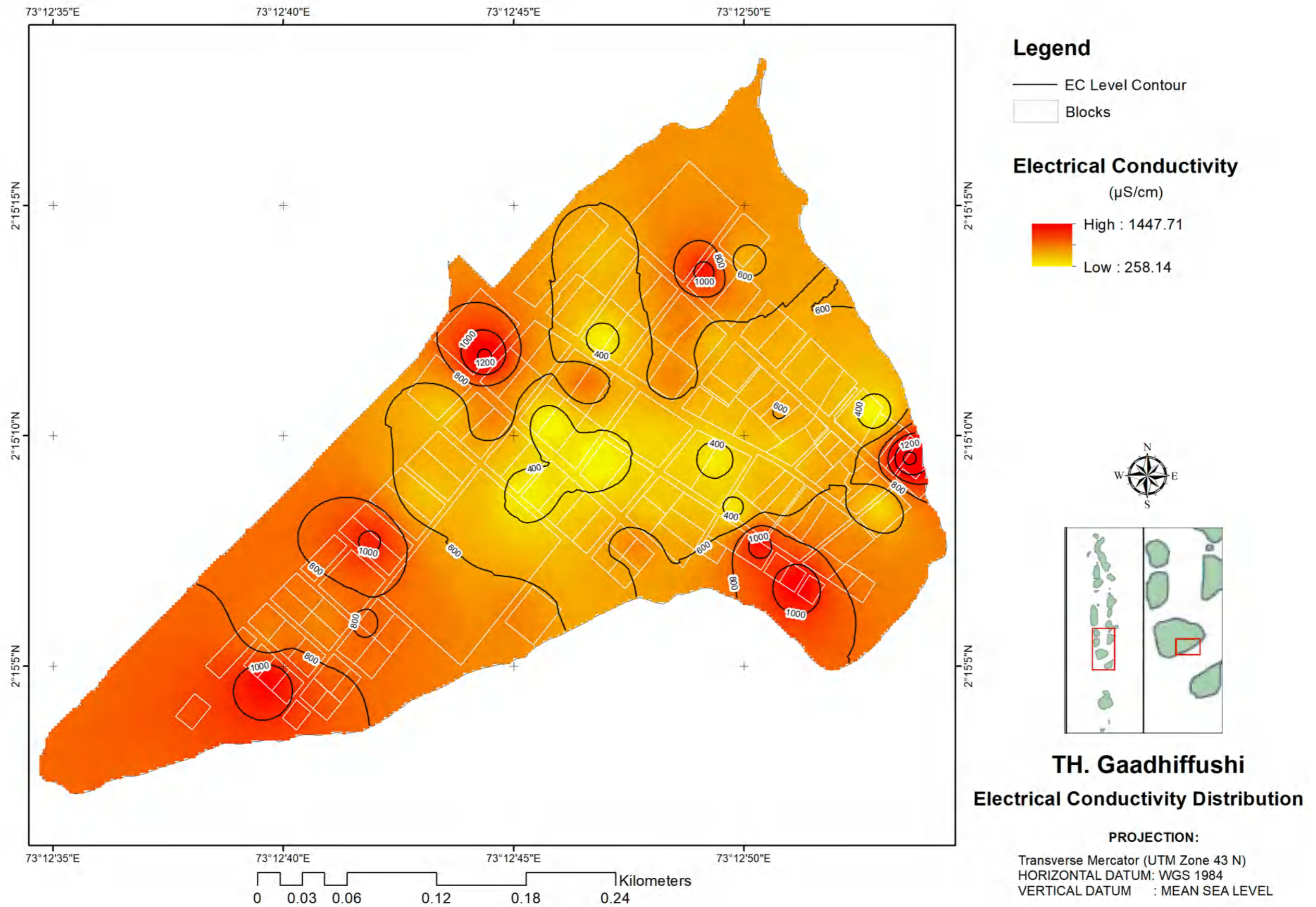


Figure 6-12: EC Distribution in Th. Gaadhiffushi Island

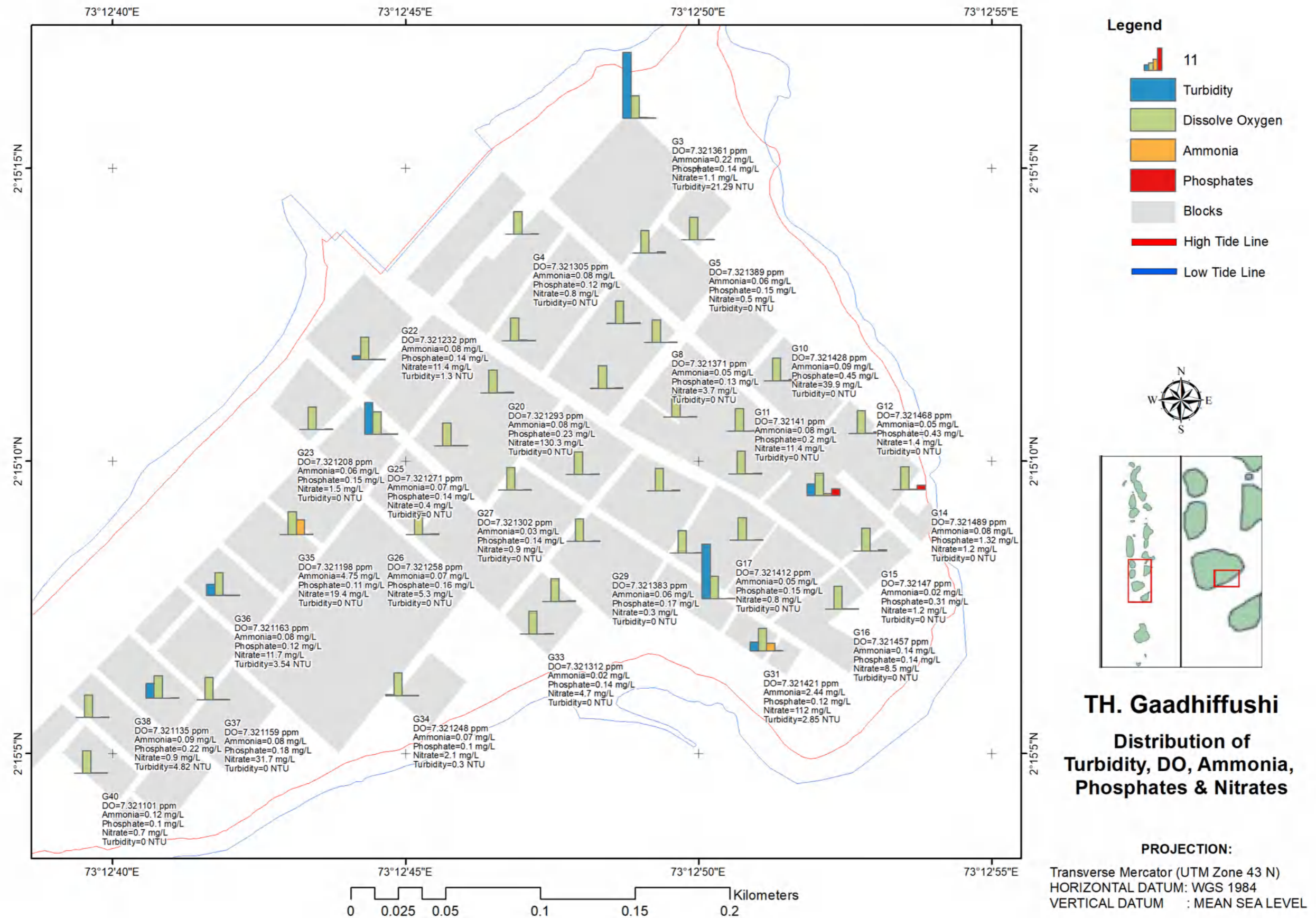


Figure 6-13: Distribution of Turbidity, DO, Ammonia, Phosphates and Nitrates in Th. Gaadhiffushi Island

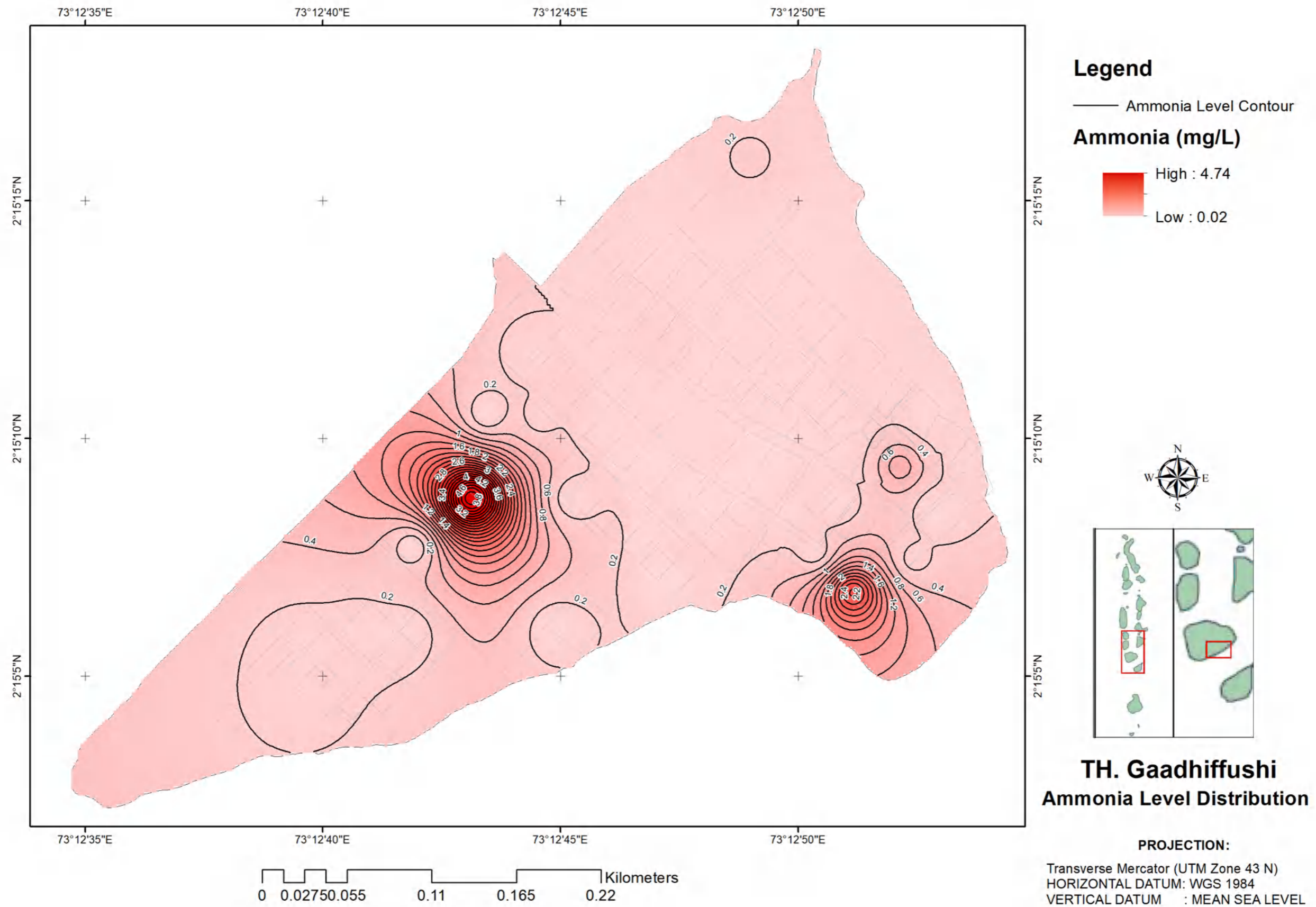


Figure 6-14: Ammonia Level Distribution in Th. Gaadhiffushi Island

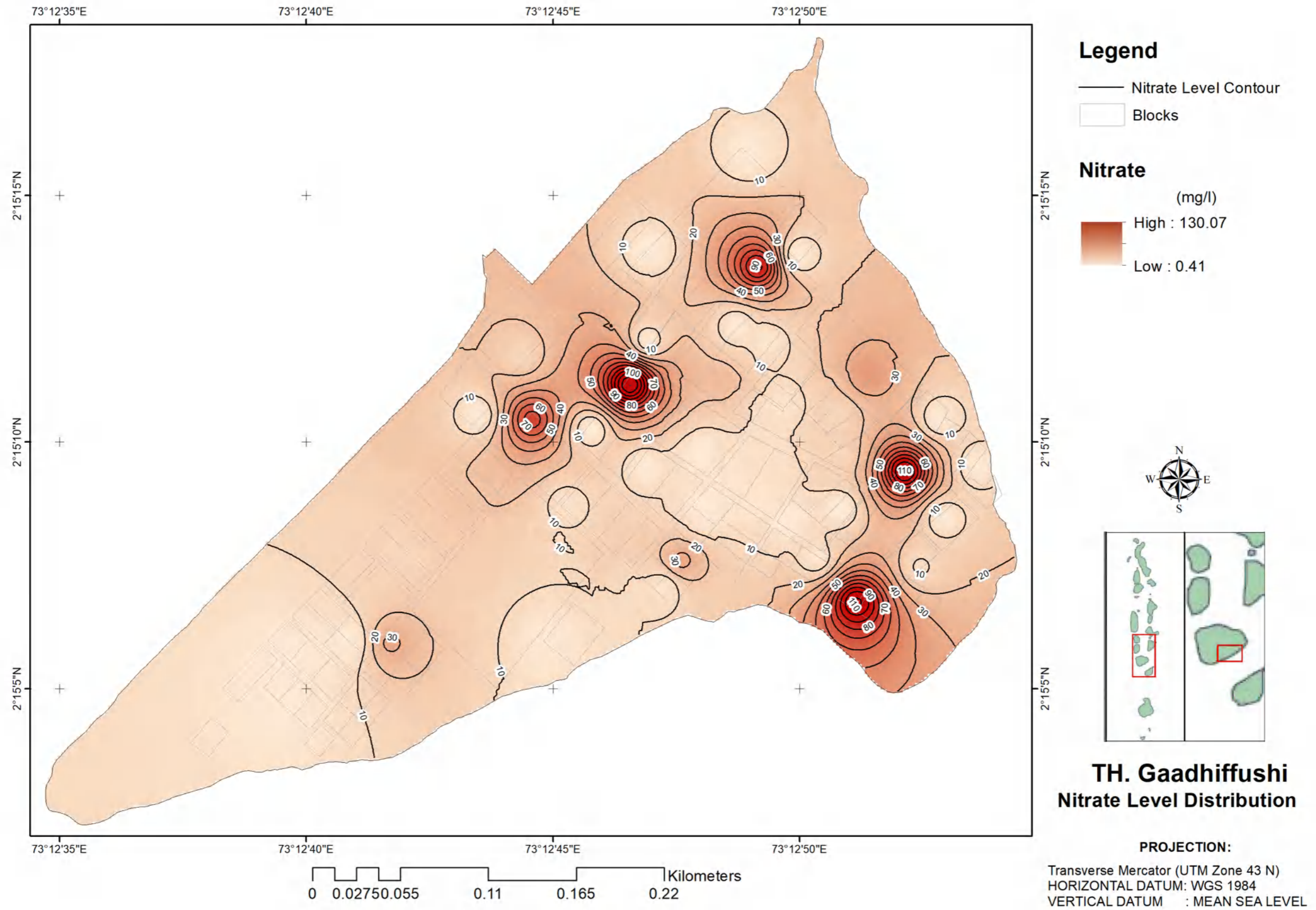


Figure 6-15: Nitrate Level Distribution in Th. Gaadhiffushi Island

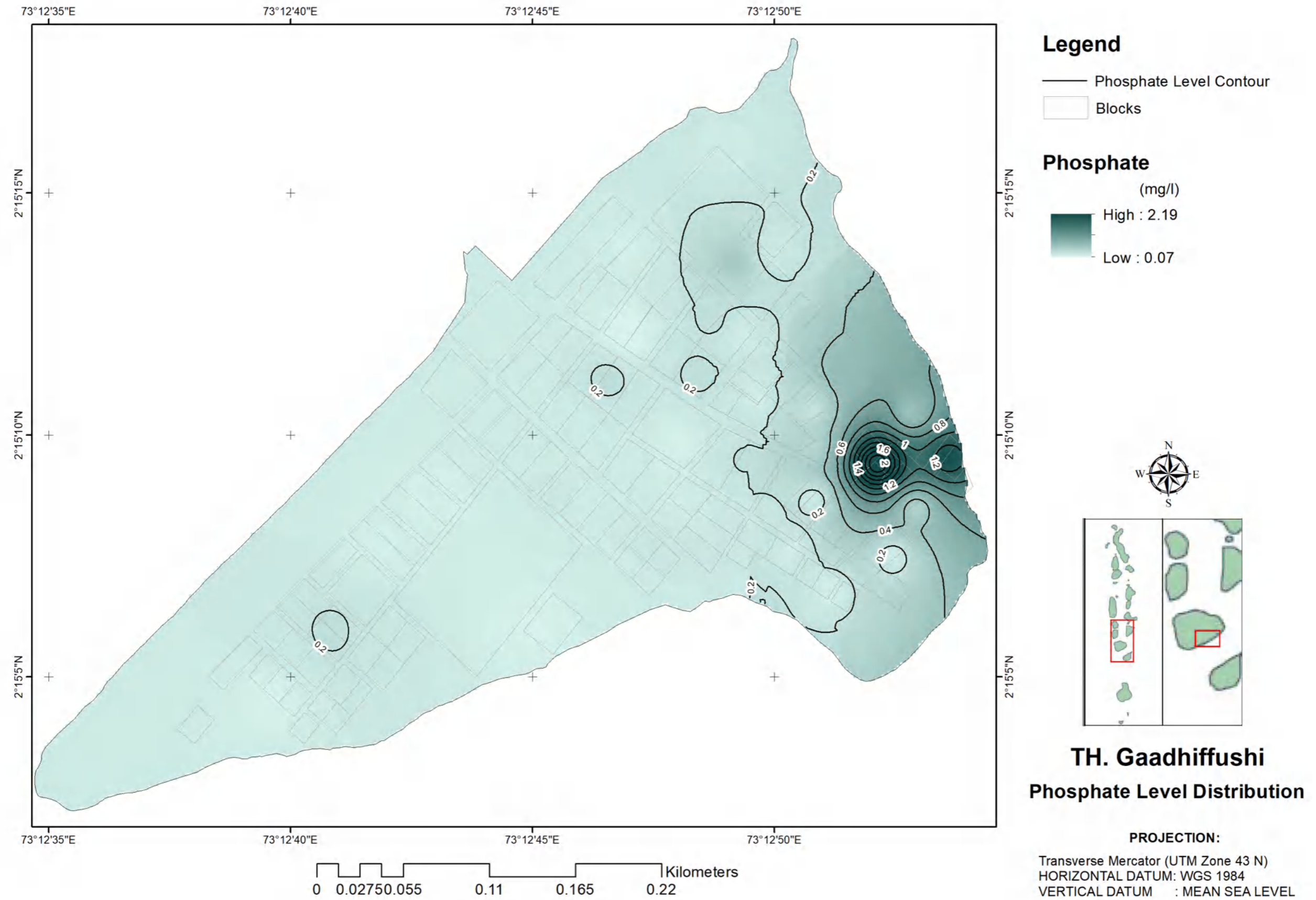


Figure 6-16: Phosphate Level Distribution in Th. Gaadhiffushi Island

6.7.6 Geophysical survey

The Electrical Resistivity (ER) tests were carried out in the locations as outlined in Figure 6-17 below. The ER survey included test points along 6 transects selected representatively based on reconnaissance surveys to adequately characterise different land uses and island cross-sections. The main transects were aligned along existing roads to maintain consistency and uniformity.

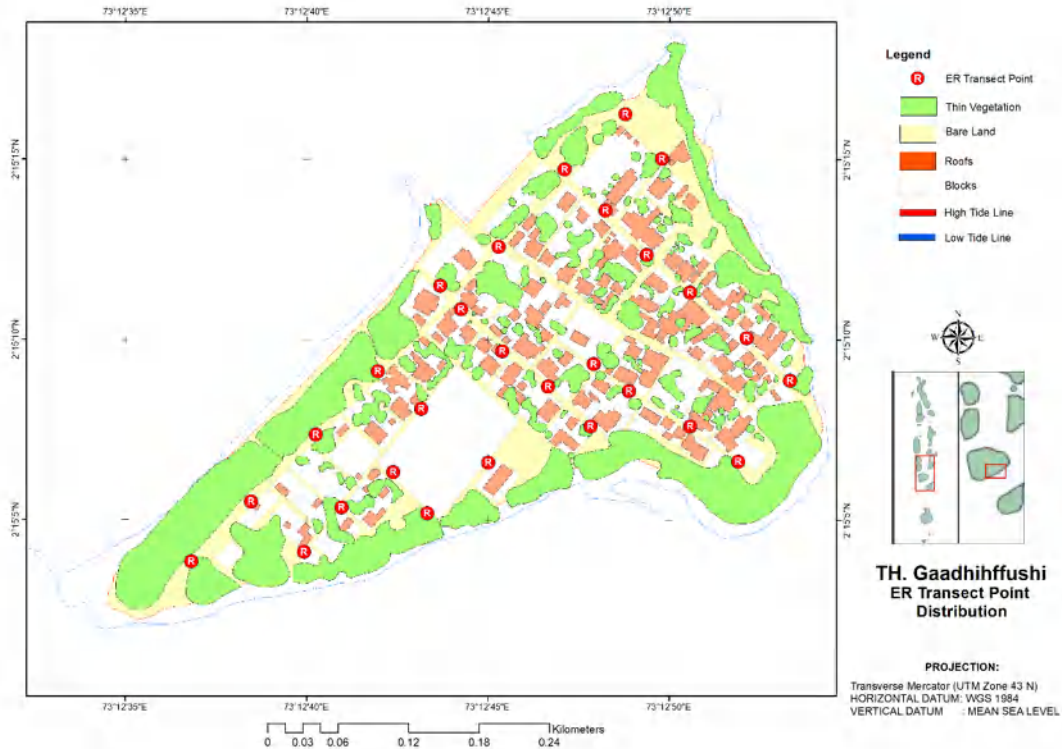


Figure 6-17: Location of ER points in Gaadhiffushi Island

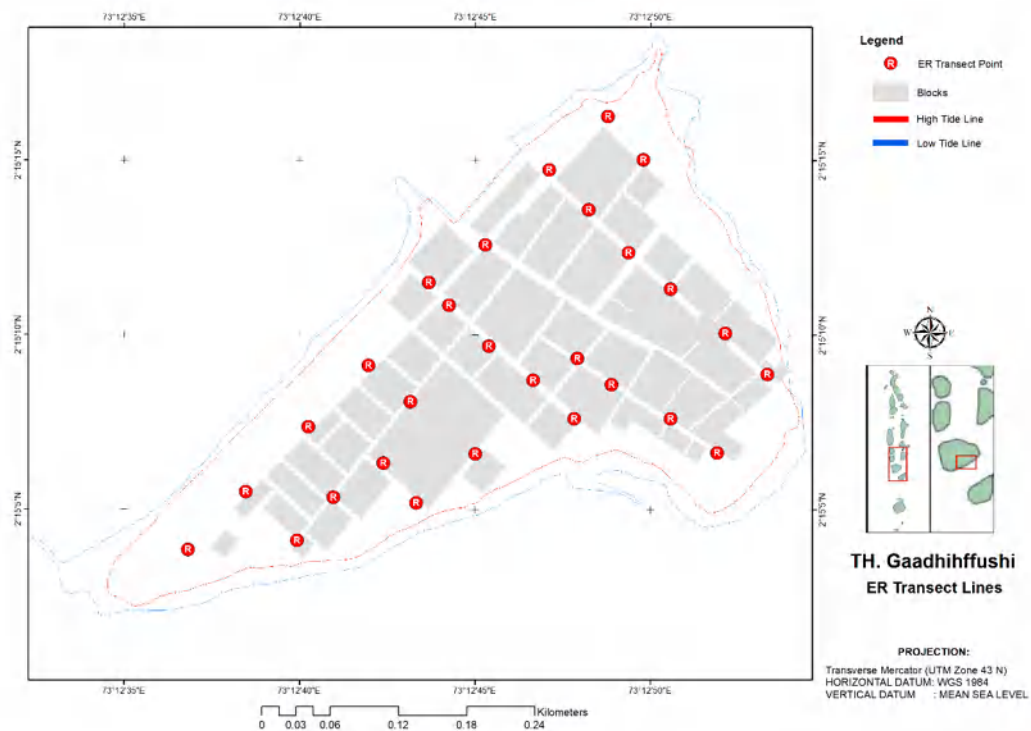


Figure 6-18: ER Test Points and Transect Lines in Gaadhiffushi Island

6.7.7 Aerial surveys

Based on the aerial survey, a multiple data set consisting of buildings, roof cover, land cover, change detection and shoreline were extracted. This data is shown in the following Figure 6-19. The total roof cover for this island is 17,436 m².

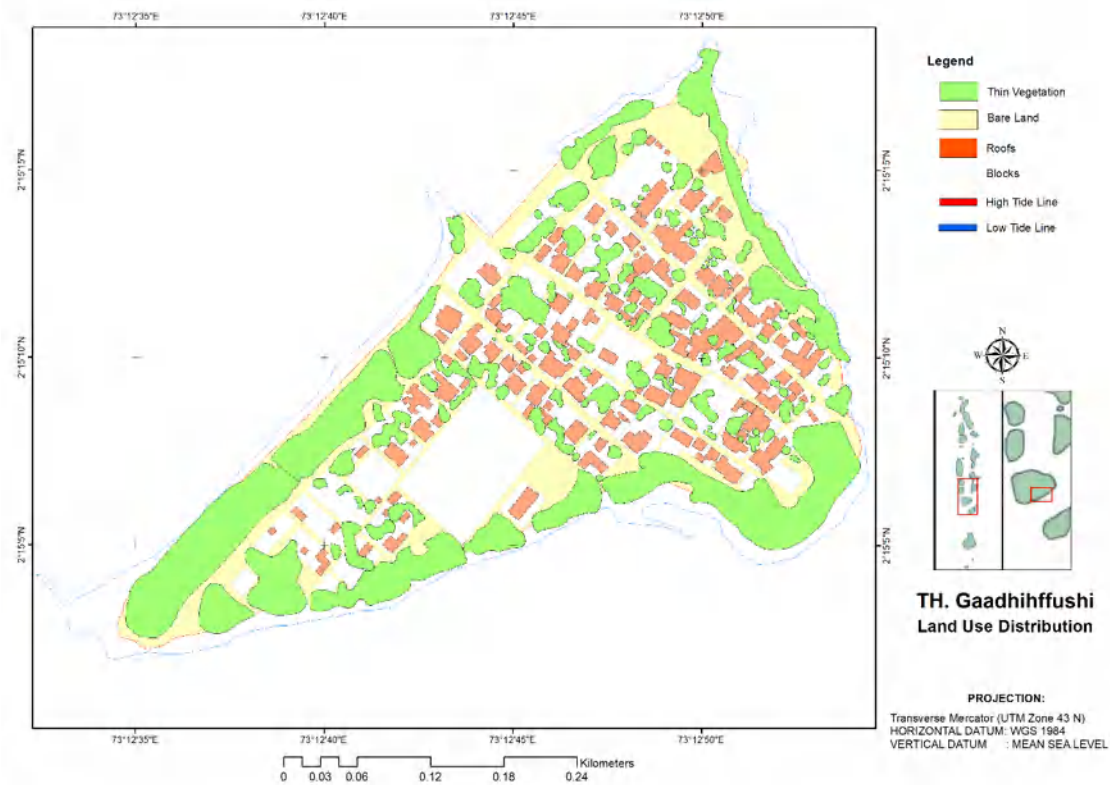


Figure 6-19: Roof Cover in Gaadhiffushi Island based on UAV Survey

6.7.8 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 yards, road surfaces, etc., is not usable as there is no mechanism for its collection and treatment.

6.7.9 Freshwater lens

Based on the Electrical Resistivity (ER) surveys, the depth to groundwater level and the freshwater-saline water interface were determined for a set of transverse transects as shown in Figure 6-18. Plots in Figure 6-2 show the main two cross-sections of the island. The dotted lines in the plots indicate a simple interpolation of levels to mean sea level in the island boundaries.

Volume of the lens has been calculated with aid of ArcGIS and Surfer Software.

$$\text{Volume of lens} = 66,352 \text{ m}^3$$

$$\text{Groundwater Storage} = \text{Porosity (15\%)} \times \text{Lens volume (m}^3\text{)} = 9,953 \text{ m}^3$$

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented below in Figure 6-20 to Figure 6-22.

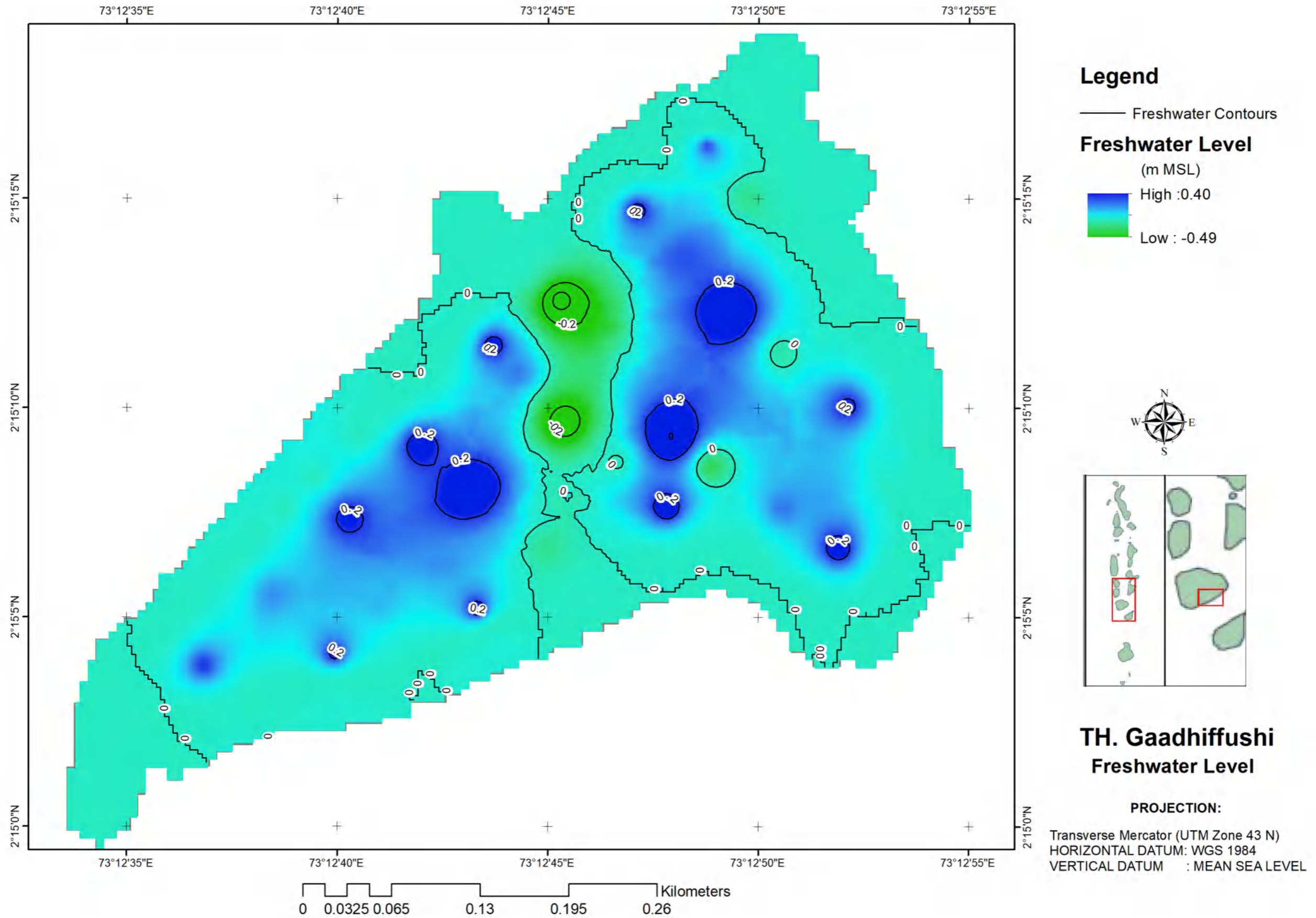


Figure 6-20: Freshwater Level in Gaadhiffushi Island

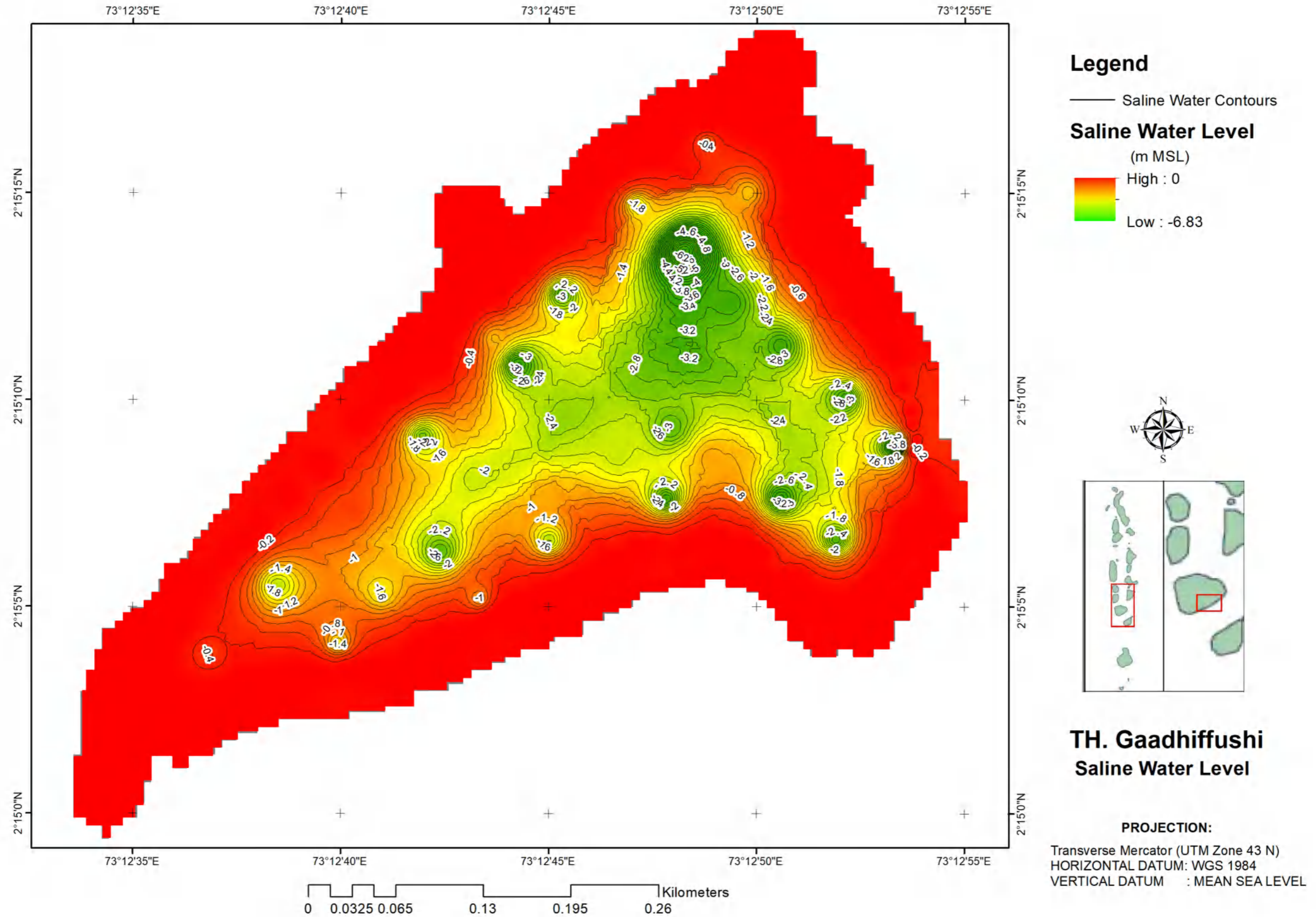


Figure 6-21: Saline water Level in Gaadhiffushi Island

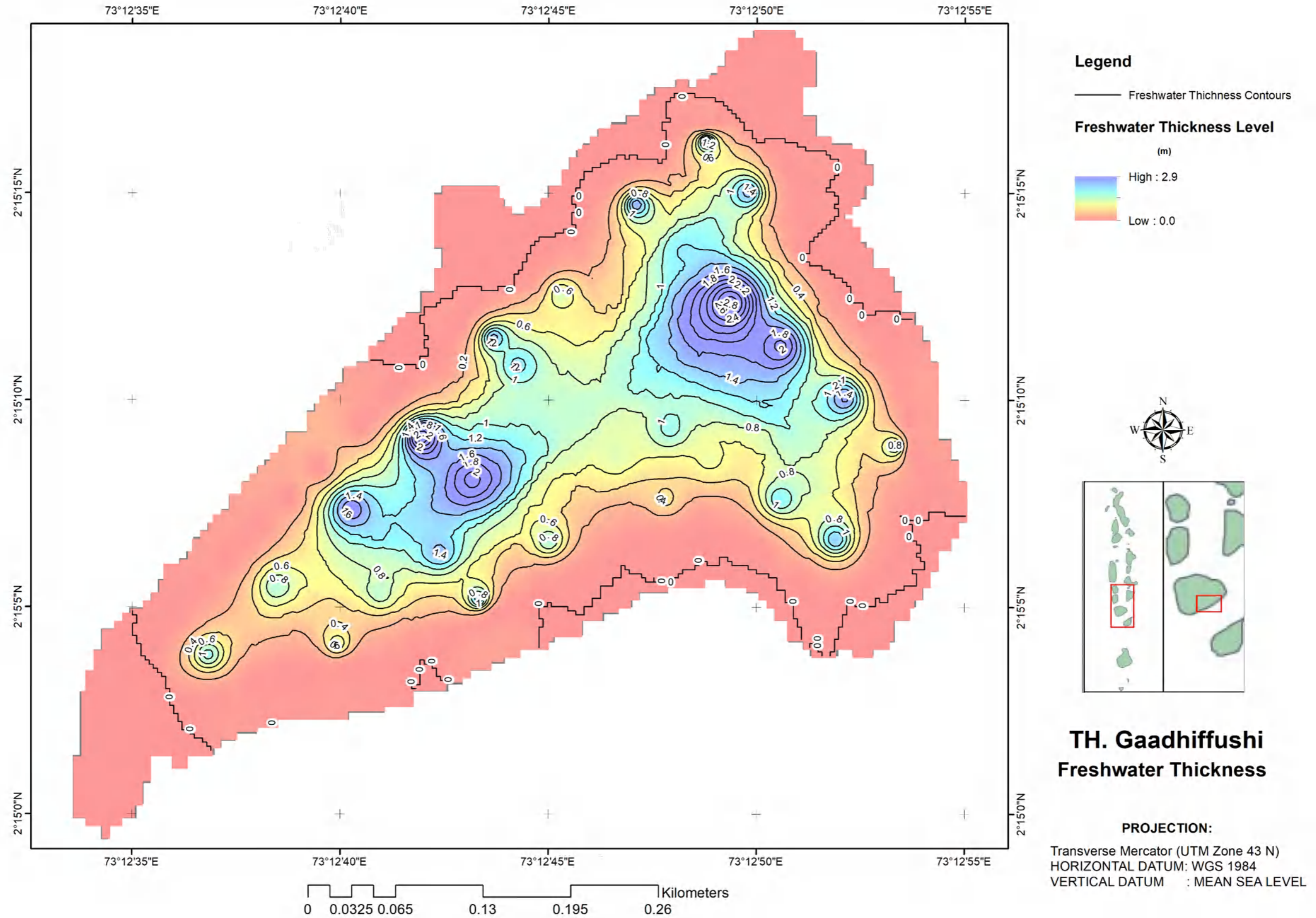


Figure 6-22: Freshwater thickness in Gaadhiffushi Island

The maximum freshwater thickness of the island is 2.90 m (It is noted here that these readings were taken in September/October, which is the wet season and the with a reasonably higher number of wet days per month of the year).

6.7.10 Water balance and recharge

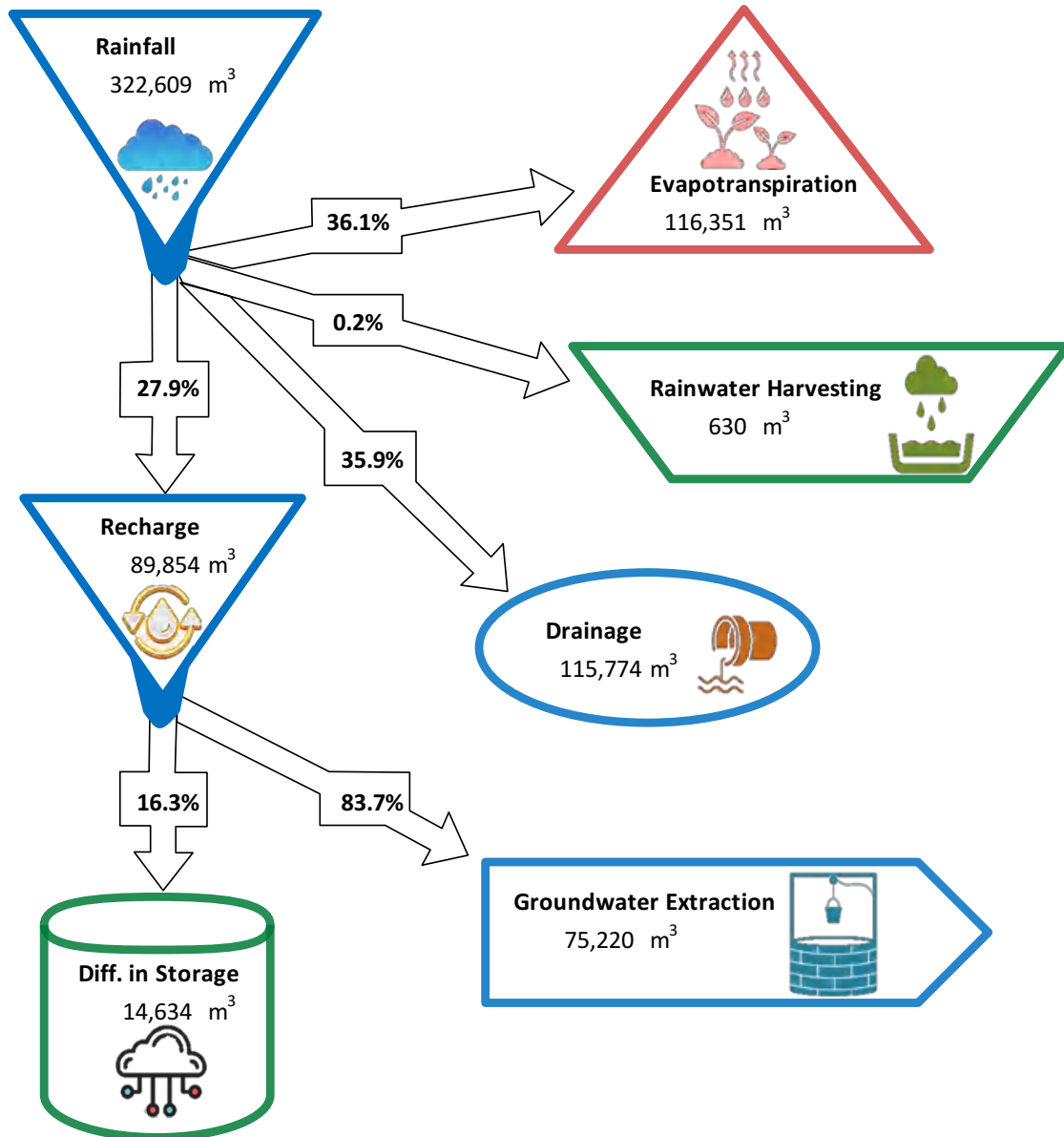


Figure 6-23: Schematic of water balance in Gaadhiffushi Island

An annual estimation is carried out based on the water balance method (Falkland, 2000). Rainwater harvesting is calculated using the number of rainwater harvesting units on the island. According to the spatial mean annual rainfall of the Maldives, the annual average rainfall of Gaadhiffushi Island is reported as 2,205 mm/year. Evapotranspiration was estimated using crop water requirements for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. Drainage or the surface runoff was calculated by considering an aggregate runoff coefficient for the island based on the land usage (roof cover, bare land, farmland, roads, playgrounds, wetlands). 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 the difference in storage.

6.7.11 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 106 m³ per day which was calculated by subtracting groundwater extraction from recharge volume derived from the schematic water balance model in Figure 6-23

6.7.12 Permeability test

Permeability tests were carried out in the selected locations as outlined in Figure 6-24.

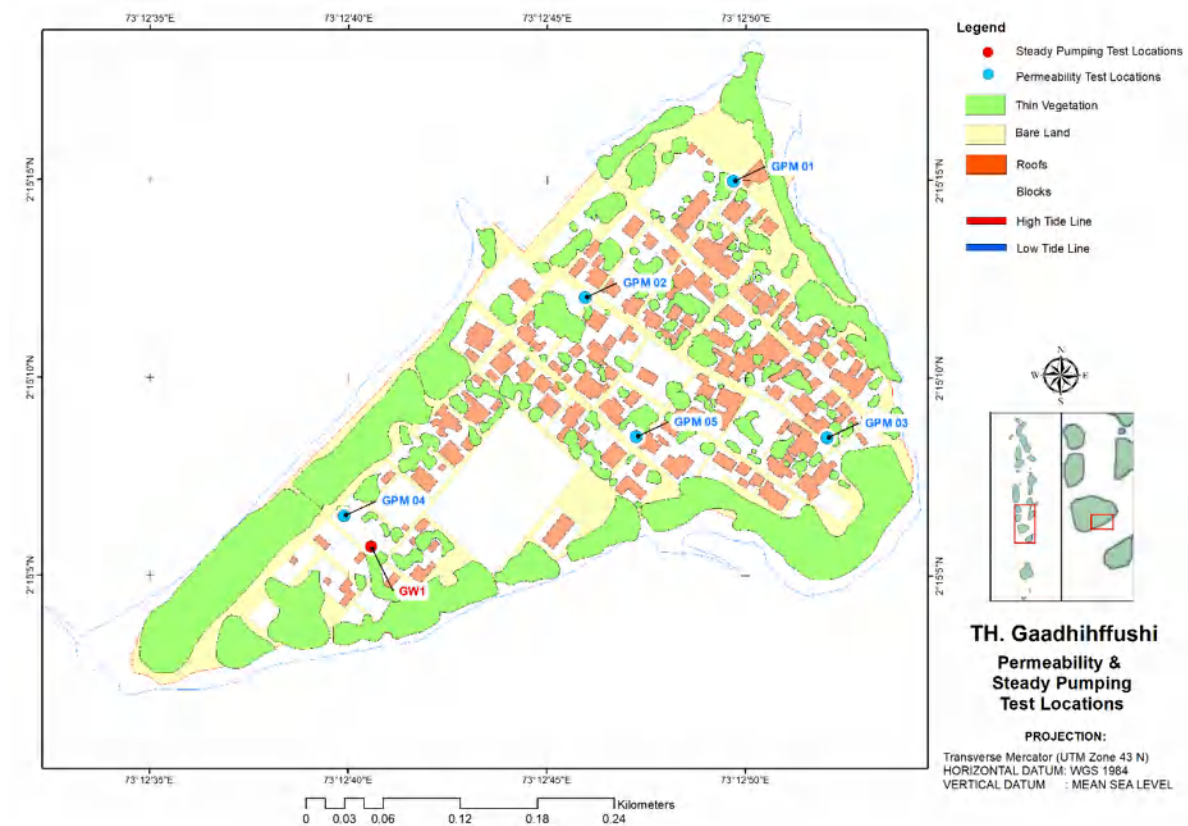


Figure 6-24: Locations of permeability and steady pumping tests in Gaadhiffushi Island

The estimated permeability values for the above test locations are presented below in Table 6.10. The data will be comparatively verified and interpreted when additional data is acquired and calculations for other islands are completed.

The parameters have their usual notations where, K = Coefficient of permeability (m/s under Q unit gradient), Q = Steady flow into well (m³/s), H = Height of water in well (m), l = length of the perforated section (m), U = thickness of saturated permeability material above water table, r_1 = outside radius of the casing (radius of the 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_s = Conductivity Coefficients, and T_u = distance from water level in the casing to water table (m).

Table 6.10: The Estimated Soil Permeability Values in Gaadhiffushi Island

Point	GPM 01	GPM 02	GPM 03	GPM 04	GPM 05
D (m)	0.480	0.680	0.700	0.680	0.800
H (m)	0.480	0.680	0.700	0.680	0.800
l (m)	0.480	0.680	0.700	0.680	0.800
U (m)	0.600	0.880	0.940	0.850	1.000
T_u (m)	0.600	0.880	0.940	0.850	1.000
r (m)	0.076	0.076	0.076	0.076	0.076
Q (m ³ /s)	3.22E-05	7.83E-05	1.01E-05	9.57E-05	1.94E-05
r_1 (m)	0.076	0.076	0.076	0.076	0.076
r_e (m)	0.010	0.010	0.010	0.010	0.010
T_u/l	1.250	1.294	1.343	1.250	1.250
X = (H/ T_u x 100)	80%	77%	74%	80%	80%
Section	Zone 2	Zone 2	Zone 2	Zone 2	Zone 2
l/r_e	46.19	65.44	67.37	65.44	76.99
C_s	98	95	100	95	120
K (m/s)	8.12E-05	1.38E-04	1.60E-05	1.74E-04	2.51E-05
K (m/day)	7.01	11.91	1.38	15.05	2.17

6.7.13 Steady Pumping Test

Pumping tests were conducted in three existing wells to estimate the aquifer properties of unconfined water bearing formation and transmissivity of the water bearing formation was estimated using Muskat's Method.

Table 6.11: Selected Steady State Pumping Test Locations in Gaadhiffushi Island

Well No.	C'	A (m ²)	t' (s)	$\ln\left(\frac{s_1}{s_2}\right)$	T (m ² /s)
GW1	4.4	1.88	720	4.11	0.007519

The measured transmissivity (m²/s) is 0.0075 m²/s. During the testing period, EC (Electrical conductivity) of the well increase from 950 μ s/cm to 4950 μ s/cm.

6.7.14 Status of groundwater availability in Gaadhiffushi Island

1). The selected Gaadhiffushi island has dimensions of width = 400 m and length = 700 m, with a total land area of 14.63 ha, a population of 272 persons, and a land use of Roof cover (Built up area) 2.21 ha (15.1%), Vegetation (Thick) 0.00 ha (0.0%), Vegetation (Light) 6.27 ha (42.9%), and Barelands 6.15 ha (42.0%).

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

3). Soil overburden permeability tests (constant head) were carried out at five (05) locations while steady-state pumping tests were conducted at 01 locations. In addition, the groundwater level was also recorded at 10 locations where groundwater water quality samples were tested.

4). Permeability tests were carried out at representatively selected five (05) 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 \pm Standard Deviation).

5). The ground elevation values ranged from a minimum of -0.34 m MSL to a maximum of 1.89 m MSL, with an average of 0.64 ± 0.39 m MSL (Mean \pm Standard Deviation).

6). The upper boundary of the freshwater lens (FWL) varied from a minimum of -0.49 m MSL to a maximum of 2.18 m MSL, with an average of 0.04 ± 0.07 m MSL (Mean \pm Standard Deviation).

7). The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -6.83 m MSL to a maximum of 0.00 m MSL, with an average of -0.82 ± 1.03 m MSL (Mean \pm Standard Deviation).

8). Accordingly, the freshwater lens (FWL) volumetric values ranged from a minimum of 0.07 m to a maximum of 1.23 m, with an average of 0.67 ± 0.21 m (Mean \pm Standard Deviation).

9). The groundwater profile in the island is characterised by a relatively Low (0.20%) Rainwater Harvesting (%) relatively Very High (35.89%) Drainage (%) relatively High (27.85%) Recharge (%) while the water use shows relatively Very High (83.71%) Groundwater extraction (%) leading to relatively Very Low (16.29%) Difference in Balance Storage (%).

10). The freshwater lens (FWL) volume calculated based on ER transect test data is 66,352 m³ with a maximum FWL thickness of 2.90 m and a steady state groundwater storage of 9,953 m³.

6.8 Conclusion

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 106 m³ per day, while it is 88 m³ per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 299 m³ per day and this exceeds the allowable Safe Yield in the island by 514% (Very Highly Stressed). At present, there exists no island wide water supply network and the sewerage network is under construction.

Relative hydraulic condition of the island lies in 'Semi-pervious' state while present aquifer condition remains at 'Poor' – 'Good' state based on the hydraulic conductivity estimation carried out as per Bear (1972) and transmissivity of the formation was compared as per Krany (1993). Moreover, general status based on transmissivity ranged 'High' and potential for groundwater recharge remains 'Low' – 'Moderate' as per the estimations.

7 SH. FOAKAIDHOO ISLAND

7.1 General overview of the island

The island of Foakaidhoo (Figure 7-1) is located on the middle of Shaviyani Atoll at coordinates 73° 08'55"E and 6°19'35"N. The island has an area of about 0.66 km² and measures about 0.78 km in width and 1.152 km in length. The population of the island was found to be about 1,882 residents as of December 2021. The island has a harbour on the North Western side of the island. The following table outlines some basic information about the island and the following map outlines the location of Foakaidhoo.

Table 7.1: Basic statistical information on Foakaidhoo island in Shaviyani Atoll.

Name of the island	Th. Foakaidhoo
Longitude and Latitude	73° 8'55"E, 6°19'35"N
Area	66.01 ha (0.66 km ²)
Population (Dec 2021)	1,882
Distance from Male'	241 km
Harbour	Present
Island sewerage network	Under Construction
Water supply network	No
Other infrastructure	RO Plant (Under Construction)

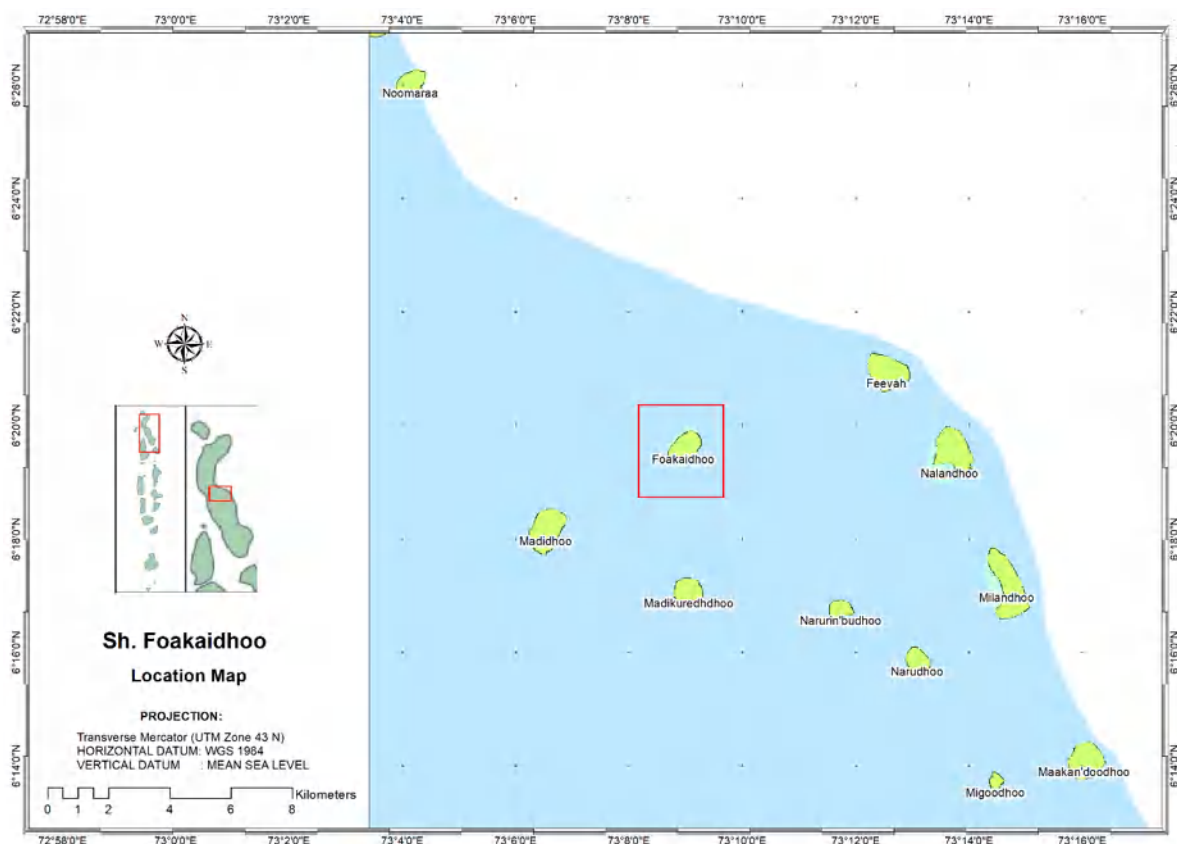


Figure 7-1: Location map for Foakaidhoo Island, Shaviyani Atoll.

7.2 Topography and Geology

Foakaidhoo island is in the middle of the “Shaviyani Atoll” in Northern Maldives. It is located as an isolated island in the Eastern part of the atoll. Foakaidhoo island is ellipsoidal in shape and extends about 1,200 m in length and about 750 m in width. Here, basic topography and the geological setting is mostly based on the properties of the underground coral beds and actions of ocean waves and currents. The elevation of the island varies from 0 m to 2.52 m and generally flatland through the island. General geological profile in the island is composed of topsoil and beach coral sand deposits underlain by sandy coral rock. The sandy coral rock consists of weathered coral rock layer and hard fresh coral rock. The cross-section A to B shows a thin topsoil layer (0-0.5 m) and beach coral sand deposit layer about 0.5 m thickness in beach areas and about 1.5 m thickness in the middle of the island. In beach areas mostly beach coral sand exists as the top layer. Coral sand layer is mostly unconsolidated and permeable layer. Weathered coral rock depth is varying between 0.5 m (coastal area) to 8 m (middle of the island) from the MSL and it is a semi permeable layer. Fresh groundwater lens occupied both coral sand layer and weathered coral rock. Hard coral layer is mostly unconsolidated and impermeable and present as a fresh rock. Both cross-sections A-B and C-D in the island show a uniform weathering and a general trend observed is that the central part of the island shows a higher weathering compared to the coastal areas. However, both cross sections clearly show deep weathered areas up to 8 m from msl in the middle part of the island.

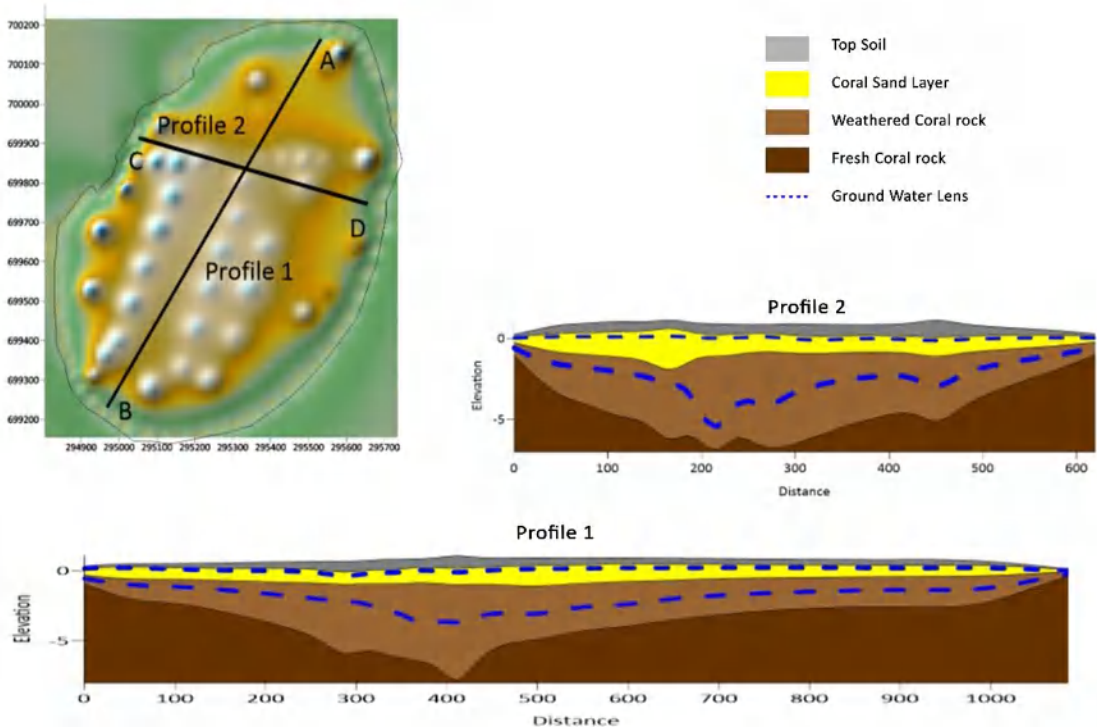


Figure 7-2: Geological sections of the island showing subsurface geological characteristics

7.3 Climate

Foakaidhoo experiences the typical two monsoons in the Maldives namely, the North-east monsoon from December/January to March/April and the South-west monsoon from Mid-May to November. There are no specific wind and rainfall data available for Foakaidhoo as there are no weather monitoring stations on the island itself. Based on the rainfall data of the nearest weather monitoring station, it shows a declining trend in rainfall for the past 30 years (Inception Report, 2021).

The historical rainfall data records from Hanimadhoo Island (not included in the 6 selected islands in Lot 2) located in the Haa Alifu atoll (47 km to the north from Foakaidhoo Island) has an annual

average rainfall of 1,747 mm with a standard deviation of 279.1 mm and the trend with the decadal means were shown in the following graph (MEE, 2021).

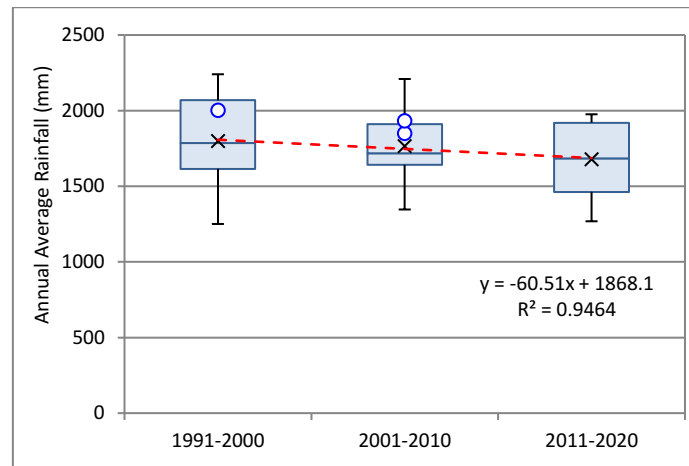


Figure 7-3: Decadal means and trend for rainfall in Hanimadhoo (1990 - 2020).

7.4 Demography

The total registered population of the island is reported by the island council as 1882 at present, with 936 males and 946 females. The resident population of Foakaidhoo is 1675 of which 105 are foreigners. The following Table 7.2 shows the population breakdown available for Foakaidhoo.

Table 7.2: Demographic Breakdown of Foakaidhoo Island as of December 2021

Registered Population (locals)			Resident population								
			Total			Maldivians			Foreigners		
Both	Male	Female	Both	Male	Female	Both	Male	Female	Both	Male	Female
1882	936	946	1675	-	-	1570	-	-	105	100	5

7.5 Socio-economic condition

7.5.1 Natural resources and land uses

Foakaidhoo is located at the Northern region of Maldives in Shaviyani atoll and has an area of 66 ha. There is no approved land use plan as of yet however they do have a draft plan. Approximately 40% of the island is occupied with residential plots and support services. The remaining areas are mostly wetlands which encompass around 55% of the island. The island council now has the authority to allocate lands for different purposes with an approved land use plan. Economic Activities

The main economic activities people are involved in include fisheries, agriculture and boatbuilding. Women are mostly involved in fish processing and thatching/weaving ropes which is supplied to tourist resorts.



Figure 7-4: Summary of household and socio-economic activities

7.5.2 Accessibility and Transport

The only direct mean of access to the island is via sea transport by speed boats or Dhonis. It can be private hire or by ferries. Other means of transport is via air to the domestic airport at Funadhoo of the same atoll and launch transfer from airport to Foakaidhoo.

A harbour with quay walls facing the North Western side of the island is used to access the island. Harbour upgrades works are ongoing at present and this involves land reclamation as well.

The island is equipped with the basic services and supporting infrastructures.

7.5.2.1 Public Facilities and Amenities

The public facilities available in the island include:

- Power House
- Health Center
- Preschool
- Primary/Secondary School
- Mosques
- Government institutions (Office for Island Council, Island Court)
- Police Center
- Fuel Station

7.5.2.2 Water supply

The main source of water for all uses except drinking and cooking is groundwater. Rainwater and bottled water are used for drinking and cooking. This is further discussed in Section 7.6 and 7.7.

7.5.2.3 Energy supply

The island community has access to power 24 hours a day.

7.5.2.4 Waste and Wastewater disposal

Solid Waste: They have a waste management plan and waste is collected and disposed of according to this plan. Households segregate waste at the household level (to 4 categories) and the segregated waste is collected from households by the Council. Waste at the waste site is also managed by the island council.

Sewage Disposal: Main method of sewerage disposal at Foakaidhoo is by means of septic tanks. Each household has a septic tank within close proximity and is infiltrated into the ground. This is further discussed in Section 7.6.

7.6 Existing water and sanitation situation

7.6.1 Water

Groundwater is the main source of water for all uses except drinking and cooking.

In general groundwater quality is considered bad as it has an odour, change of colour and in some areas the water gets murky specially during dry seasons. The reason of this contamination is unknown but as similar to most of the other islands, households use septic tanks to manage sewage and this could be one reason for the contamination. Some of the households use oxygen pumps to improve the water quality and some have more than one well that they use alternatively to get better quality groundwater. Survey results on such practices and perception of the community on groundwater quality are described further in Section 7.7.

Rainwater and bottled water are mainly used for drinking and cooking. Rainwater is harvested at both the household level and island level. At the household level, each household has at least one water tank with a capacity of 2,500 L. The council have established community tanks with a total capacity of 100,000L for rainwater harvesting. All tanks are used especially by the labourers and fish processing groups.

The general practice of rainwater harvesting at the island level is to clean the roofs thoroughly and letting the first flush pass to the roads which would eventually seep into the ground. Excess rainwater is also discharged to the roads in a similar manner. This sometimes causes flooding as well. Even with a large water storage capacity, they had to request for water during last year (2020) as a lot of workers were residing in the island for various projects and their main source of water was from these tanks. It was also noted that during the past 10 years, they had to request for water 4 times during the dry season and this need has decreased with the establishment of more tanks.

A government funded rainwater harvesting system is also under construction where roofs of all government institutions buildings/offices (council, mosque, health centre, school, etc) will be used to collect rainwater into public tanks which will then be filtered and distributed to 3 different areas of the island through common water taps to be used by the public. The project is still ongoing.

Establishment of a RO Plant is also ongoing is expected to be completed in early next year 2022.

7.6.2 Wastewater and Sewage Disposal

Currently sewage is disposed by means of septic tanks. Each household has a septic tank within close proximity and are infiltrated into the ground. It was noted that most of the households keep the soakage pits outside the house, away from the groundwater wells although the septic tank is inside the house, to reduce the impact of sewage to the groundwater. According to the social survey that was carried out under this study, about 61% of the respondents kept the septic tanks 15 ft or more away from the well.

Establishment of a proper sewerage system with household connections is currently ongoing. It is expected to be completed by end of this or early next year 2022. Once the new sewerage facility has been established, the existing facility will be abandoned. The septic tank inflows from the pipes will be ceased by disconnecting the inflow pipes. The remaining sludge in the pipes and septic tanks will then be removed by sewer jetting and released to the sea via an outfall pipe.

7.7 Results of the Baseline Surveys: Water Usage

7.7.1 Summary of socio-economic surveys

As detailed in the methodology section of this report (Section 1.4.3.2), a survey was carried out to determine the water usage at households (HHs), commercial entities (cafés), institutions and places with industrial uses (agricultural lands, fish processing). The survey was carried out from 18th May to 22nd May 2021 with the help of local enumerators. The following Table 7.3: summarizes samples taken for each sector at a 95% confidence interval and total number of completed surveys for each.

Table 7.3: Population and Sample taken for the social survey

Categories	Population	Sample	Forms Completed
Households	280	162	147
Farmers	54	19	14
Fishing Vessels	7	7	5

Categories	Population	Sample	Forms Completed
Fish Processing	3	3	3
Institutions	4	4	3
Guest houses	1	1	1
Café/restaurants	4	4	2

Note: A number of mitigation measures were adopted to ensure to achieve the 95% confidence level sample size. The challenges and limitations and the measures undertaken to mitigate the challenges are listed in Section 1.4.3.3.

The key findings from this survey show that a total of 666.38 liters of groundwater are estimated to be used per capita per day for various domestic uses. The respective water use situations including domestic, commercial and institutional uses are illustrated in the following sections.

7.7.2 Water usage for domestic purposes

7.7.2.1 Domestic Water Usage

A household survey was carried out at 95% confidence interval. A total of 159 HHs were surveyed of which 147 HHs responded. As presented in Table 7.4, 95% of HHs have at least one of 2,500L capacity HDPE rainwater tanks at their homes to collect rainwater for daily uses. Among the 147 HHs, 87% uses rainwater for drinking while 98% also uses it for cooking.

Groundwater is mainly used for non-potable use in all the households surveyed.

Table 7.4: Groundwater and rainwater use data for Foakaidhoo

Rainwater	Per cent (%)
Households with rainwater tanks	95%
Rainwater use for drinking	87%
Rainwater use for cooking	98%
Groundwater	Per cent (%)
Groundwater as drinking source	0%
Groundwater for cooking	7%
Groundwater for non-potable use	77%
Total number of household wells surveyed	147
Percentage of wells surveyed fitted with pumps	99%

As it can be observed from Table 7.4, it is very significant that the people of Foakaidhoo are heavily dependent on rainwater for all potable uses.

Based on the survey carried out, an average daily groundwater demand per capita for domestic non-potable 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 7.5. The total domestic groundwater use is estimated to be 666.38 liters per capita per day.

Table 7.5: Domestic Ground Water Usage in Foakaidhoo

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
159.4	45.0	45.0	60.8	310.2

7.7.2.2 Perception on Groundwater

The HHs were also asked about their perception on groundwater, if it is safe to use for daily purposes and whether the quality of groundwater is good or bad.

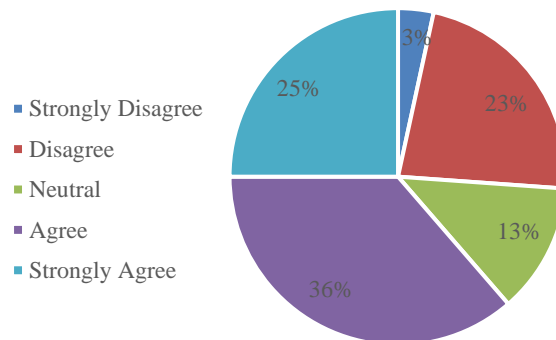


Figure 7-5: Perception of HHs of Sh Foakaidhoo on safety of Groundwater

As it can be seen from Figure 7-5, a total of 61% agreed that groundwater is safe to use for non-potable uses, whereas a total of 26% disagreed that groundwater is safe for use and 13% noted it as neutral.

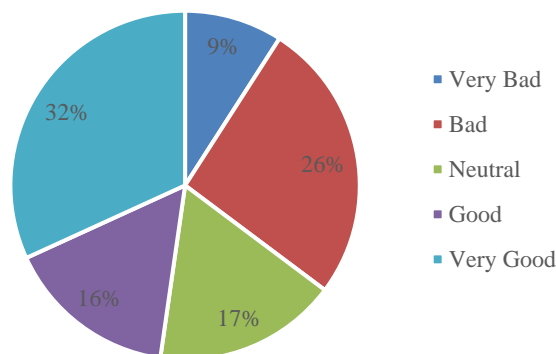


Figure 7-6: Perception of HHs of Sh. Foakaidhoo

Furthermore, the HHs were asked about the quality of groundwater with regard to their experience. While a 48% of the respondents reported the groundwater quality as good (32% good and 16% very good) 35% considers water quality as bad (26% bad and 9% very bad). The varying opinion on groundwater quality is because in Foakaidhoo as similar to many other islands surveyed in this project, in different parts of the island water quality is different and it varies with the change of weather.

During the consultations with the island council, it was noted that the groundwater quality is especially bad during dry seasons.

7.7.3 Water Usage by Commercial Activities

Foakaidhoo has 4 cafés of which 2 cafés were surveyed. There were no guesthouses.

The table below presents a summary of water usage by the cafés.

Table 7.6: Water Usage by commercial activities in Foakaidhoo

Cafés	Total Volume of water per day (Liters)
1	45
2	45

For the cafés, they use groundwater only for washing dishes. From the total 2 cafés that were surveyed, the total groundwater consumption for these Cafés was estimated to be 90 liters with an average of approximately 45 liters per café’ per day. It is important to note here that the average figure cannot be generalised for every café’ in the island as the capacity of each café’ and its level of operation would be different.

7.7.4 Water Usage by Institutions

Based on the survey carried out to collect data on water consumption by institutions, although the island has five places that can be considered as institutions which are the island council, power house, island court, school and health center we only got responses from the magistrate court, power house and school.

As per the respondents, groundwater in the institutions in Foakaidhoo are mainly used for mopping floors, flushing toilets and to some extent gardening. A total of approximately 11,831 liters of groundwater are estimated to be used per day by the institutions surveyed. As the use of each institution is different, to generalize water consumption of institutions to an average figure will not be accurate. However, it can be deduced that based on the data, 229.86 liters of groundwater are estimated to be used per staff per day at the institutions of Foakaidhoo (Table 7.7).

Table 7.7: Water Usage by commercial activities in Foakaidhoo

	Water Flushed (Liters)	Gardening (Liters)	Mopping (Liters)	Sub-Total Water Used (Liters)	Total Water Used (Liters)	Institutional Groundwater Usage (Liters Per Staff Per Day)
Magistrate court	72	409	7	488		
Power House	240	409	N/A	649	11,831	229.86
School	864	9,816	14	10,694		

7.7.5 Water Usage for Farming

A total of 19 out of the 54 farmers participated in the survey. Farmers mainly use groundwater for watering the plants. 100% of the surveyed farmers use groundwater extracted from wells using pumps to water their plants. Table 7.8 below summarizes the water usage to water the plants every day.

Table 7.8: Water Usage by Farmers in Foakaidhoo

Farmlands	Area of farmland	Volume of water used per day (Liters)	Total volume of water used per day (Liters) per sqft
5	65,000 sqft	300	0.0067
8	2,000 sqft	208	0.104
11	420 sqft	50	0.119
12	14,000 sqft	1,227	0.088
Total		1,785	

From the total 19 farmers that were surveyed, due to missing data only data from 4 farmers were able to be used in the analysis. Hence this is not a statistically significant sample. Nevertheless, from the available data it can be observed that total of approximately 0.029 liters (29ml) of ground water per sqft per day is used by farmers of Foakaidhoo.

7.7.6 Water Usage for Fisheries Activities

In Foakaidhoo, we were only able to survey the 3 fishermen and 2 fish processors. One of the fishermen respondents was also a fish processor. The fisherman represents a fishing boat and water usage depicts water used by the whole team for the fishing activity in that boat. Likewise, a fish processor represents 1 setup of fish processing, which maybe more than 1 person. In the fishing boat, they use groundwater for dishwashing, cleaning, showering and for laundry. In fish processing, they use groundwater mostly for the cleaning/gutting of fish. Rainwater is used for cooking fish.

Table 7.9: Water Usage by Fisheries activities in Foakaidhoo

Fishing Processors	Total Volume of groundwater used per day (Liters)
Fishing Vessel 1	14.29
Fishing Vessel 2	1,285.71
Fishing Vessel 3	428.57
Fishing Processing unit 1	
Fishing Processing unit 2	
Fishing Processing unit 3	
Total	1,728.57

As per Table 7.9, the volume of water used by each vessel is very different. This may be due to the difference in the capacity of the vessels and the type of fishery practiced. As this is not a statistically significant sample, a generalization of water usage per vessel cannot be deduced from the findings. Hence water usage per vessel is presented in Table 7.9.

7.7.7 Groundwater quality

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

The following Table 7.10 summarizes the water quality results.

Table 7.10: Summary of groundwater quality tests from Foakaidhoo Island in 2021

Sample No	EC ($\mu\text{S/cm}$)	pH	Turbidity (NTU)	DO (ppm)	Temp ($^{\circ}\text{C}$)	Salinity (PSU)	Nitrates (mg/L)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
Samples in Residential Areas											
F1	1280.90	7.28	0.186	0.74	27	0.63	37.30	19.00	0.12	105	0
F2	832.90	7.21	0.109	0.95	27	0.40	22.60	<0.02	0.58		
F3	1386.10	7.21	0.101	2.34	27	0.69	5.20	<0.03	0.44		
F4	669.50	7.51	<0.1	3.34	27	0.32	6.60	<0.04	0.16	1120	7
F5	1208.70	7.08	0.159	1.51	27	0.60	3.70	17.50	0.58	1414	21
F6	1981.70	7.08	<0.1	1.33	27	1.00	42.50	0.90	0.28	>2420	26
F7	812.30	7.59	0.141	3.67	27	0.40	7.50	<0.02	0.12		
F8	655.40	7.64	<0.1	2.38	27	0.32	0.10	<0.02	0.06		
F9	1190.00	7.58	<0.1	3.45	27	0.59	14.50	<0.02	<0.05	1414	32
F10	429.50	8.11	0.104	3.55	27	0.20	3.60	<0.02	<0.05		
F11	748.90	7.18	0.118	3.74	27	0.36	6.80	<0.02	0.10	>2420	218
F12	543.70	7.49	0.107	2.51	27	0.26	0.10	<0.02	<0.05		
F13	735.60	7.21	0.975	2.65	27	0.36	0.10	<0.02	0.18		
F14	1193.30	7.48	0.431	1.82	27	0.59	9.00	<0.02	0.08	816	37
F15	732.80	7.39	0.129	3.74	27	0.36	5.40	<0.02	0.14		
F16	689.00	7.22	<0.1	3.69	27	0.33	0.60	<0.02	1.31		
F17	1629.10	7.15	0.222	1.67	27	0.82	2.20	53.50	0.83	2420	980
F18	1427.60	7.52	0.135	4.06	27	0.71	5.90	<0.02	0.52	>2420	147
F19	687.50	7.40	<0.1	3.16	27	0.33	4.50	<0.02	0.73		
F20	1017.60	6.98	<0.1	1.61	27	0.50	33.50	0.03	<0.05		
F21	463.40	7.88	<0.1	5.93	27	0.22	0.30	<0.02	0.06	272	21
F22	889.50	7.32	<0.1	4.03	27	0.43	8.60	<0.02	0.11		
F23	567.10	7.42	0.441	2.91	27	0.27	4.40	<0.02	0.09	1120	10
F24	953.40	6.97	<0.1	1.56	27	0.47	69.40	0.02	<0.05	866	11
F25	778.30	7.39	<0.1	3.35	27	0.38	7.60	<0.02	0.49	579	579
F26	535.50	8.17	0.362	4.93	27	0.26	0.90	0.04	1.08		
F27	1679.30	8.18	0.770	1.63	27	0.84	1.30	57.00	<0.05		
F28	902.50	7.23	0.122	3.54	27	0.44	20.50	<0.02	<0.05		
F29	515.40	7.71	0.121	5.59	27	0.25	27.90	<0.02	<0.05		
F30	676.10	7.08	<0.1	1.63	27	0.33	16.90	<0.02	0.31	153	1
F31	1163.50	6.94	0.129	2.38	27	0.57	113.90	2.20	<0.05		
F32	852.10	7.39	0.115	3.98	27	0.42	21.00	<0.02	<0.05		
F33	947.90	7.21	1.650	1.77	27	0.46	0.40	5.00	<0.05		
F34	584.00	7.69	0.105	5.20	27	0.28	16.80	<0.02	<0.05		
F35	796.20	7.16	0.128	2.53	27	0.39	20.00	0.04	<0.05		

Sample No	EC (µS/cm)	pH	Turbidity (NTU)	DO (ppm)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
F36	442.50	7.79	<0.1	5.96	27	0.21	1.90	<0.02	<0.05		
F37	735.30	7.36	0.125	5.12	27	0.36	1.50	<0.02	<0.05		
F38	842.80	7.27	<0.1	5.16	27	0.41	1.70	<0.02	<0.05		
F39	397.00	8.12	0.101	5.70	27	0.19	1.80	<0.02	<0.05	816	7
F40	715.50	7.72	<0.1	5.49	27	0.35	1.00	<0.02	<0.05		
F41	926.20	7.13	<0.1	2.36	27	0.45	5.80	0.02	<0.05		
F43	1402.80	7.46	0.140	2.12	27	0.70	59.20	11.50	0.05		
Samples in Industrial Areas											
F42	28944.00	8.12	0.633	5.96	27	17.81	4.70	<0.02	<0.05		

Based on the full results and the summary shown in Table 7.10, the following can be summarized for Foakaidhoo Island:

- The EC of the groundwater is generally high, with an average of 1547.96 µS/cm which is below an acceptable limit for potable water of 1500 µS/cm. The electrical conductivity readings range from 397 to 28944µS/cm. 91% of readings fall within the acceptable limit.
- The pH of groundwater ranged from 6.94 to 8.18 with an average of 7.44. The pH values of all samples were within the WHO permissible limits of 6.5-8.5.
- Turbidity ranged from the lowest of 0.1 NTU to 1.65 NTU with an average of 0.22 NTU.
- Dissolved oxygen levels were low to moderate, with values varying from 0.735 mg/L to 5.96 mg/L with an average of 3.27 mg/L.
- The salinity of groundwater ranged from 0.19 PSU to 17.81 PSU with an average of 0.84 PSU. Salinity is expressed in Practical Salinity Units (PSU) which is equivalent to PPT.
- The average Nitrate concentration was 14.40 mg/L and therefore it exceeded the WHO guideline limit of 5.09 mg/L. But 24 of the 43 tested water samples exceeded this limit of 5.09 mg/L. The Nitrate concentrations ranged from 0.1 mg/L to 113.9 mg/L.
- Ammonia concentrations were generally low. The average ammonia concentration was 0.23 mg/L. This is within the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. Only 2 tested water samples exceeded this limit out of 38 (ranged from 0.02 to 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. All values were within the range 0.05-1.31 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). There were 25 samples tested below 0.1 mg/L.
- Total coliform levels were also found to be significant and ranged from the lowest count of 105 MPN/100 mL to the highest count of more than 2420 MPN/100 mL, with an average count of 1223.67 MPN/100 mL. Faecal Coliform levels were found to be less significant and ranged from the lowest count of 0 MPN/100 mL to the highest count of 980 MPN/100 mL.

EC values of the selected wells were collected at the start of wet period (September – October) and following table show the summary of all the result collected during dry and wet periods based on the land use distribution.

Table 7.11: Comparison of WQ results based on land usage

Land Use	Number of samples	Results are lined with conditions	Enrichment of measured parameters	Remark
Residential area	75	64	F1, F5, F6, F17, F24, F27, F31, F33, F42, F43, FW1	F1,F5,F6,F17,F24,F27,F31, F33,F42,F43 indicate the pollution due to anthropogenic activities. FW1-EC enrichment is due to higher groundwater extraction.
Agricultural area	4	-	FW31,FW33, FW34,FW36	These points are located within water logged area and sea water is mixing with water at water logged area.
Industrial areas	1	-	F42	This place is located along the beach line.
Total	58	52	6	

Considered desirable water quality limits:

- 1) EC<2500 $\mu\text{s}/\text{cm}$ (water could be used for potable and non-potable use depending of EC.
- 2) Nitrate (<50 mg/l), Phosphate (<5 mg/l), and ammonia (<0.5 mg/l) as per WHO guideline.

Ten (10) samples (F1,F5,F6,F17,F24,F27,F31,F33,F42,and F43) out of 75 analyzed samples in resident area has recorded higher concentration of ammonia and nitrate in groundwater. The enrichment of ammonia and nitrate could be due to contamination of sewerage into groundwater.

Sampling point (FW 1) at the area close to harbour has recorded high EC and it could be due to higher groundwater extraction.

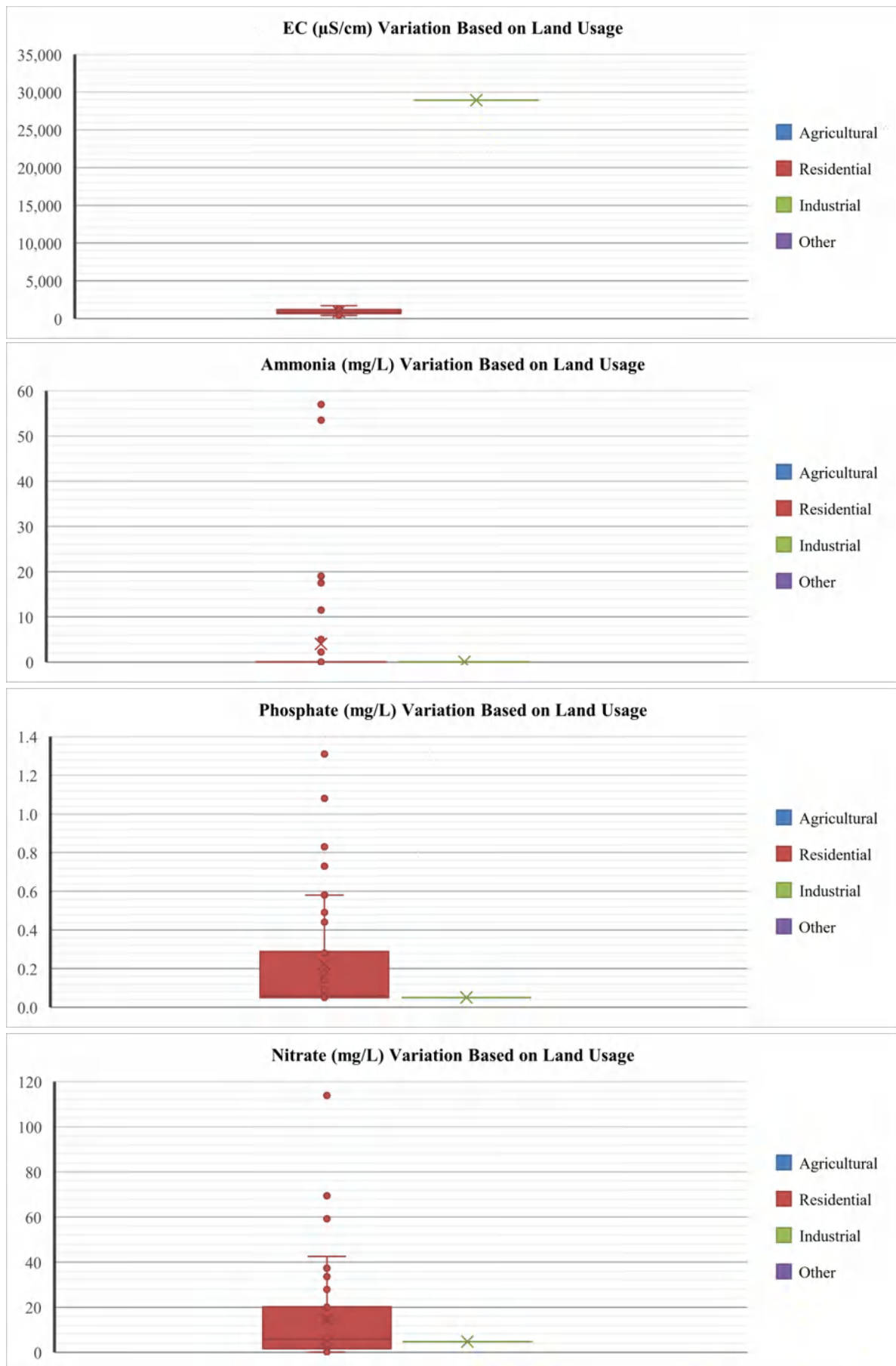


Figure 7-7: Variation of measured WQ parameters in Foakaidhoo Island

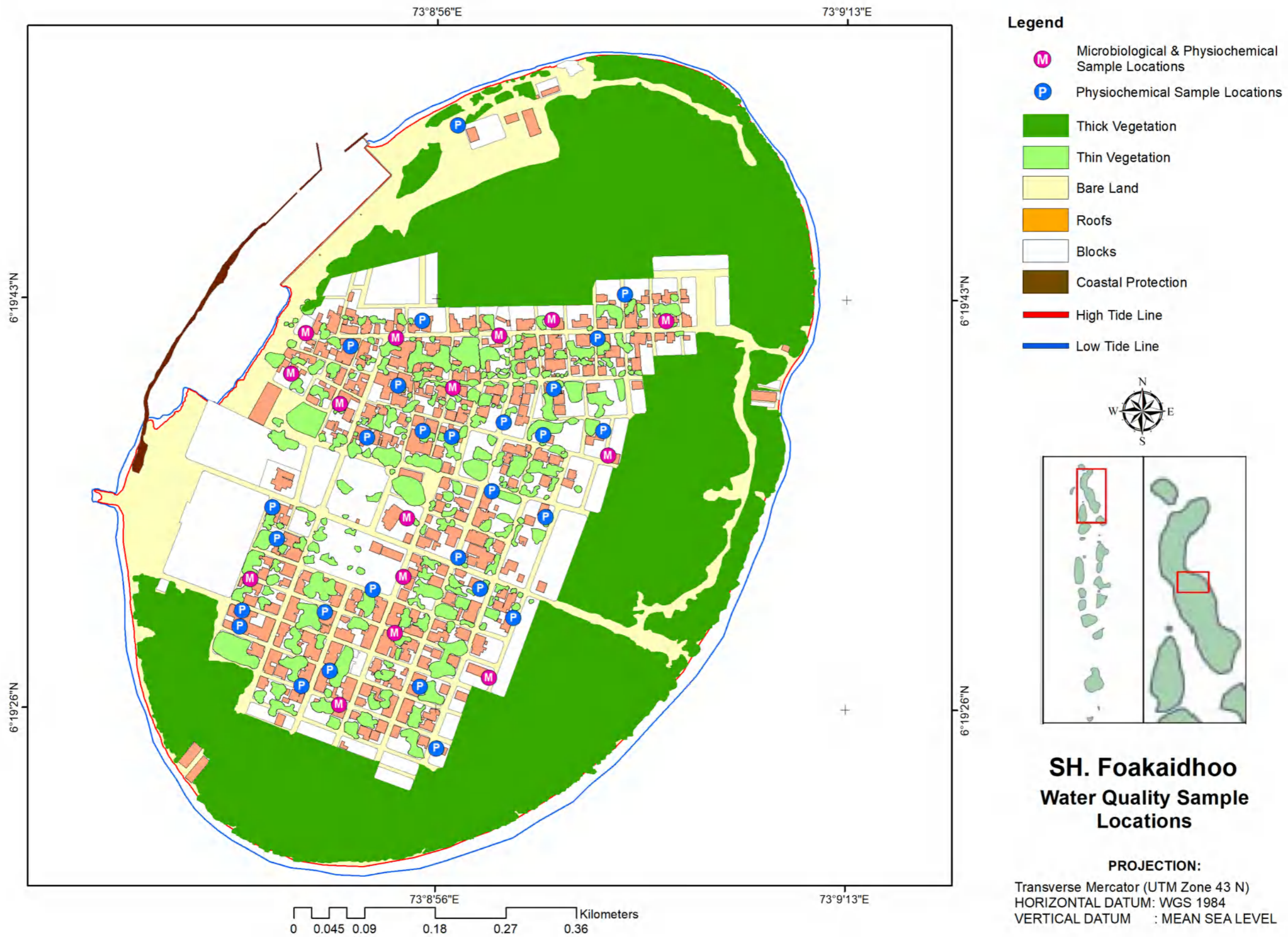


Figure 7-8: Location of groundwater sampling points in Foakaidhoo Island

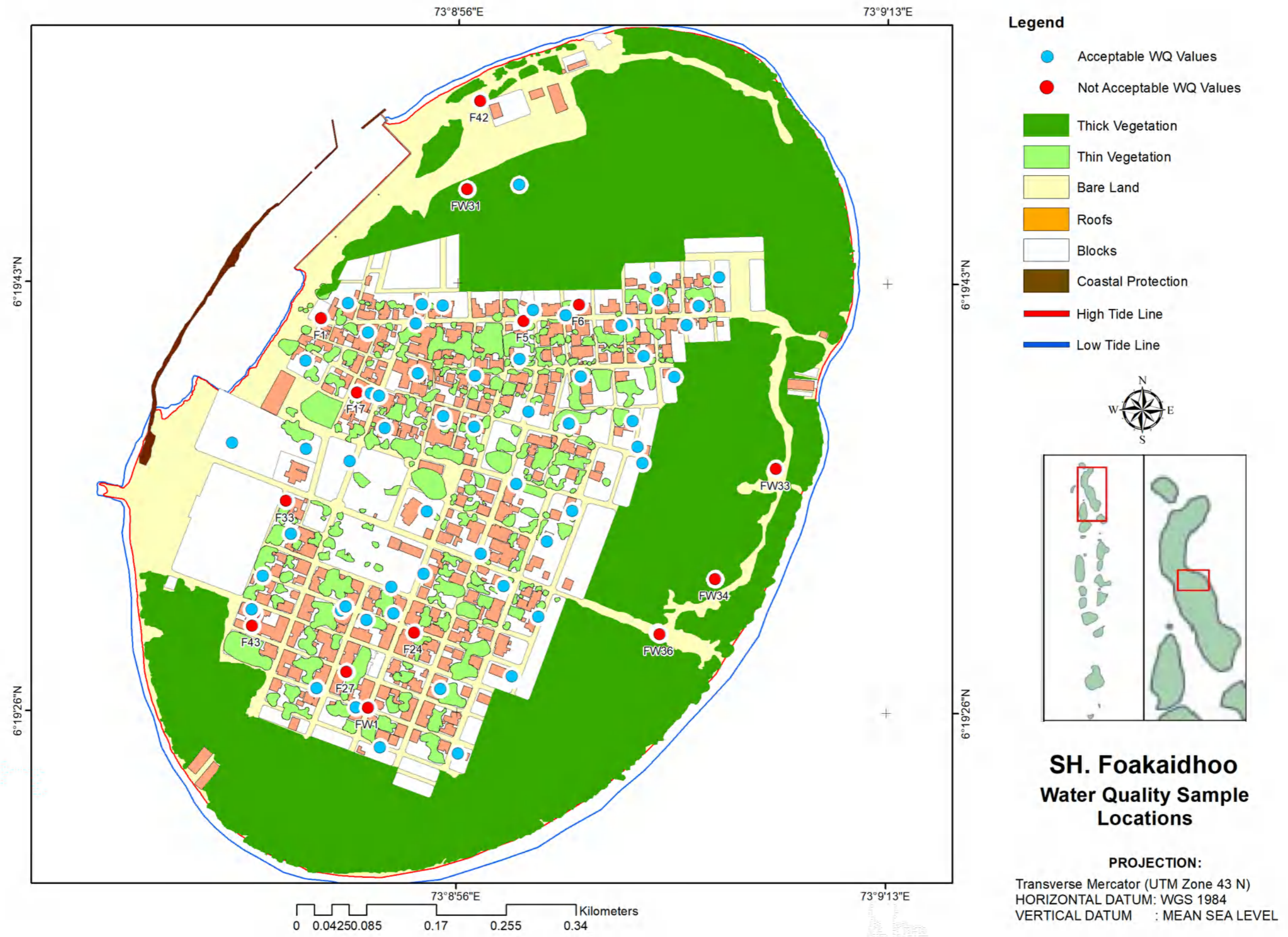


Figure 7-9: Location of groundwater sampling points in Foakaidhoo Island

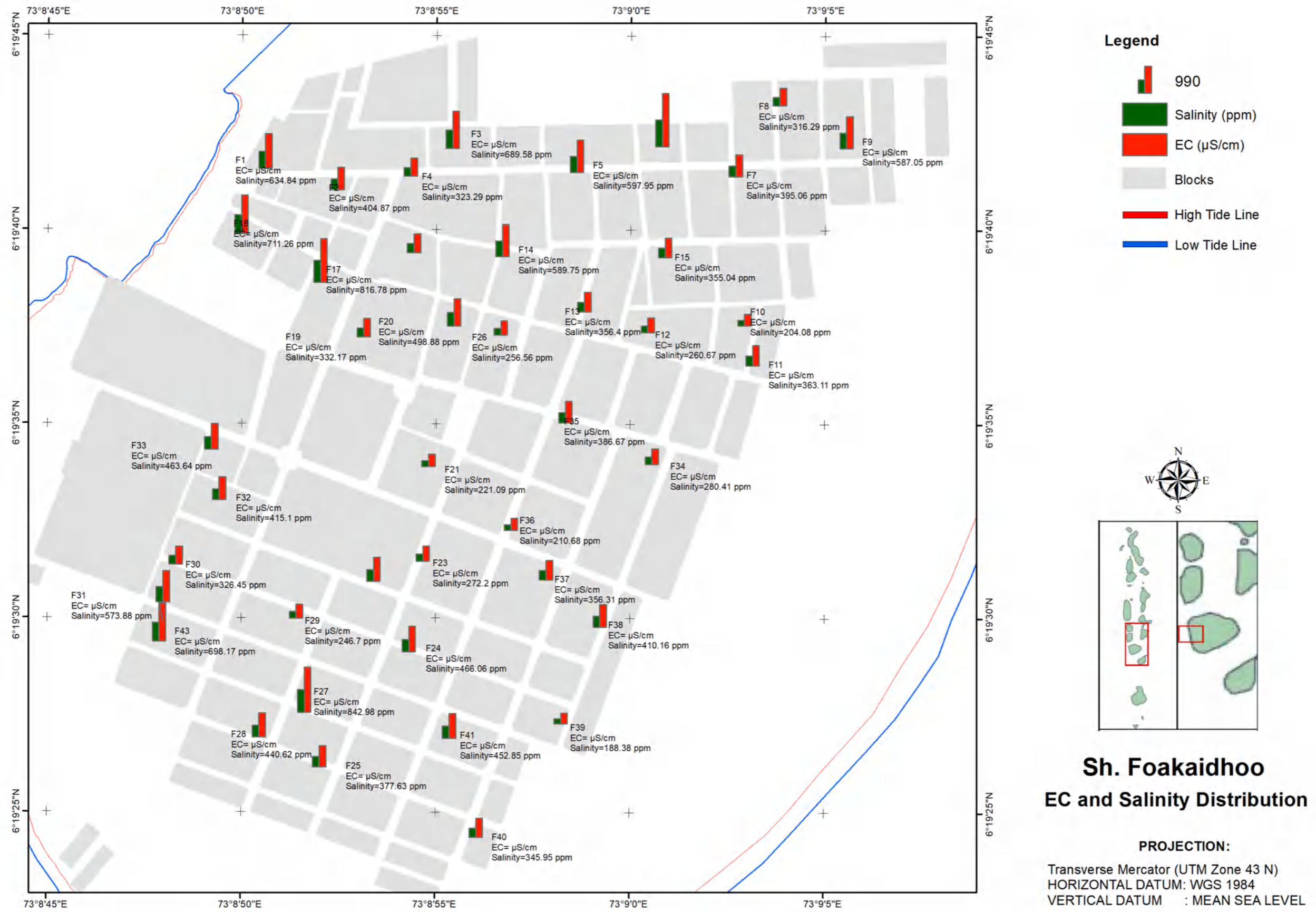


Figure 7-10: EC and Salinity Distribution in Sh. Foakaidhoo Island

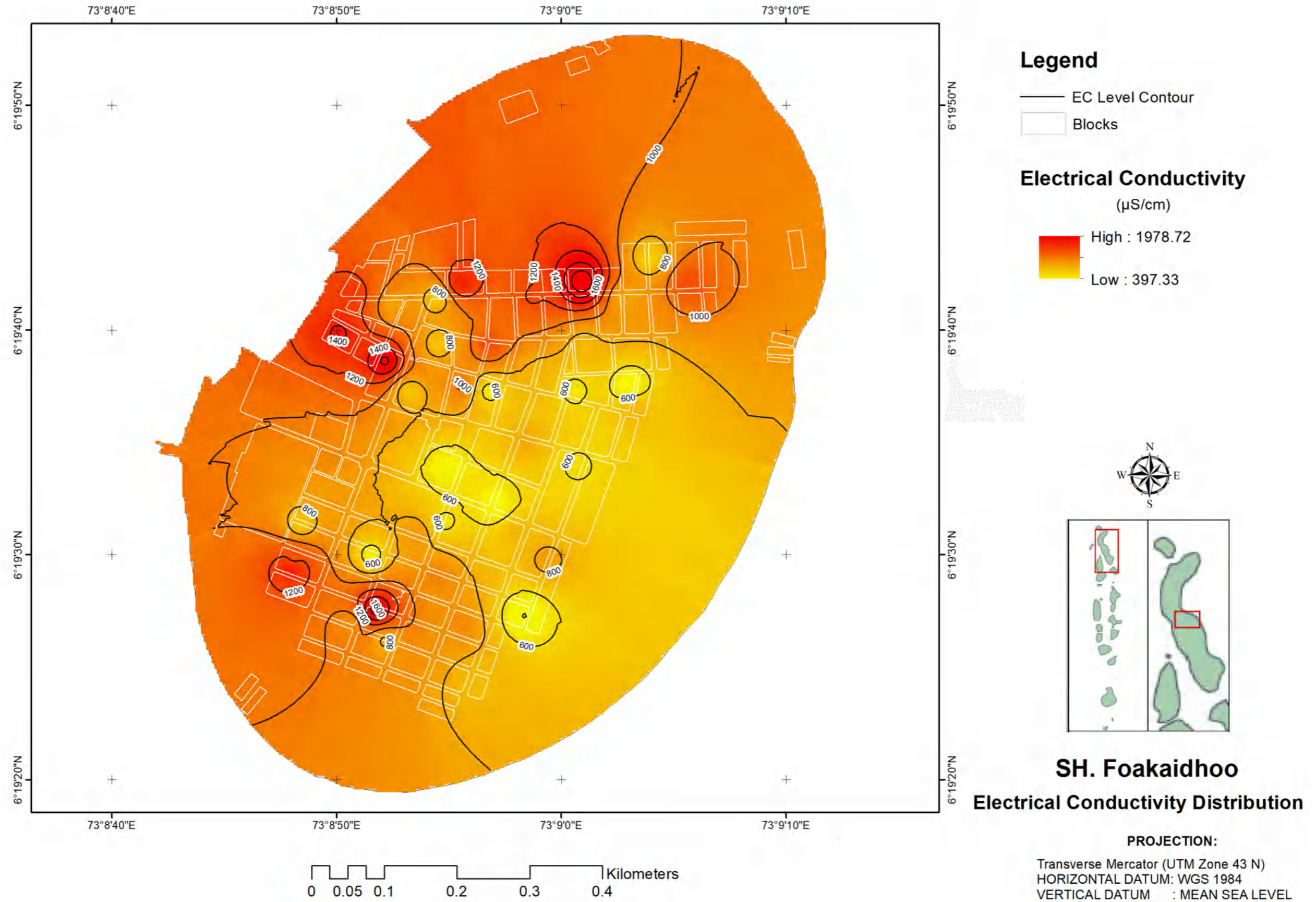


Figure 7-11: EC Distribution in Sh. Foakaidhoo Island

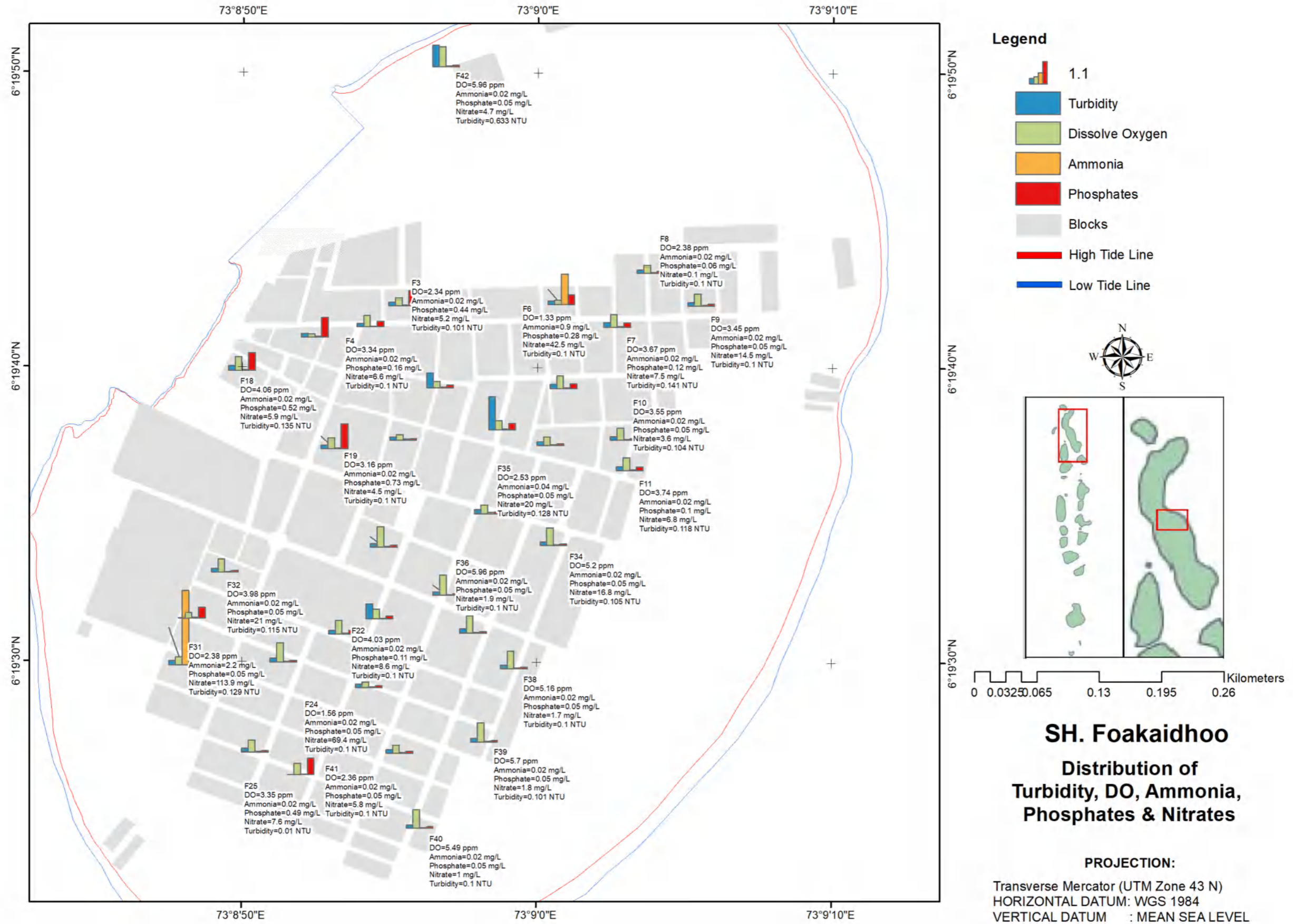


Figure 7-12: Distribution of Turbidity, DO, Ammonia, Phosphates and Nitrates in Sh. Foakaidhoo Island

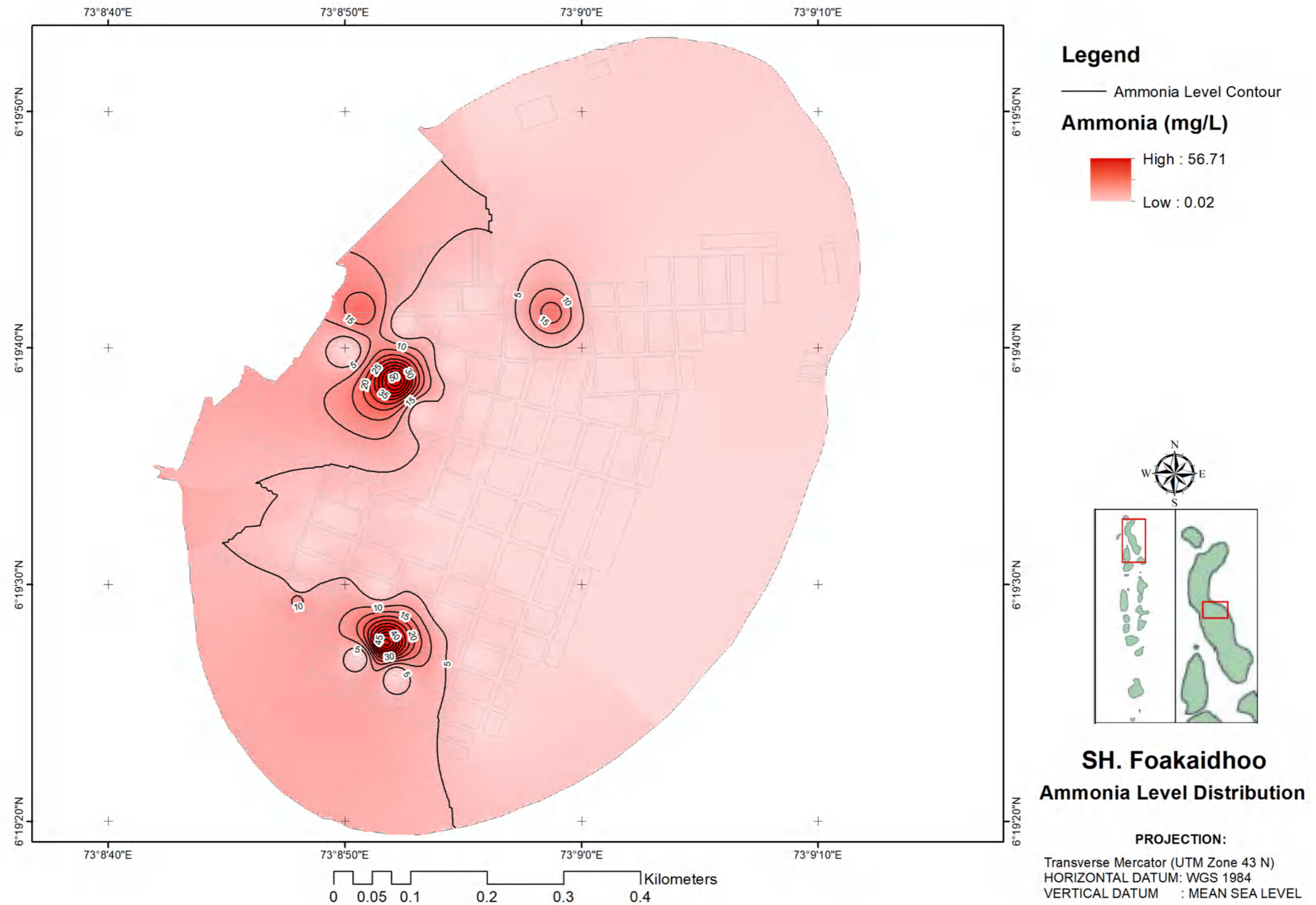


Figure 7-13: Ammonia Level Distribution in Sh. Foakaidhoo Island

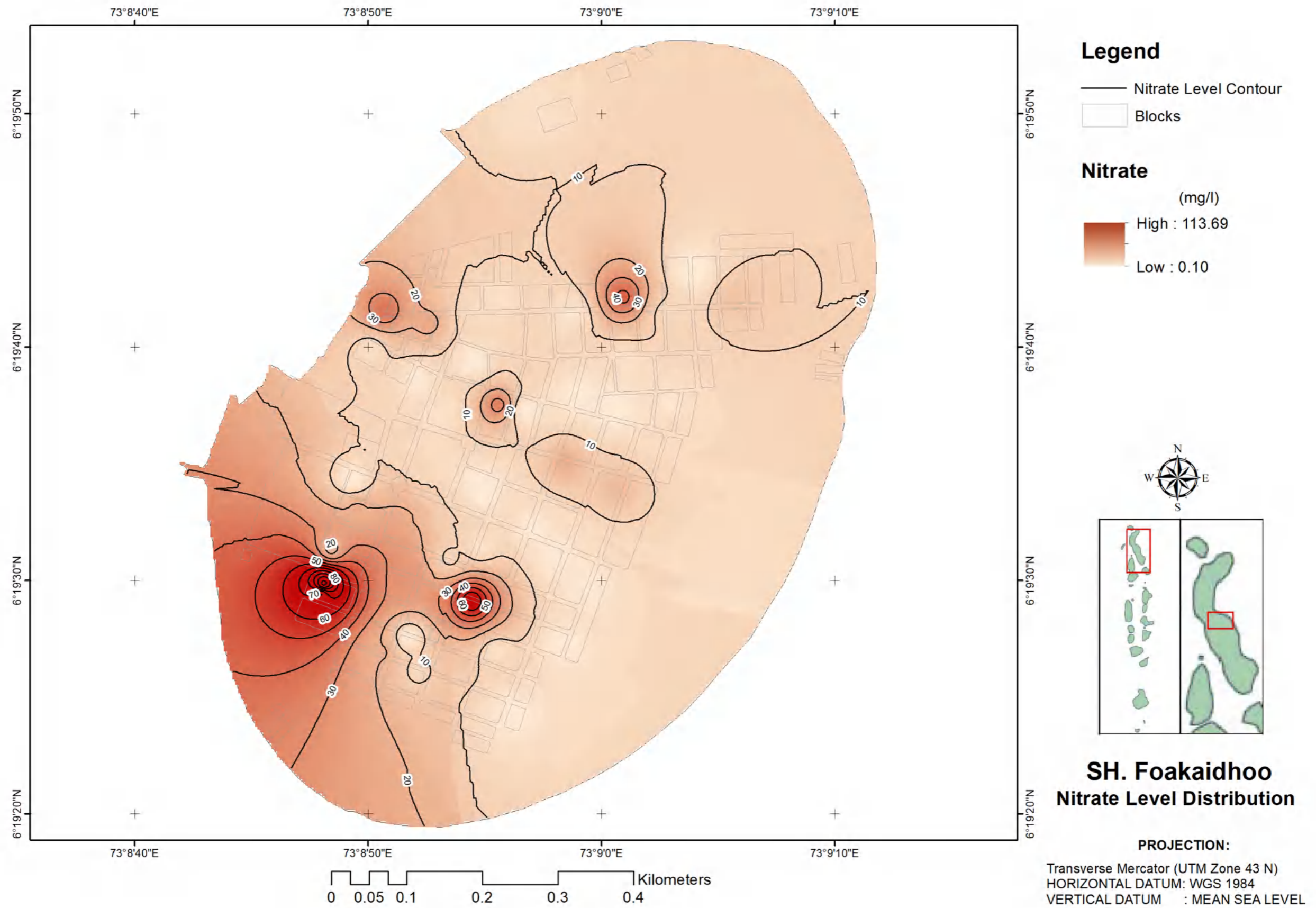


Figure 7-14: Nitrate Level Distribution in Sh. Foakaidhoo Island

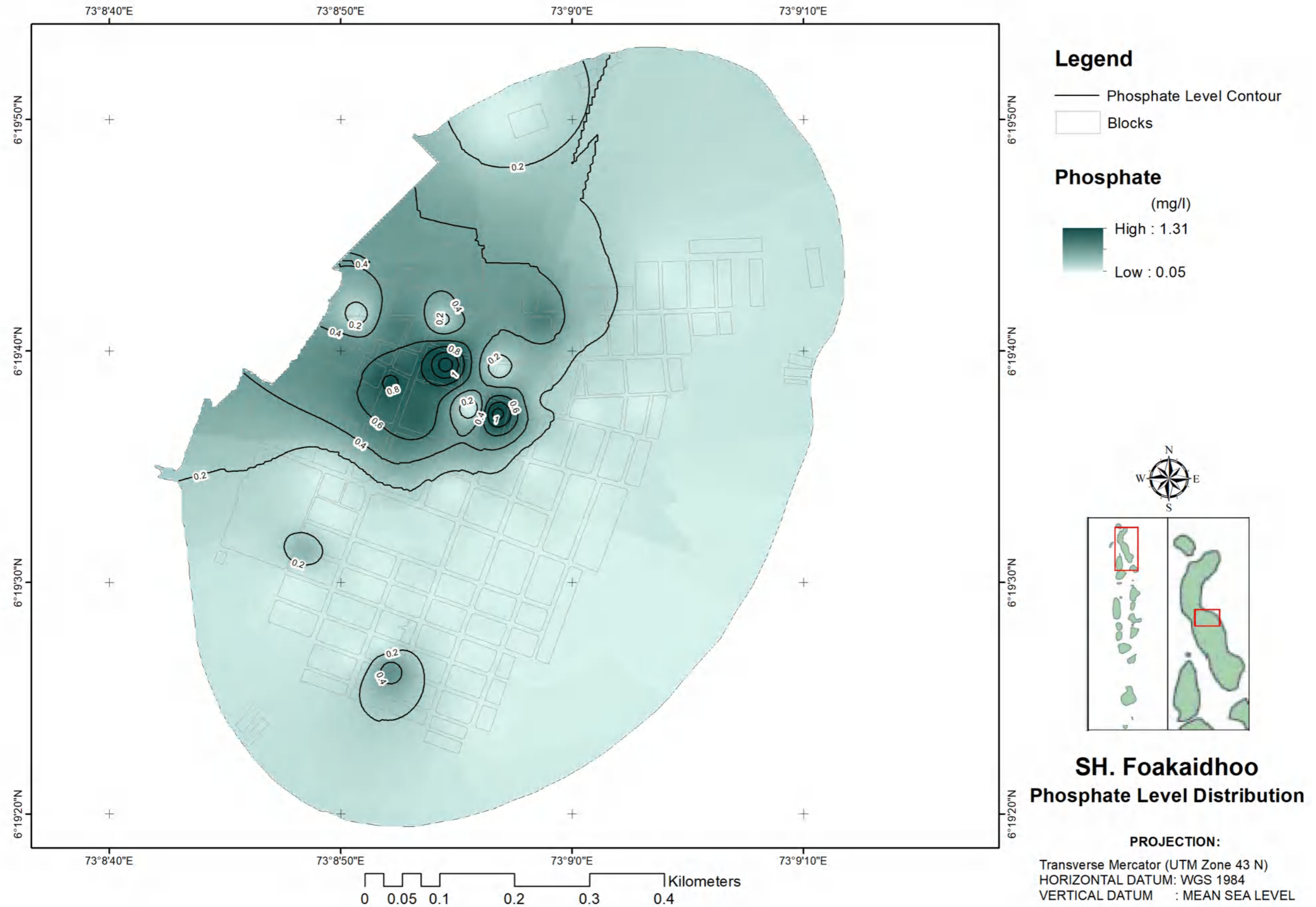


Figure 7-15: Phosphate Level Distribution in Sh. Foakaidhoo Island

7.7.8 Geophysical survey

The Electrical Resistivity (ER) tests were carried out in the locations as outlined in Figure 7-16 below. The ER survey included test points along 9 transects selected representatively based on reconnaissance surveys to adequately characterise different land uses and island cross-sections. The main transects were aligned along existing roads to maintain consistency and uniformity.

7.7.9 Aerial surveys

Based on the aerial survey, a multiple data set consisting of buildings, roof cover, land cover, change detection and shoreline were extracted. This data is shown in Figure 7-17. The total roof cover for this island is 60,872 m².



Figure 7-16: Location of ER points in Foakaidhoo Island

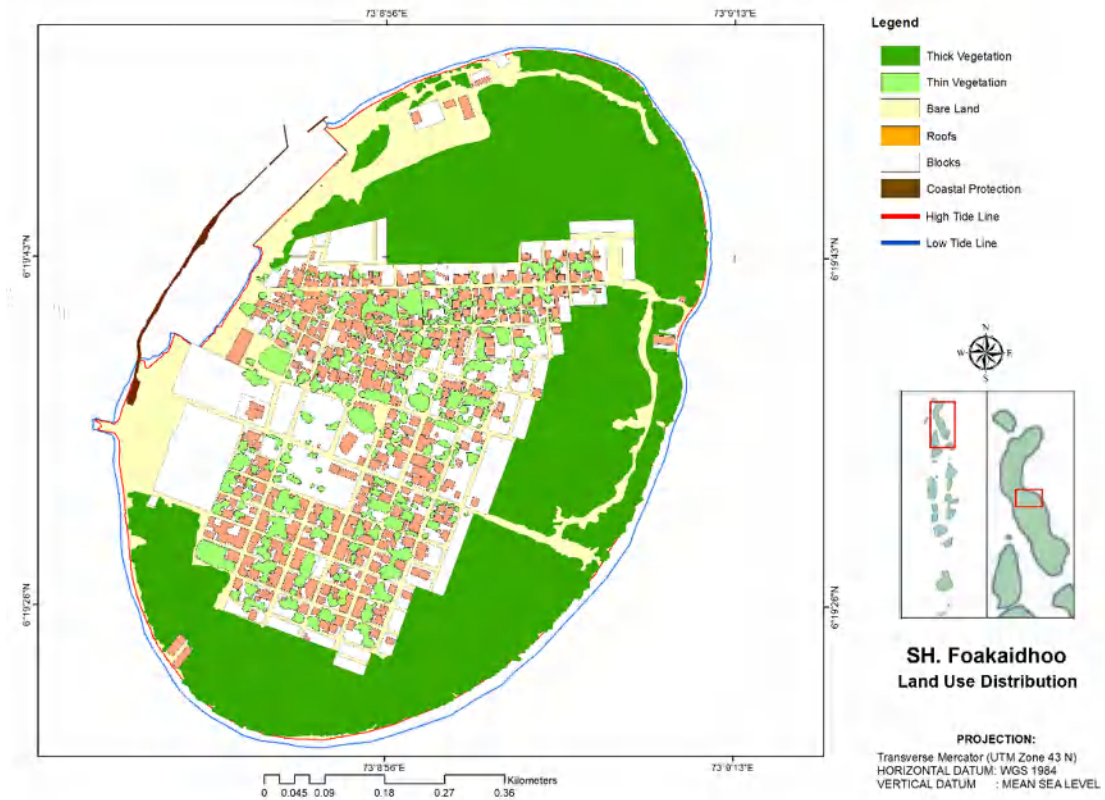


Figure 7-17: Roof Cover in Foakaidhoo Island based on UAV Survey

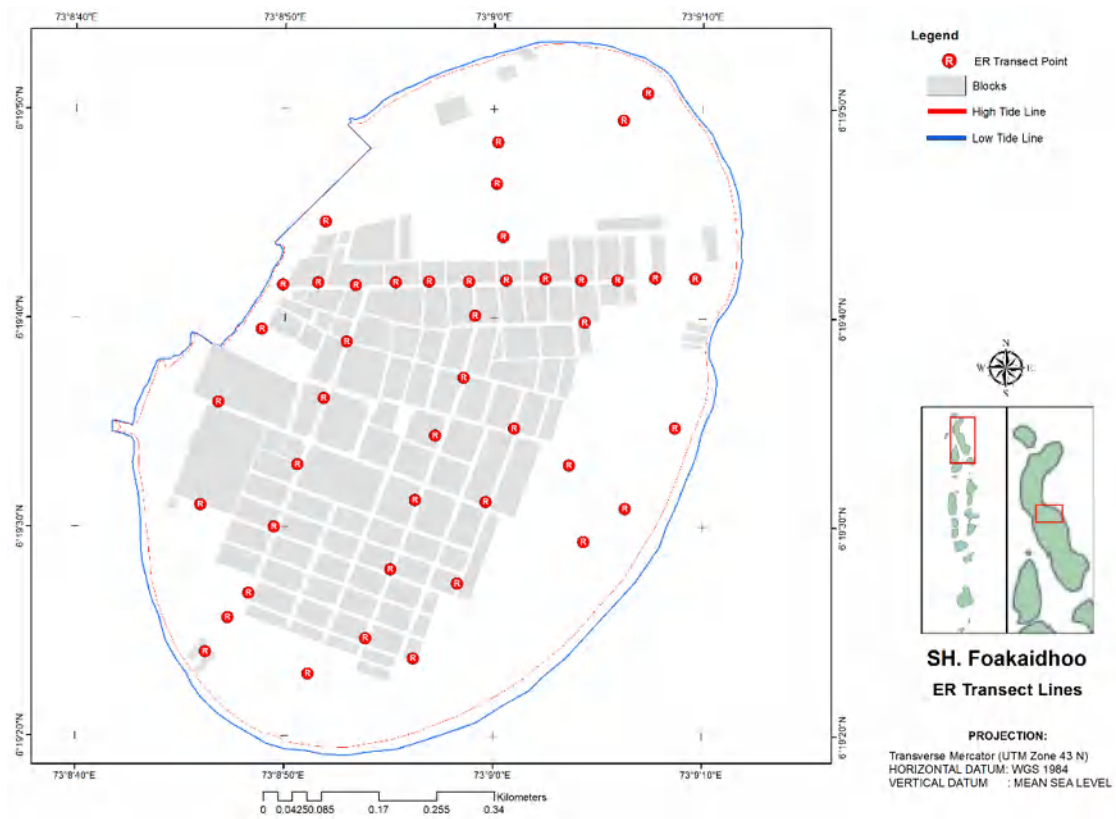


Figure 7-18: ER Test Points and Transect Lines in Foakaidhoo Island

7.7.10 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 yards, road surfaces, etc., is not usable as there is no mechanism for its collection and treatment.

7.7.11 Freshwater lens

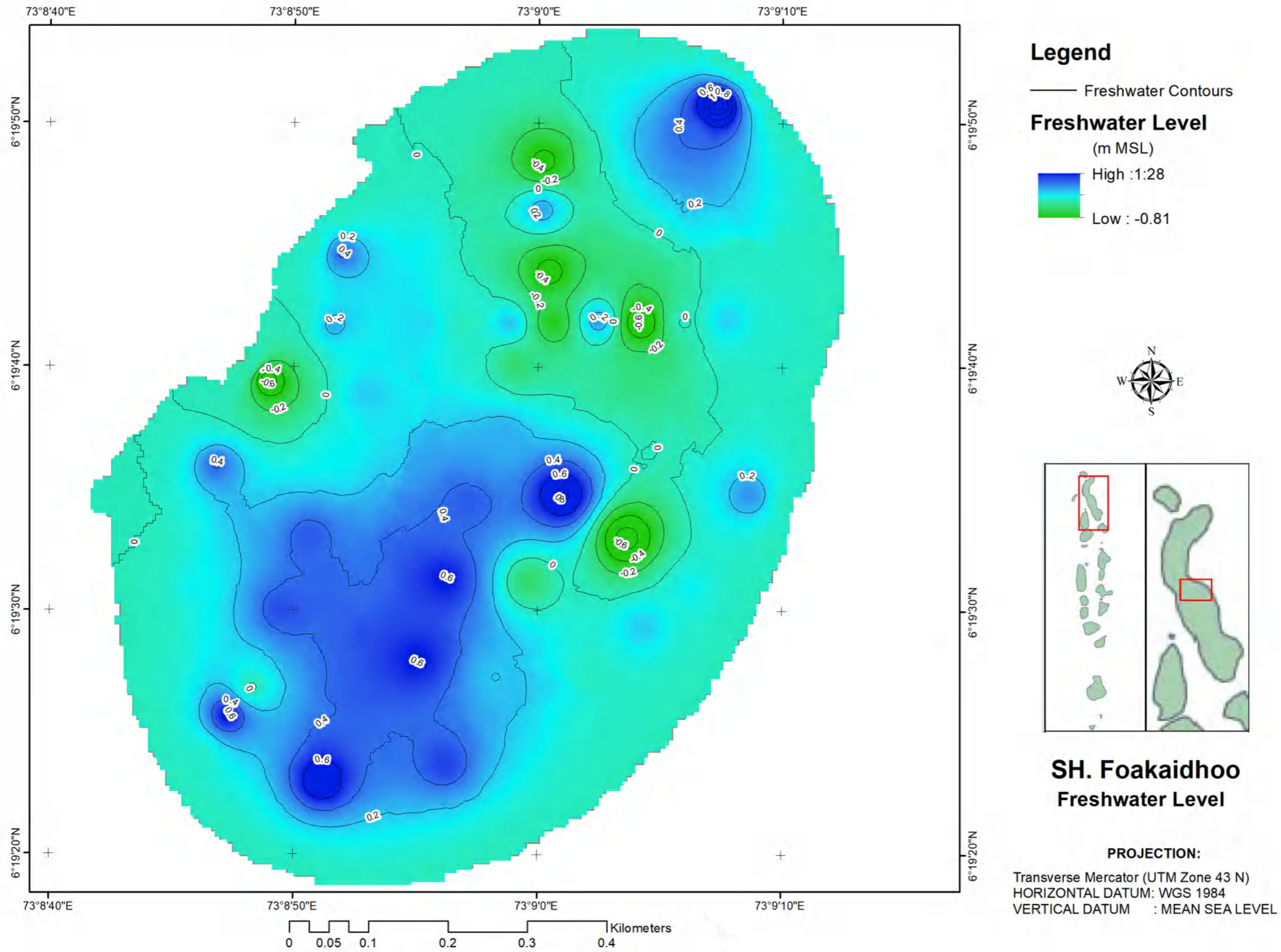
Based on the Electrical Resistivity (ER) surveys, the depth to groundwater level and the freshwater-saline water interface were determined for a set of transverse transects as shown in Figure 7-18. Plots in Figure 7-2 show the main two cross-sections of the island. The dotted lines in the plots indicate a simple interpolation of levels to mean sea level in the island boundaries.

Volume of the lens has been calculated with aid of ArcGIS and Surfer Software.

Volume of lens = 517,753 m³

Groundwater Storage = Porosity (15%) x Lens volume (m³) = 77,663 m³

The 2-D freshwater lens distribution density maps produced with GIS software for visualization of the spatial and volume extents are also presented below in Figure 7-19 to Figure 7-21.



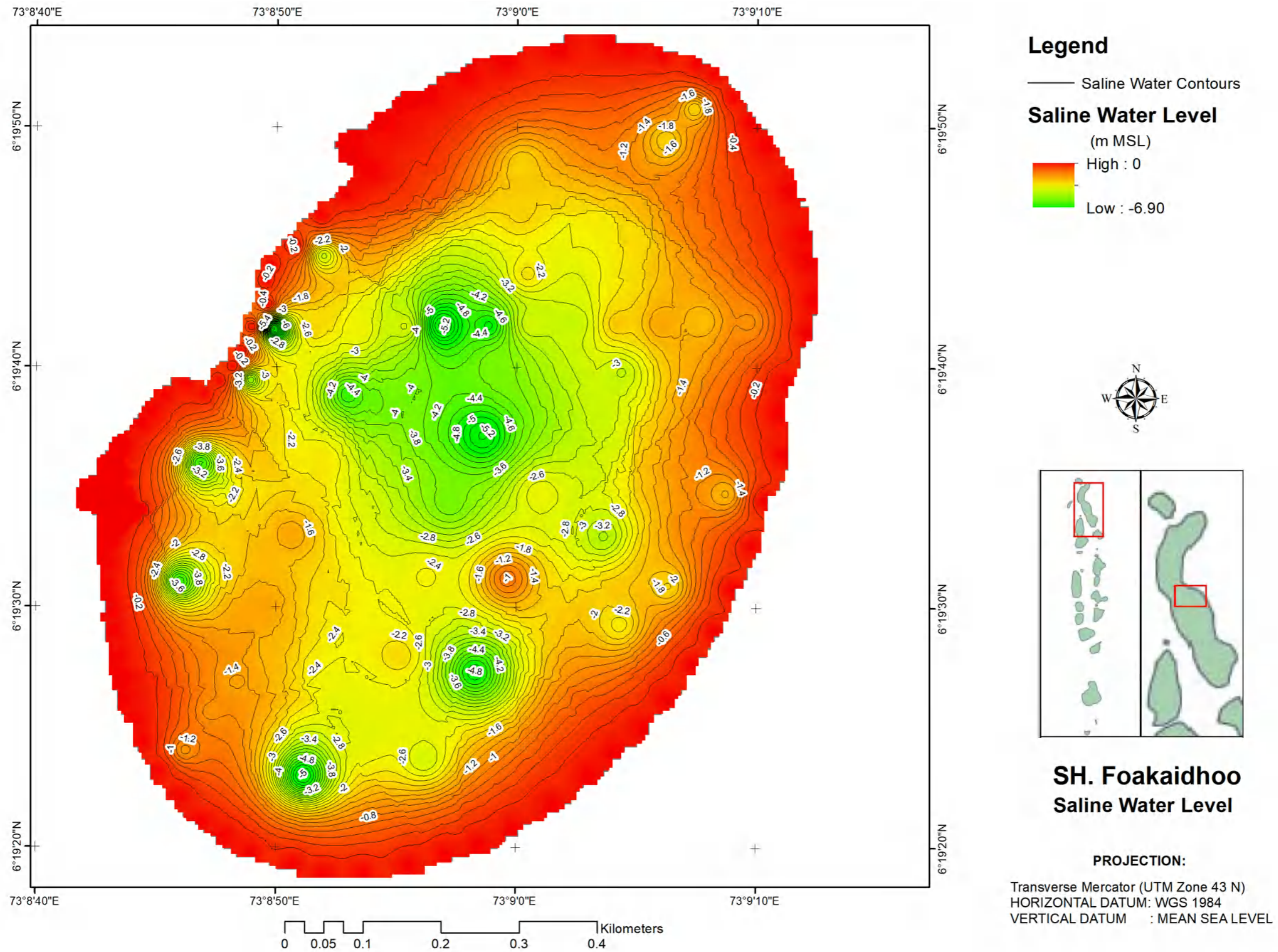


Figure 7-20: Saline water Level in Foakaidhoo Island

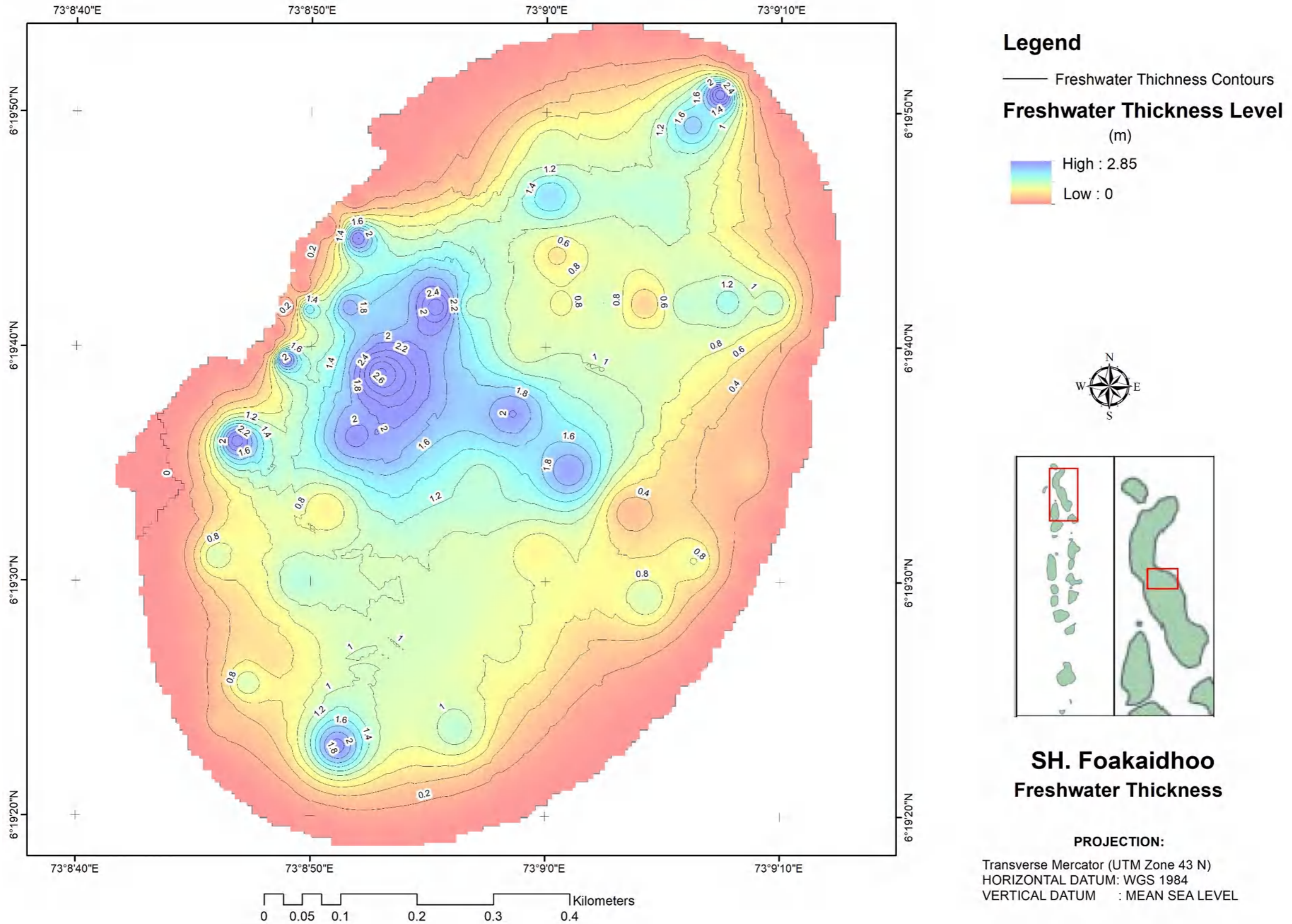


Figure 7-21: Freshwater thickness in Foakaidhoo Island

The maximum freshwater thickness of the island is 2.85 m (It is noted here that these readings were taken in September/October, which is the wet season and the with a reasonably higher number of wet days per month of the year).

7.7.12 Water balance and recharge

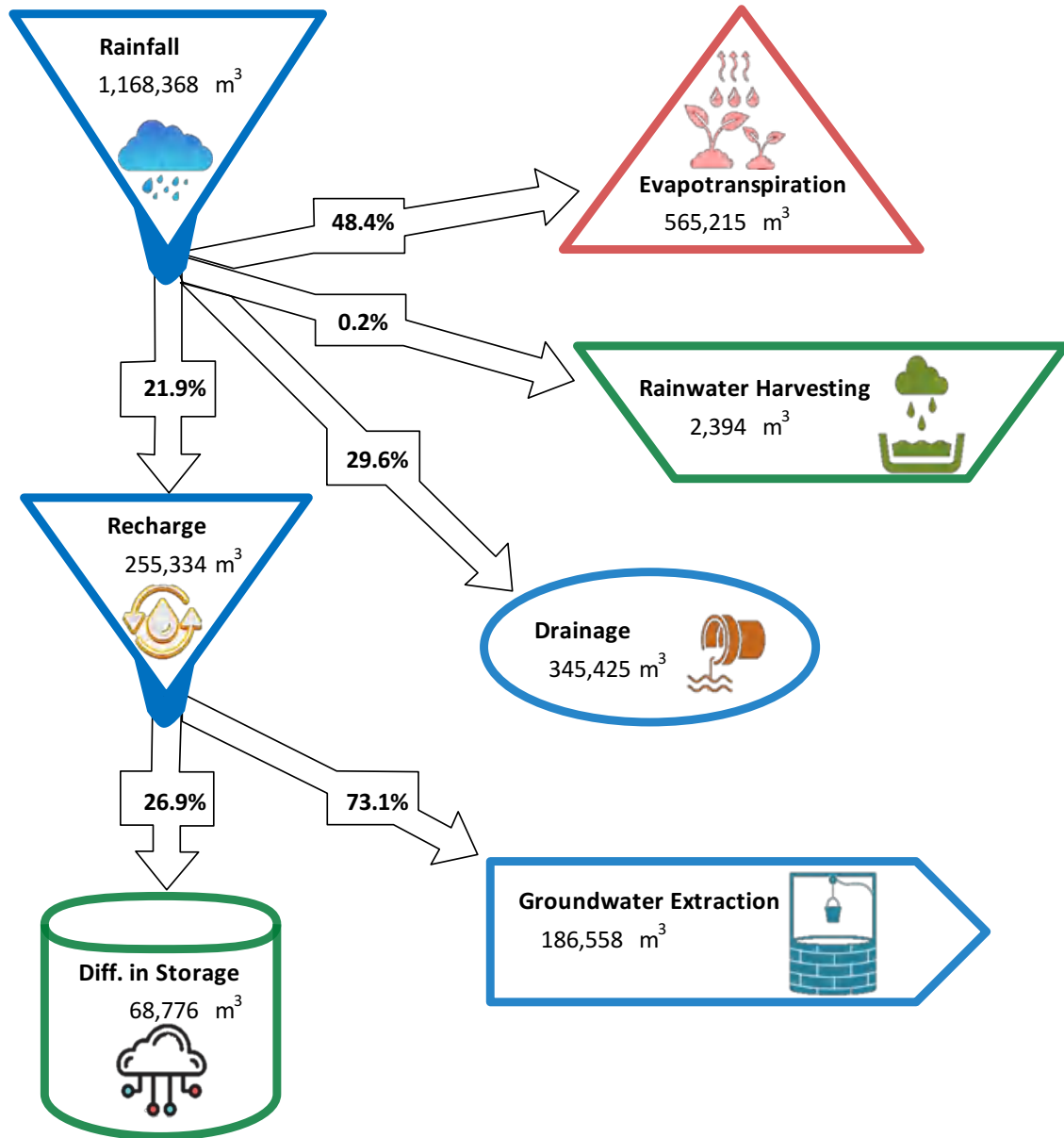


Figure 7-22: Schematic of water balance in Foakaidhoo Island

An annual estimation is carried out based on the water balance method (Falkland, 2000). Rainwater harvesting is calculated using the number of rainwater harvesting units on the island. According to the spatial mean annual rainfall of the Maldives, the annual average rainfall of Foakaidhoo Island is reported as 1,770 mm/year. Evapotranspiration was estimated using crop water requirements for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. Drainage or the surface runoff was calculated by considering an aggregate runoff coefficient for the island based on the land usage (roof cover, bare land, farmland, roads, playgrounds, wetlands). 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 the difference in storage.

7.7.13 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 199 m³ per day which was calculated by subtracting groundwater extraction from recharge volume derived from the schematic water balance model in

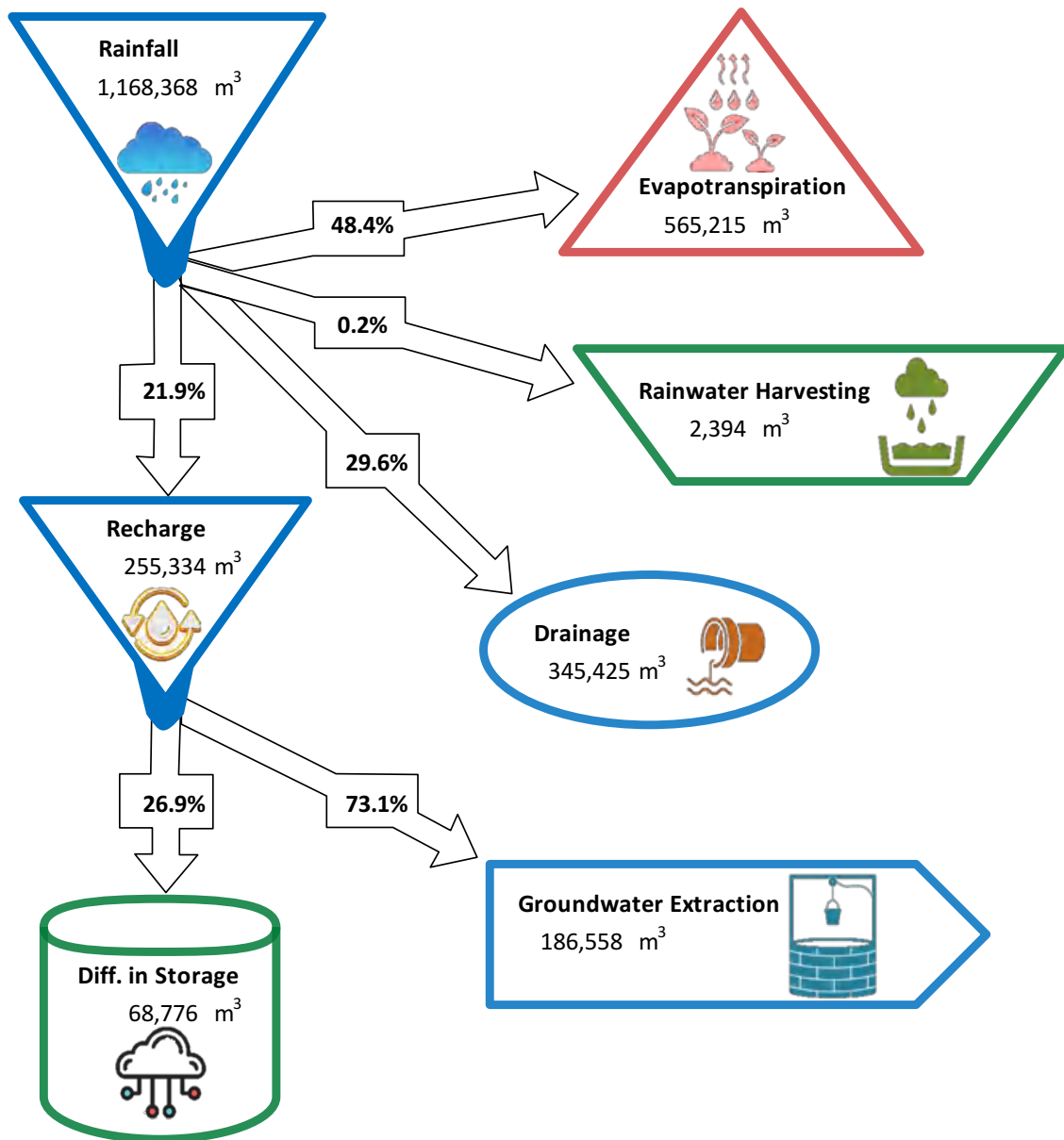


Figure 7-22.

7.7.14 Permeability test

Permeability tests were carried out in the selected locations as outlined in the following Figure 7-23.

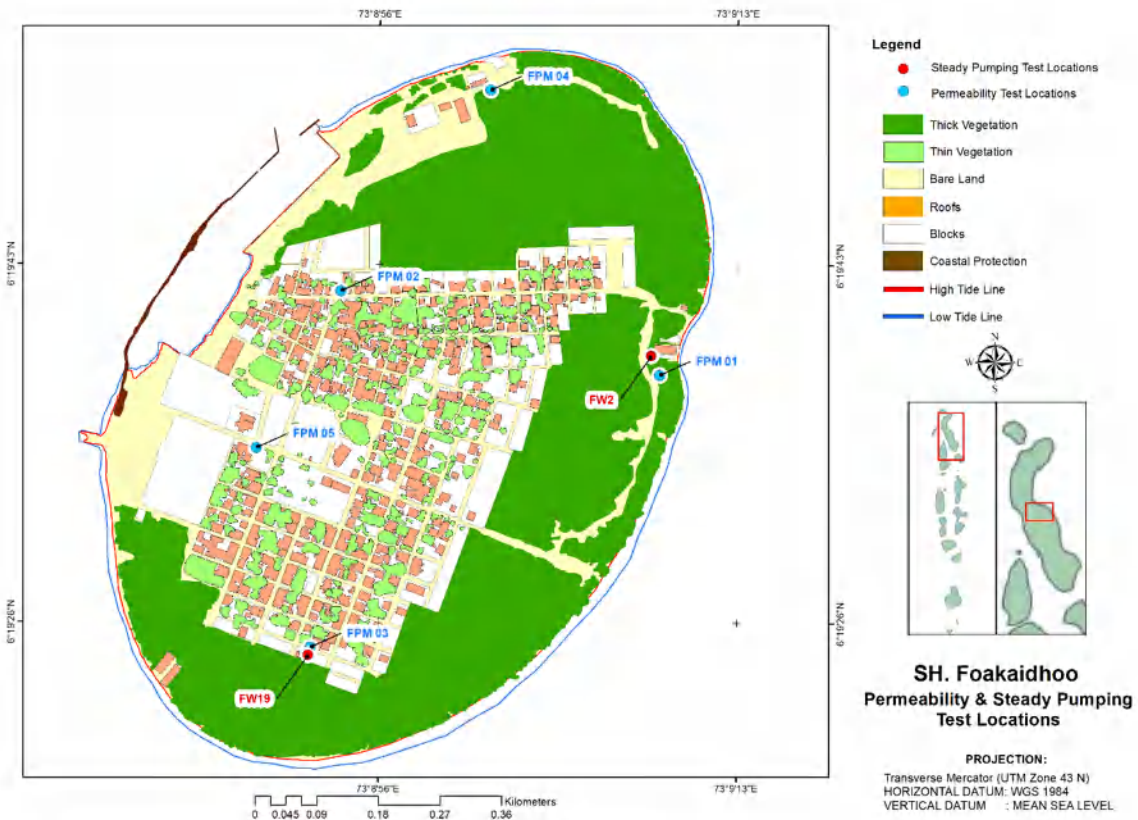


Figure 7-23: Locations of permeability and steady pumping tests in Foakaidhoo Island

The estimated permeability values for the above test locations are presented below in Table 7.12. The data will be comparatively verified and interpreted when additional data is acquired and calculations for other islands are completed.

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 the perforated section (m), U = thickness of saturated permeability material above water table, r_1 = outside radius of the casing (radius of the 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_s = Conductivity Coefficients, and T_u = distance from water level in the casing to water table (m).

Table 7.12: The Estimated Soil Permeability Values in Foakaidhoo Island

Point	FPM 01	FPM 02	FPM 03	FPM 04	FPM 05
D (m)	0.570	1.100	0.500	0.450	1.100
H (m)	0.570	1.100	0.500	0.450	1.100
l (m)	0.570	1.100	0.500	0.450	1.100
U (m)	0.700	1.350	0.750	0.700	1.250
T _u (m)	0.700	1.350	0.750	0.700	1.250
r (m)	0.076	0.076	0.076	0.076	0.076
Q (m ³ /s)	1.39E-05	1.37E-05	3.22E-06	5.22E-05	7.00E-06
r ₁ (m)	0.076	0.076	0.076	0.076	0.076
r _e (m)	0.010	0.010	0.010	0.010	0.010
T _u /t	1.228	1.227	1.500	1.556	1.136
X = (H/T _u x 100)	81%	81%	67%	64%	88%
Section	Zone 2	Zone 2	Zone 2	Zone 2	Zone 2
t/r _e	54.86	105.86	48.12	43.31	105.86
C _s	79	145	73	67	145
K (m/s)	3.53E-05	1.12E-05	8.08E-06	1.49E-04	6.18E-06
K (m/day)	3.05	0.97	0.70	12.88	0.53

7.7.15 Steady Pumping Test

Pumping tests were conducted in two existing wells to estimate the aquifer properties of unconfined water bearing formation

Table 7.13: Selected Steady State Pumping Test Locations in Foakaidhoo Island

Well No.	C'	A (m ²)	t' (s)	ln ($\frac{s_1}{s_2}$)	T (m ² /s)
FW2	5.3	1.14	2100	4.99	0.0023
FW19	4.7	3.53	1800	2.5	0.0037

The measured transmissivity (m²/s) values ranged from a minimum of 0.0023 m²/s to a maximum of 0.013 m²/s., with an average of 0.0037 m²/s.

During the testing period, EC (Electrical conductivity) of tested wells was increased as below.

- For FW 2, EC (Electrical conductivity) increases from 3080 µs/cm to 6200 µs/cm.
- For FW 19, EC (Electrical conductivity) increases from 1050 µs/cm to 1060 µs/cm.

7.7.16 Status of groundwater availability in Foakaidhoo Island

"1). The selected Foakaidhoo island has dimensions of width = 780 m and length = 1152 m, with a total land area of 66.01 ha, a population of 737 persons, and a land use of Roof cover (Built up area)

6.09 ha (9.2%), Vegetation (Thick) 29.35 ha (44.5%), Vegetation (Light) 5.03 ha (7.6%), and Barelands 25.54 ha (38.7%).

2). In order to recognize the fluctuation in the groundwater table, freshwater-saline interphase and estimate the volume of the freshwater lens (FWL) and its associated recharge-discharge characteristics, 55 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 five (05) locations while steady-state pumping tests were conducted at 02 locations. In addition, the groundwater level was also recorded at 09 locations where groundwater water quality samples were tested.

4). Permeability tests were carried out at representatively selected five (05) 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 \pm Standard Deviation).

5). The ground elevation values ranged from a minimum of 0.00 m MSL to a maximum of 2.52 m MSL, with an average of 1.07 ± 0.43 m MSL (Mean \pm Standard Deviation).

6). The upper boundary of the freshwater lens (FWL) varied from a minimum of -0.81 m MSL to a maximum of 1.28 m MSL, with an average of 0.11 ± 0.19 m MSL (Mean \pm Standard Deviation).

7). The lower boundary of the freshwater lens (FWL) or freshwater-saline interphase ranged from a minimum of -6.90 m MSL to a maximum of 0.00 m MSL, with an average of -1.68 ± 1.22 m MSL (Mean \pm Standard Deviation).

8). Accordingly, the freshwater lens (FWL) volumetric values ranged from a minimum of 0.00 m to a maximum of 2.85 m, with an average of 0.87 ± 0.05 m (Mean \pm Standard Deviation).

9). The groundwater profile in the island is characterised by a relatively Low (0.20%) Rainwater Harvesting (%) relatively Very High (29.56%) Drainage (%) relatively Low (21.85%) Recharge (%) while the water use shows relatively Very High (73.06%) Groundwater extraction (%) leading to relatively Very Low (26.94%) Difference in Balance Storage (%).

10). The freshwater lens (FWL) volume calculated based on ER transect test data is 517,753 m³ with a maximum FWL thickness of 2.85 m and a steady state groundwater storage of 77,663 m³.

7.8 Conclusion

The Safe Yield for the island estimated based on 'Recharge - Extraction' is 293 m³ per day, while it is 320 m³ per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 564 m³ per day and this exceeds the allowable Safe Yield in the island by 271% (Highly Stressed). At present, there exists no island wide water supply network and the sewerage network is under construction.

Relative hydraulic condition of the island lay in 'Semi-pervious' state while present aquifer condition remains at 'Poor' – 'Good' state based on the hydraulic conductivity estimation carried out as per Bear (1972) and transmissivity of the formation was compared as per Krany (1993). Moreover, general status based on transmissivity ranged 'High' and potential for groundwater recharge remains 'Low' – 'Moderate' as per the estimations.

8 TH. DHIYAMIGILI ISLAND

8.1 General Overview of the Island

The island of Dhiyamigili (**Error! Reference source not found.**) is located on the south eastern periphery of Thaa Atoll at coordinates 73°20'12"E, 2°20'20"N. The island has an area of about 0.292 km² and measures about 0.41 km in width and 1.12 km in length. The population of the island was found to be about 974 residents as of December 2021. The island has a harbour on the North Western side of the island. The following table outlines some basic information about the island and the following map outlines the location of Dhiyamigili.

Table 8.1: Basic statistical information on Dhiyamigili island in Thaa Atoll.

Name of the island	Th. Dhiyamigili
Longitude and Latitude	73°20'12"E, 2°20'20"N
Area	29.62 ha (0.292 km ²)
Population (Dec 2021)	974
Distance from Male'	204 km
Harbour	Present
Island sewerage network	Under Construction
Water supply network	No
Other infrastructure	No

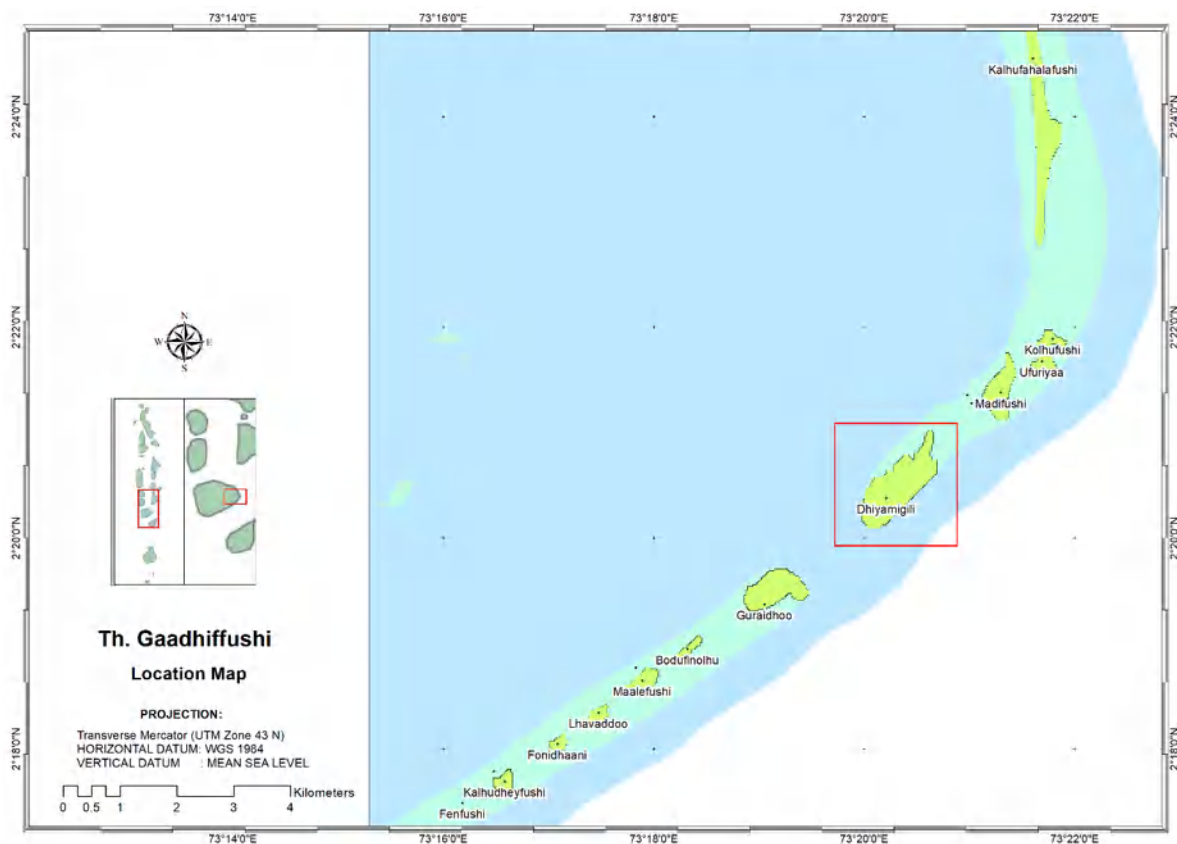


Figure 8-1: Location map for Dhiyamigili Island, Thaa Atoll.

8.2 Climate

Dhiyamigili experiences the typical two monsoons in the Maldives namely, the North-east monsoon from December/January to March/April and the South-west monsoon from Mid-May to November. There are no specific wind and rainfall data available for Dhiyamigili as there are no weather monitoring stations on the island itself. Based on the rainfall data of the nearest weather monitoring station, it shows a declining trend in rainfall for the past 30 years (Inception Report, 2021).

The historical rainfall data records from Kandhdhoo Island (not included in the 6 selected islands in Lot 2) located in the Laamu atoll (57 km to the south from Dhiyamigili Island) has an annual average rainfall of 2,242 mm with a standard deviation of 370.4 mm and the trend and the decadal means were shown in the following graph. (MEE, 2021).

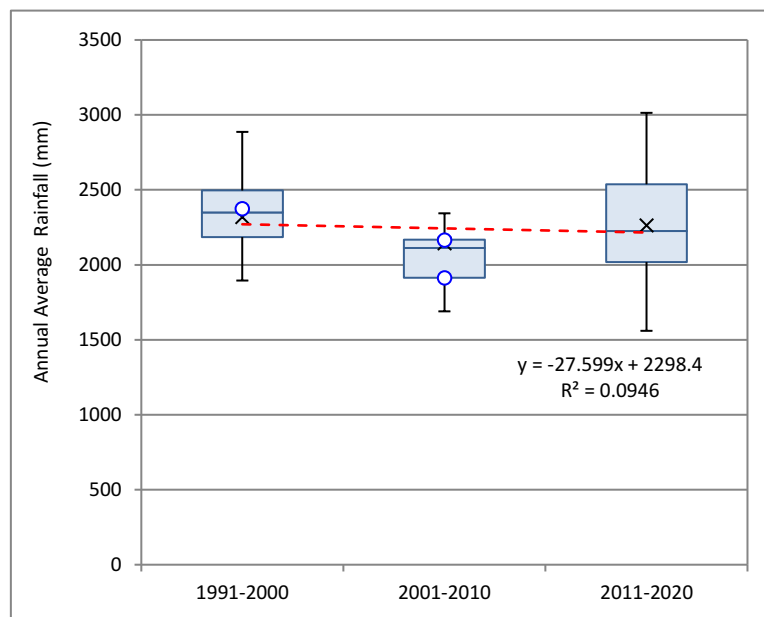


Figure 8-2: Decadal means and trend for rainfall in Kadhdhoo (1990 - 2020).

8.3 Demography

The total registered population of the island is reported by the island council as 974 at present, with 505 males and 469 females (Table 8.2).

Table 8.2: Demographic Breakdown of Dhiyamigili Island as of December 2021

Registered Population (locals)		
Both	Male	Female
974	505	469

8.4 Socio-economic condition

8.4.1 Natural Resources and Land Uses

Th. Dhiyamigili is located at the eastern rim of Thaa atoll with an area of 29.6 ha. There is no formal land use plan at present. The island council now has the authority to allocate lands for different purposes with an approved land use plan.

8.4.2 Economic Activities



Figure 8-3: Summary of household and socio-economic activities

The main economic activities at the island include the operation of small businesses, construction, fishing and agriculture. Women are involved in weaving sewings.

8.4.3 Accessibility and Transport

The only direct mean of access to the island is via sea transport by speed boats or Dhonis. It can be private hire or by ferries. Other means of transport is via air to the domestic airport at Thimarafushi of the same atoll and launch transfer from airport to Dhiyamigili.

A harbour with quay walls facing the North Western side of the island is used to access the island. It was noted that after the construction of the harbour and because of the reclamation done to join two islands to form the present Dhiyamigili, erosion is observed more than before. Services and Infrastructures

The island is equipped with the basic services and supporting infrastructures.

8.4.3.1 Public Facilities and Amenities

The public facilities available in the island include:

- Power House
- Health Center
- Primary/Secondary School
- Mosques
- Government institutions (Office for Island Council, Island Court)
- Sewerage Network System

8.4.3.2 Water supply

The main source of water for all uses except drinking and cooking is groundwater. Rainwater and bottled water are used for drinking and cooking. This is further discussed in Section 8.5 and 8.6.

8.4.3.3 Energy supply

The island community has access to power 24 hours a day.

8.4.3.4 Waste and Wastewater disposal

Solid Waste: They do not have a waste management plan yet though a plan is under formulation. Currently, all HHs are required to take segregated waste to the waste dumping site. Within the area, all waste is segregated and managed by Women's Development Committee.

Sewage Disposal: Main method of sewerage disposal at Dhiyamigili is by means of a sewerage network system. This is further discussed in section 8.5.

8.5 Existing water and sanitation situation

8.5.1 Water

Groundwater is the main source of water for all uses except drinking and cooking.

In general groundwater quality is considered bad. Even with a proper sewerage system, the groundwater quality has not improved and they experience odour, change of colour and murkiness. Furthermore, groundwater at higher grounds is especially not in good condition. Because of how the island is formed, 2 natural islands joined with reclamation, there are uneven ground levels. Groundwater in the reclaimed area is observed to be saline as well. Perception of community on groundwater quality is described further in Section 8.6.

Rainwater and bottled water are mainly used for drinking and cooking. Rainwater is harvested at both the household level and island level. At the household level, each household has at least one water tank with a capacity of 2,500 L. The council have established 4 community tanks of 5,000L for rainwater harvesting. All tanks are used by the community.

The general practice of rainwater harvesting at the island level is to clean the roofs thoroughly and letting the first flush pass to the roads which would eventually seep into the ground. Excess rainwater is also discharged to the roads in a similar manner. This sometimes causes flooding as well.

A rainwater harvesting system is also established where roofs of all government institutions buildings/offices (council, mosque, health center, school, etc) will be used to collect rainwater into public tanks which will then be filtered and distributed to 5 different areas of the island through common water taps to be used by the public. The project is complete and is in testing phase.

It was noted that during the dry season they have to order for water from outside of the island, approximately 20,000 L and during the dry season the groundwater also seems to reduce and the quality also deteriorates.

Establishment of an RO Plant is also ongoing is expected to be completed in early next year 2022.

8.5.2 Wastewater and Sewage Disposal

A sewerage system with pump stations and a proper outfall has been installed in Dhiyamigili since 2007. While most of the houses use the established system, there are few houses which uses septic tanks and are not connected to the island sewer network.

Currently, due to damage to the outfall pipe, effluents are not discharged to sea but rather to near-shore and reef. This would cause negative impacts to the marine environment of the nearshore of the island which in turn would impact the island.

8.6 Results of the Baseline Surveys: Water Usage

8.6.1 Summary

As detailed in the methodology section of this report (Section 1.4.3.2), a social survey was carried out to determine the water usage at households (HHs), commercial entities (cafés/restaurants), institutions and places with industrial uses (agricultural lands, fish processing). The survey was carried out from

18th May to 20th May 2021 with the help of local enumerators. The following Table 8.3 summarizes samples taken for each sector at 95% confidence interval and total number of completed surveys for each.

Table 8.3: Population and Sample taken for the social survey

Categories	Population	Sample	Forms Completed
Households	121	93	76
Farmers	7	7	7
Fishermen	7	7	2
Fish Processing	2	2	1
Institutions	4	4	3
Guest houses	0	0	0
Café/restaurants	5	5	2

Note: A number of mitigation measures were adopted to ensure to achieve the 95% confidence level sample size. The challenges and limitations and the measures undertaken to mitigate the challenges are listed in Section 1.4.3.3.

The key findings from this survey show that a total of 317.66 liters of groundwater are estimated to be used per capita per day for various domestic uses. The respective water use situations including domestic, commercial and institutional uses are illustrated in the following sections.

8.6.2 Water usage for domestic purposes

8.6.2.1 Domestic Water Usage

A household survey was carried out at 95% confidence interval. A total of 121 HHs were surveyed of which 76 HHs responded. As presented in Table 8.4, 84% of HHs have at least one of 2,500L capacity HDPE rainwater tanks at their homes to collect rainwater for daily uses. Among the 94 HHs, 56% uses rainwater for drinking while 97% also uses it for cooking.

Groundwater is mainly used for non-potable use in all the households surveyed.

Table 8.4: Groundwater and rainwater use data for Dhiyamigili

Rainwater	Per cent (%)
Households with rainwater tanks	96%
Rainwater use for drinking	95%
Rainwater use for cooking	99%
Groundwater	Per cent (%)
Groundwater as drinking source	0%
Groundwater for cooking	3%
Groundwater for non-potable use	83%

Total number of household wells surveyed	76
Percentage of wells surveyed fitted with pumps	99%

As it can be observed from Table 8.4, it is very significant that the people of Dhiyamigili are heavily dependent on rainwater for all potable uses.

Based on the survey carried out, average daily ground water demand per capita for domestic non-potable 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 8.5. The total domestic ground water use is estimated to be 296.15 liters per capita per day.

Table 8.5: Domestic Ground Water Usage in Dhiyamigili

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
114	45	20.28	70.37	249.7

8.6.2.2 Perception on Groundwater

The HHs were also asked about their perception on groundwater, if it is safe to use for daily purposes and whether the quality of groundwater is good or bad.

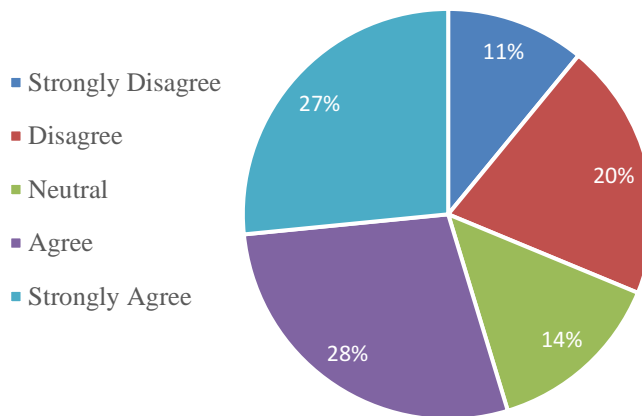


Figure 8-4: Perception of HHs of Th Dhiyamigili on safety of Groundwater

As it can be seen from Figure 8-4, a total of 55% agreed that groundwater of Dhiyamigili is safe to use for non-potable uses, whereas a total of 31% disagreed that groundwater is not safe for use and 14% noted it as neutral.

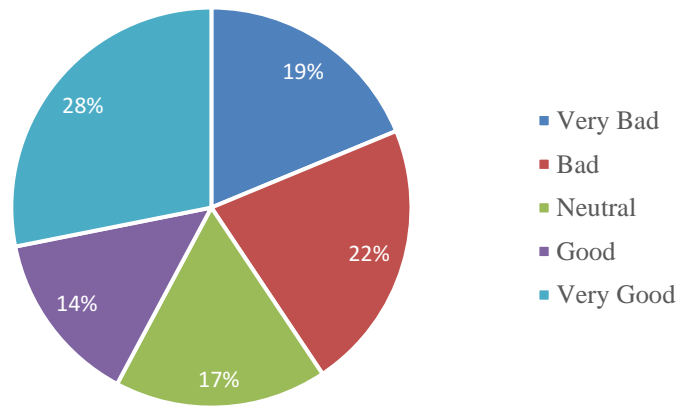


Figure 8-5: Perception of HHs of Th. Dhiyamigili on quality of groundwater

Furthermore, the HHs were asked about the quality of groundwater with regard to their experience. While a 41% of the respondents reported the groundwater quality is bad (19% very bad, 22% bad) another 42% consider water quality as good (14% good and 28% very good). The varying opinion on groundwater quality is because in Dhiyamigili as similar to many other islands surveyed in this project, in different parts of the island water quality is different.

During the consultations with the island council, it was noted that the groundwater quality especially bad at higher grounds caused due to reclamation and join of two islands.

8.6.3 Water Usage by Commercial Activities

Dhiyamigili has five (5) cafés of which two (2) cafés were surveyed. There were no guesthouses.

The table below presents a summary of water usage by the cafés.

Table 8.6: Water Usage by commercial activities in Dhiyamigili

Cafés	Total Volume of water per day (Liters)
1	45
2	n/a

For the cafés, while 1 café used groundwater for cleaning tables and floors, the other café used it for dishwashing in addition to the groundwater usage in the toilets. From the total 2 cafés that were surveyed, data on water usage quantity was available only from 1 café and that is approximately 45 liters per day. It is important to note here that this amount cannot be generalised for every café' in the island as the capacity of each café' and its level of operation would be different.

8.6.4 Water Usage by Institutions

Based on the survey carried out to collect data on water consumption by institutions, although the island has five places that can be considered as institutions which are the island council, powerhouse, island court, school and health center we only got responses from the health center, power house and school.

As per the respondents, in the institutions, groundwater is mainly used for mopping floors, flushing toilets and to some extent gardening. A total of approximately 4,409.5 liters of groundwater are estimated to be used per day by the institutions surveyed. As the use of each institution is different, to generalize the water consumption of institutions to an average figure will not be accurate. However,

it can be deduced that based on the data, 151.86 liters of groundwater are estimated to be used per staff per day by the institutions of Dhiyamigili (Table 8.7).

Table 8.7: Water Usage by commercial activities in Dhiyamigili

	Water Flushed(Liters)	Gardening(Liters)	Mopping(Liters)	Sub-Total Water Used (Liters)	Total Water Used (Liters)	Institutional Groundwater Usage (Liters Per Capita Per Day)
Health Center	264	2454	40	2758		
Power House	312	0	200	512	4,409.5	151.86
School	516	613.5	10	1,139.5		

8.6.5 Water Usage for Farming

A total of 6 out of the 7 farmers participated in the survey. Farmers mainly use groundwater for watering the plants. A 100% of the surveyed farmers use groundwater extracted from wells using pumps to water their plants. Table 8.8 below summarizes the water usage to water the plants every day.

Table 8.8: Water Usage by Farmers in Dhiyamigili

Farmlands	Area of farmland	Volume of water used per day (Liters)	Total volume of water used per day (Liters) per sqft
1	3,000	96	0.032
2	3,000	100	0.033
3	3,000	818	0.272
4	3,000	50	0.017
5	3,000	1,227	0.409
6	2,000	100	0.05
Total		2,391	

From the total 6 farmers that were surveyed, a total of approximately 2,391 liters of groundwater is estimated to be used per day by the farmers. Based on this data farmers use in average 0.14 liters (140 ml) of water per sqft per day to water their farmlands.

8.6.6 Water Usage for Fisheries Activities

In Dhiyamigili, we were only able to survey one (1) fishing vessel and one (1) fish processor. The fishermen represent a fishing boat and water usage depicts water used by the whole team for the fishing activity in that boat. In the fishing boat, they use groundwater for dishwashing, cleaning, showering and for laundry. In fish processing, they use groundwater for cleaning/gutting of fish. Rainwater is used for cooking fish.

Table 8.9: Water Usage by Fisheries activities in Dhiyamigili

Fishing Processors	Total Volume of groundwater used per day (Liters)
Fishing Vessel	1.43
Fish processor	1,915.71
Total	1,917.14

As per the findings, a total of approximately 1.43 liters of groundwater are estimated to be used by the fishing vessel per day whereas the fish processing unit requires 1,915.71 liters of water per day for cleaning/gutting of fish. As this is not a statistically significant sample, a generalization of water usage per vessel cannot be deduced from the findings.

8.6.7 Groundwater quality

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

The following Table 8.10 summarizes the water quality results.

Table 8.10: Summary of groundwater quality tests from Dhiyamigili Island in 2021

Sample No	EC (µS/cm)	pH	Turbidity (NTU)	DO (ppm)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
D1	1173.30	7.57	0.00	0.29	28	0.58	0.50	0.89	0.28	101	82
D2	342.00	7.64	0.00	1.61	28	0.16	9.70	0.14	0.12	>2420	198
D3	815.10	7.45	0.56	0.63	28	0.40	0.60	0.25	0.34		
D4	841.30	7.65	0.00	5.23	28	0.41	2.60	0.02	0.38		
D5	1231.70	7.79	0.00	4.22	28	0.61	3.00	0.12	3.30		
D6	920.20	7.82	0.00	4.92	28	0.45	1.40	0.29	0.52		
D7	608.00	7.74	0.00	4.07	28	0.29	3.80	0.04	0.55		
D8	759.00	7.52	0.00	2.05	28	0.37	5.30	0.13	0.24		
D9	399.20	8.03	0.00	3.69	28	0.19	1.70	0.16	0.18		
D10	1435.10	7.42	26.66	0.31	28	0.71	1.00	3.02	0.36		
D11	3233.20	7.15	1.25	1.64	28	1.68	1.00	5.10	0.30		
D12	753.10	7.96	0.00	3.93	28	0.36	0.70	0.16	0.17	140	62
D13	1498.80	7.39	0.00	0.85	28	0.75	1.30	0.18	0.38	1986	770
D14	867.70	7.49	0.56	2.68	28	0.42	23.70	0.09	0.88		
D15	513.00	7.87	0.00	4.95	28	0.25	0.50	0.08	0.33		
D16	983.20	7.28	0.00	1.27	28	0.48	0.60	4.95	1.65		
D17	3077.20	7.51	4.24	2.12	28	1.59	19.90	0.16	0.92		

Sample No	EC (µS/cm)	pH	Turbidity (NTU)	DO (ppm)	Temp (°C)	Salinity (PSU)	Nitrates (mg/L)	Ammonia (mg/L)	Phosphates (mg/L)	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/100ml)
D18	1041.30	7.44	4.36	0.73	28	0.51	0.90	2.19	0.31		
D19	671.00	7.39	3.84	1.54	28	0.32	0.60	1.71	0.59		
D20	512.00	7.45	0.25	1.73	28	0.24	6.90	0.20	0.50		
D21	579.00	7.41	15.54	1.51	28	0.28	7.30	0.21	0.62	94	31
D22	820.00	7.26	0.00	0.20	28	0.40	1.10	2.06	1.29	276	43
D23	444.40	7.41	3.90	0.79	28	0.21	0.30	0.53	0.35		
D24	2980.90	7.34	10.42	1.28	28	1.54	2.00	3.58	0.54		
D25	264.00	8.08	0.00	3.86	28	0.12	1.40	0.12	0.24		
D26	1476.50	7.49	0.00	4.01	28	0.74	42.30	0.14	1.38	>2420	>2420
D27	604.40	7.91	0.00	4.62	28	0.29	19.30	0.09	1.43		
D28	565.50	7.51	5.39	1.94	28	0.27	0.60	1.50	0.29		
D29	493.00	7.95	0.00	2.21	28	0.24	0.40	0.08	0.15	>2420	>2420
D30	1530.40	7.40	0.00	2.02	28	0.76	0.90	1.22	0.21	101	54
D31	2724.00	7.80	0.00	2.27	28	1.40	0.80	0.17	0.15		
D32	454.10	7.85	0.00	4.74	28	0.22	1.60	0.07	0.17		
D33	946.90	7.61	0.00	2.63	28	0.46	0.60	0.51	0.16		
D34	686.00	7.53	0.00	0.88	28	0.33	1.20	1.16	0.14		
D35	440.10	7.46	0.00	2.29	28	0.21	0.90	0.23	0.14	116	32
D36	541.00	7.66	0.00	2.24	28	0.26	1.10	0.18	0.11	101	18
D37	435.00	7.78	0.00	4.24	28	0.21	6.90	0.13	0.26	207	82
D38	1271.80	7.53	0.00	2.56	28	0.63	6.10	0.14	1.25	32	8
D39	1185.80	7.96	10.18	1.76	28	0.58	8.80	0.33	0.20		
D40	908.00	7.44	0.00	1.35	28	0.44	0.70	0.80	0.21	201	80
D41	476.60		1.49	6.96	28	0.23					
D42	21878.00		455.17	4.80	28	13.0667					
D43	371.30		2.00	1.67	28	0.17556					
D44	372.20	8.04	0.00	5.81	28	0.17604	4.70	0.55	0.26		
D45	308.00	8.47	0.21	7.28	28	0.14485	0.80	0.12	0.88		
D46	1049.00	7.77	6.34	2.15	28	0.51506	14.70	0.14	0.35		
D47	840.00	7.43	989.24	5.79	28	0.40716	1.20	0.20	0.24		

Based on the full results and the summary shown in Table 8.10, the following can be summarized for Dhiyamigili Island:

- The EC of the groundwater is generally moderate, with an average of 1411.09 µS/cm which is below an acceptable limit for potable water of 1500 µS/cm. The electrical conductivity readings range from 264 to 21878µS/cm. 87% of readings fall within the acceptable limit.
- The pH of groundwater ranged from 7.15 to 8.47 with an average of 7.63. The pH values of all samples were within the WHO permissible limits of 6.5-8.5.
- Turbidity ranged from the lowest of 0 NTU to 989.24 NTU with an average of 32.80 NTU.
- Dissolved oxygen levels were low to moderate, with values varying from 0.197 mg/L to 7.275 mg/L with an average of 2.77 mg/L.

- The salinity of groundwater ranged from 0.12 PSU to 13.07 PSU with an average of 0.75 PSU. Salinity is expressed in Practical Salinity Units (PSU) which is equivalent to PPT.
- The average Nitrate concentration was 4.80 mg/L and therefore it does not exceed the WHO guideline limit of 5.09 mg/L. But 12 of the 44 tested water samples exceeded this limit of 5.09 mg/L. The Nitrate concentrations ranged from 0.3 mg/L to 42.3 mg/L.
- Ammonia concentrations were generally low. The average ammonia concentration was 0.78 mg/L. This is within the WHO guideline value of 1.5 mg/L based on aesthetic (taste and odour) considerations. Only 7 tested water samples exceeded this limit (range from 0.02 to 5.1 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 were within the range 0.11-3.3 mg/L with an average of 0.53 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). There were no samples tested below 0.1 mg/L.
- Total coliform levels were also found to be significant and ranged from the lowest count of 32 MPN/100 mL to the highest count of more than 2420 MPN/100 mL, with an average count of 758.21 MPN/100 mL. Faecal Coliform levels were found to be less significant and ranged from the lowest count of 8 MPN/100 mL to the highest count of 2420 MPN/100 mL.

8.6.8 Aerial surveys

Based on the aerial survey, a multiple data set consisting of buildings, roof cover, land cover, change detection and shoreline were extracted. The total roof cover for this island is 16,027 m².

8.6.9 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 yards, road surfaces, etc., is not usable as there is no mechanism for its collection and treatment.

8.6.10 Water balance and recharge

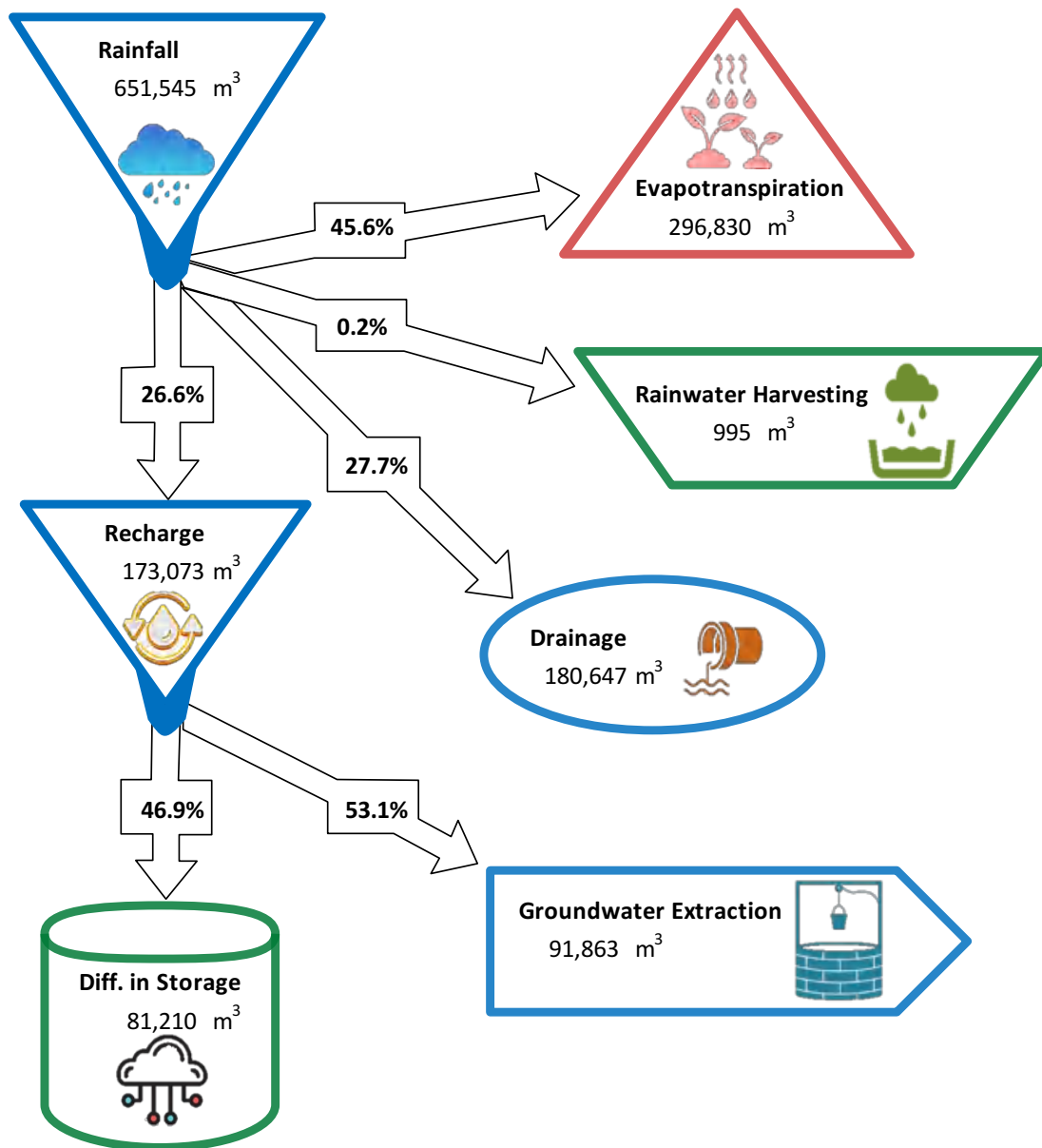


Figure 8-6: Schematic of water balance in Dhiyamigili Island

Note: Outputs of the water balance model in Dhiyamigili Islands could not be verified since geo-physical surveys were not conducted.

An annual estimation is carried out based on the water balance method (Falkland, 2000). Rainwater harvesting is calculated using the number of rainwater harvesting units on the island. According to the spatial mean annual rainfall of the Maldives, the annual average rainfall of Dhiyamigili Island is reported as 2,205 mm/year. Evapotranspiration was estimated using crop water requirements for different land use. Then, the rainfall was subtracted from rainwater harvesting, evapotranspiration, drainage to get the recharge volume. Drainage or the surface runoff was calculated by considering an aggregate runoff coefficient for the island based on the land usage (roof cover, bare land, farmland, roads, playgrounds, wetlands). 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 the difference in storage.

8.6.11 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 199 m³ per day which was calculated by subtracting groundwater extraction from recharge volume derived from the schematic water balance model in Figure 8-6.

8.6.12 Status of groundwater availability in Dhiyamigili Island

- 1). The selected Dhiyamigili island has dimensions of width = 410 m and length = 1118 m, with a total land area of 29.62 ha, a population of 839 persons, and a land use of Roof cover (Built up area) 2.78 ha (9.4%), Vegetation (Thick) 0.00 ha (0.0%), Vegetation (Light) 8.39 ha (28.3%), and Bare lands 18.44 ha (62.3%).
- 2). The ground elevation values ranged from a minimum of 0.64 m MSL to a maximum of 1.39 m MSL, with an average of 1.03 ± 0.21 m MSL (Mean \pm Standard Deviation).
- 3). The groundwater profile in the island is characterised by a relatively Low (0.15%) Rainwater Harvesting (%) relatively High (27.73%) Drainage (%) relatively Low (26.56%) Recharge (%) while the water use shows relatively High (53.08%) Groundwater extraction (%) leading to relatively Low (46.92%) Difference in Balance Storage (%).

8.7 Conclusion

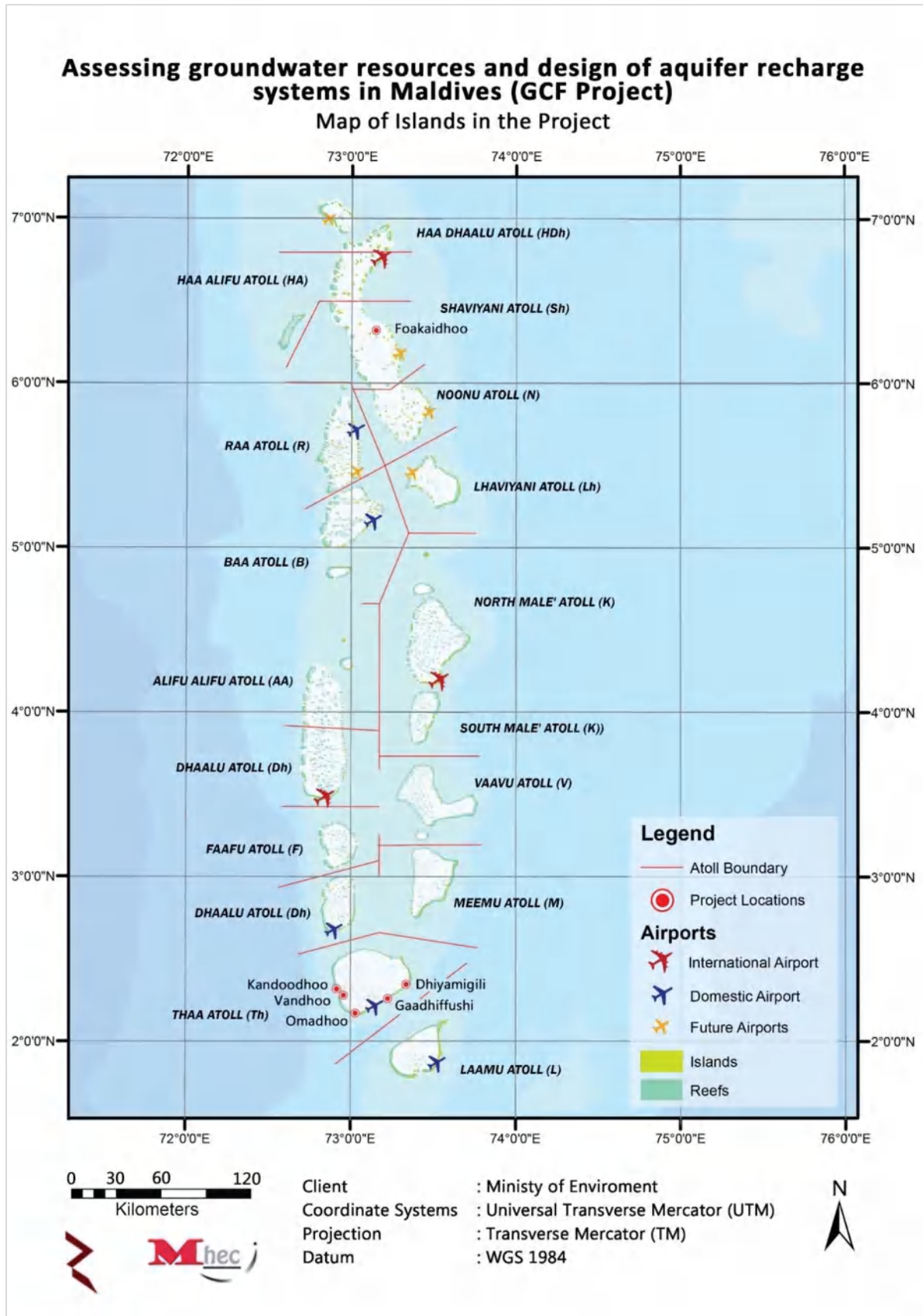
The Safe Yield for the island estimated based on 'Recharge - Extraction' is 750 m³ per day, while it is 179 m³ per day based on 10% of Average Annual Rainfall Method. The present groundwater extraction rate estimated based on survey data is 297 m³ per day and this exceeds the allowable Safe Yield in the island by 113% (moderately stressed). At present, there exists no island wide sewerage network or water supply network. Water quality aspects can be regarded as Contaminated with an Average Electrical Conductivity (EC) of 1411.09 ± 3132.94 μ S/cm with measured values ranging from a minimum of 264.00 μ S/cm to a maximum of 21,878 μ S/cm and an Average Ammonia Concentration of 0.78 ± 1.24 μ S/cm with measured values ranging from a minimum of 0.02 μ S/cm to a maximum of 0,005 μ S/cm. The Availability of space for incorporating recharge measures and related infrastructure is Low while therefore the Potential for Recharging is considered to be Low.

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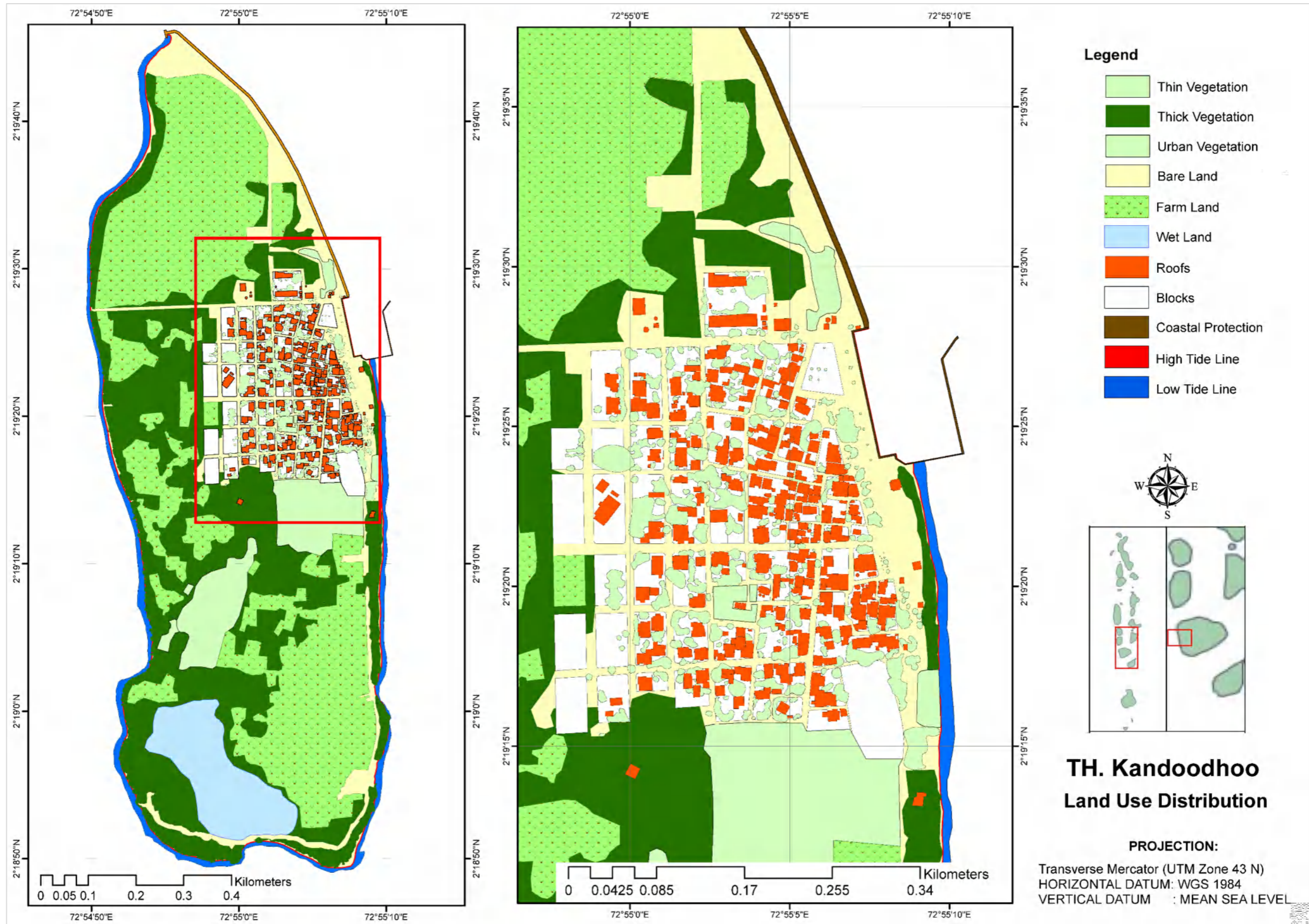
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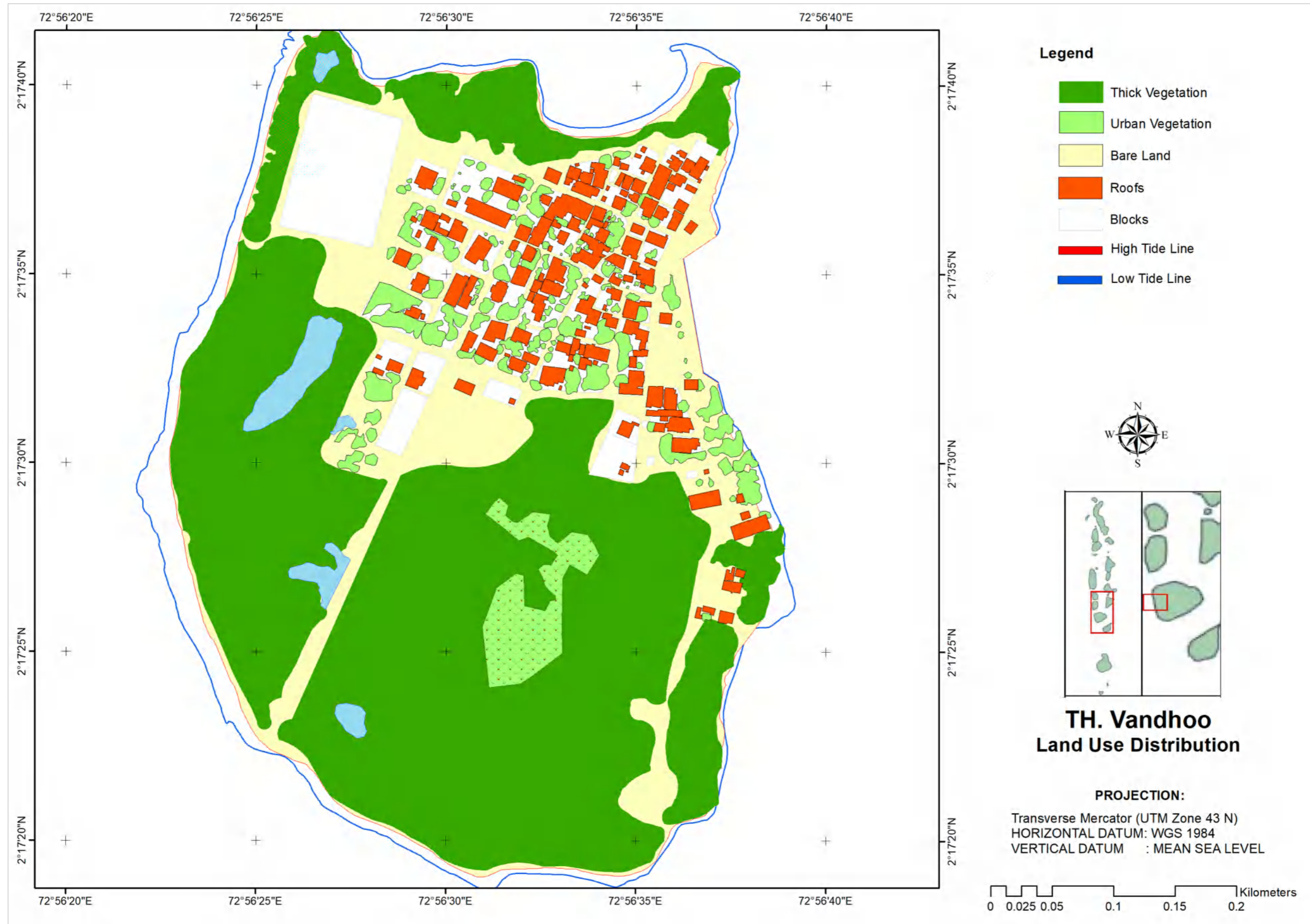
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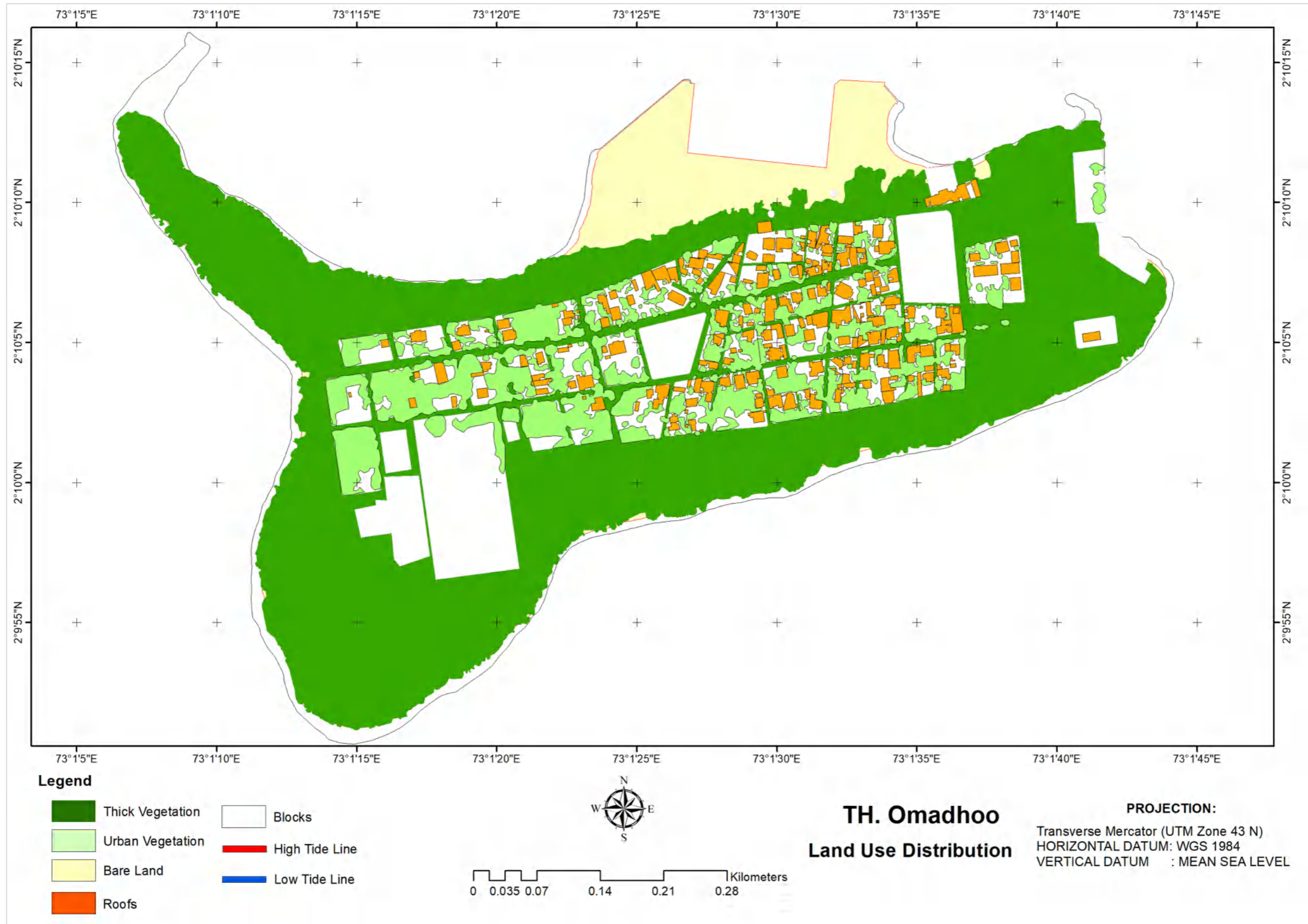
Annex I: Location Map of the Islands

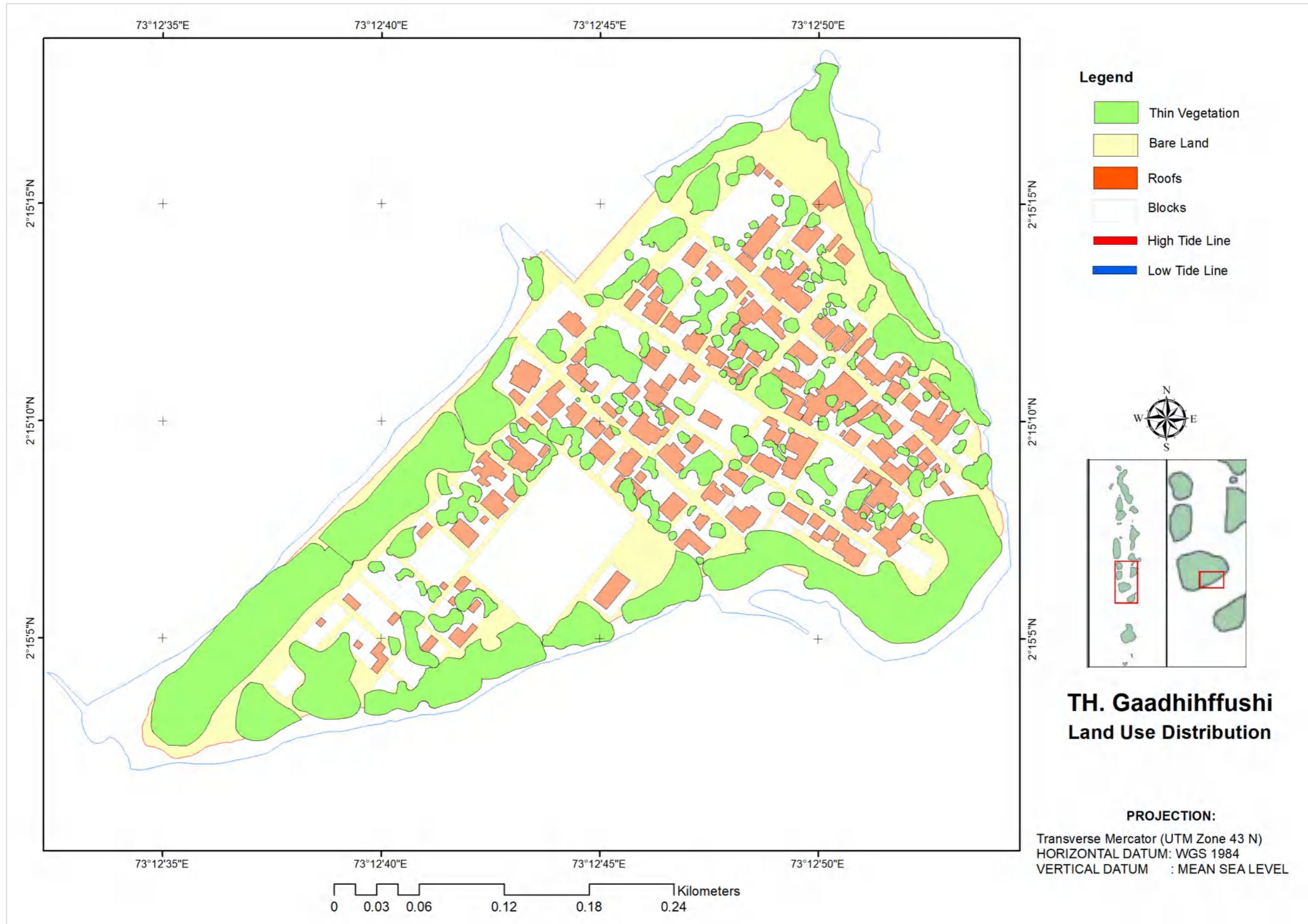


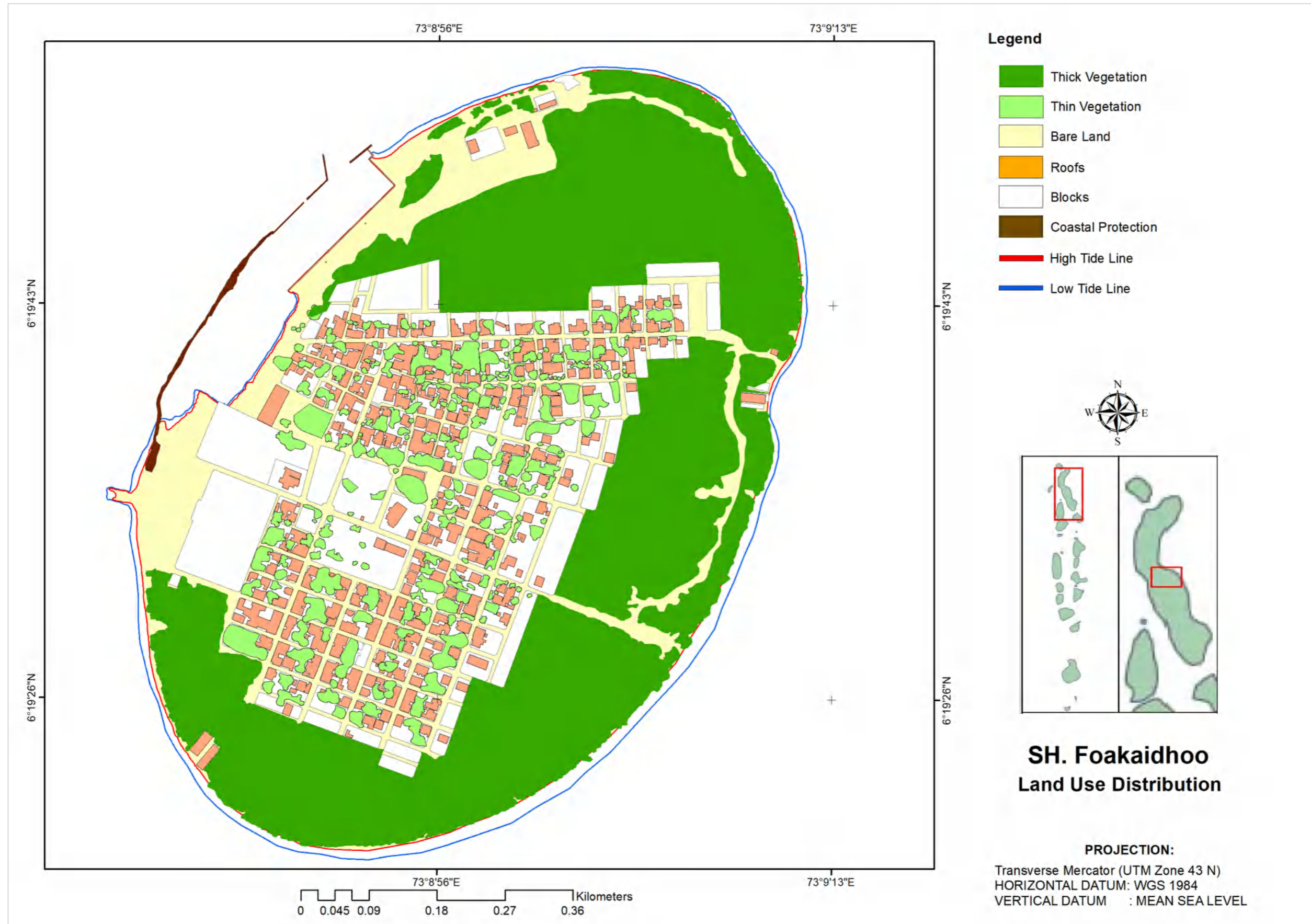
Annex II: Land Use Distribution of Islands



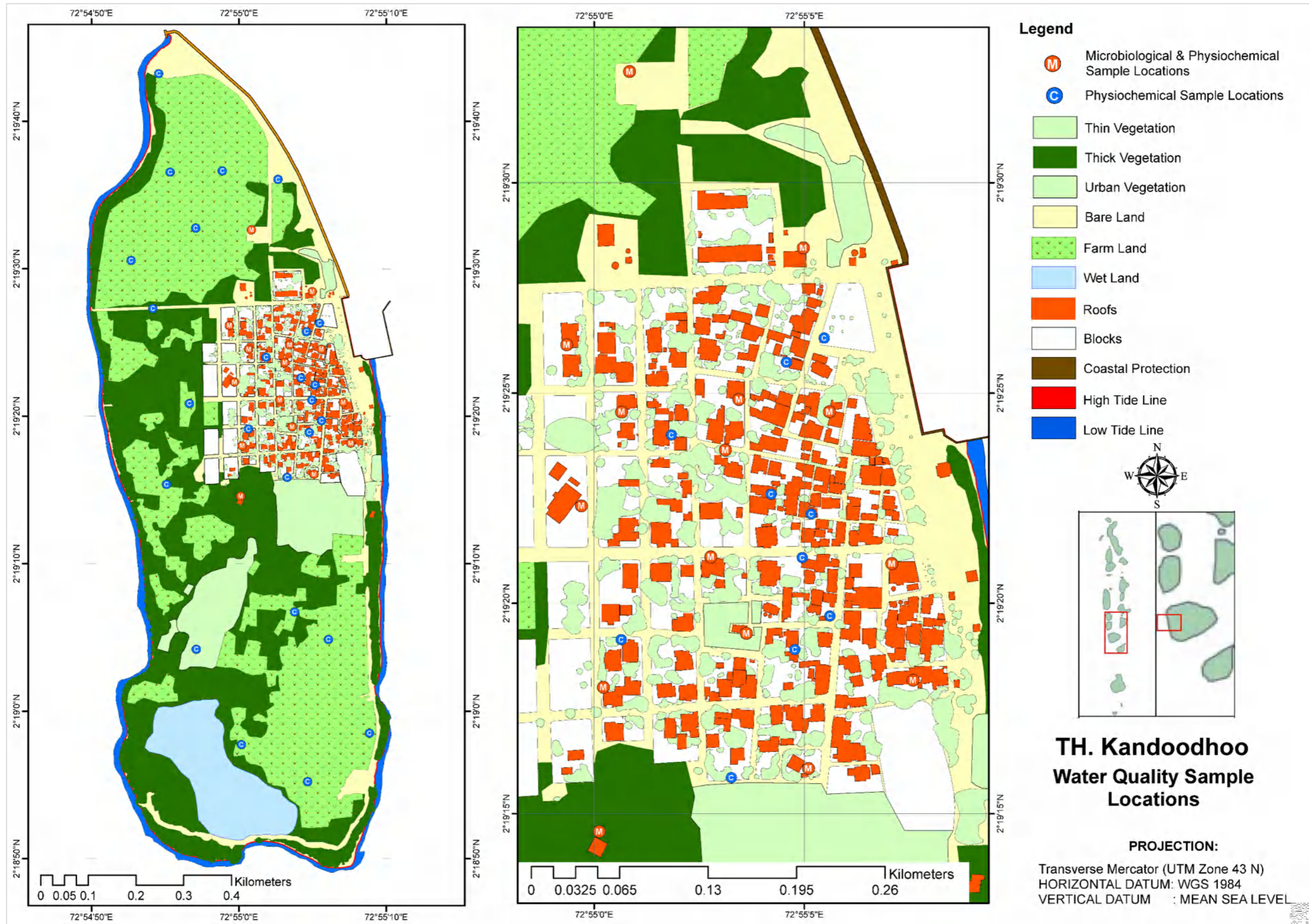


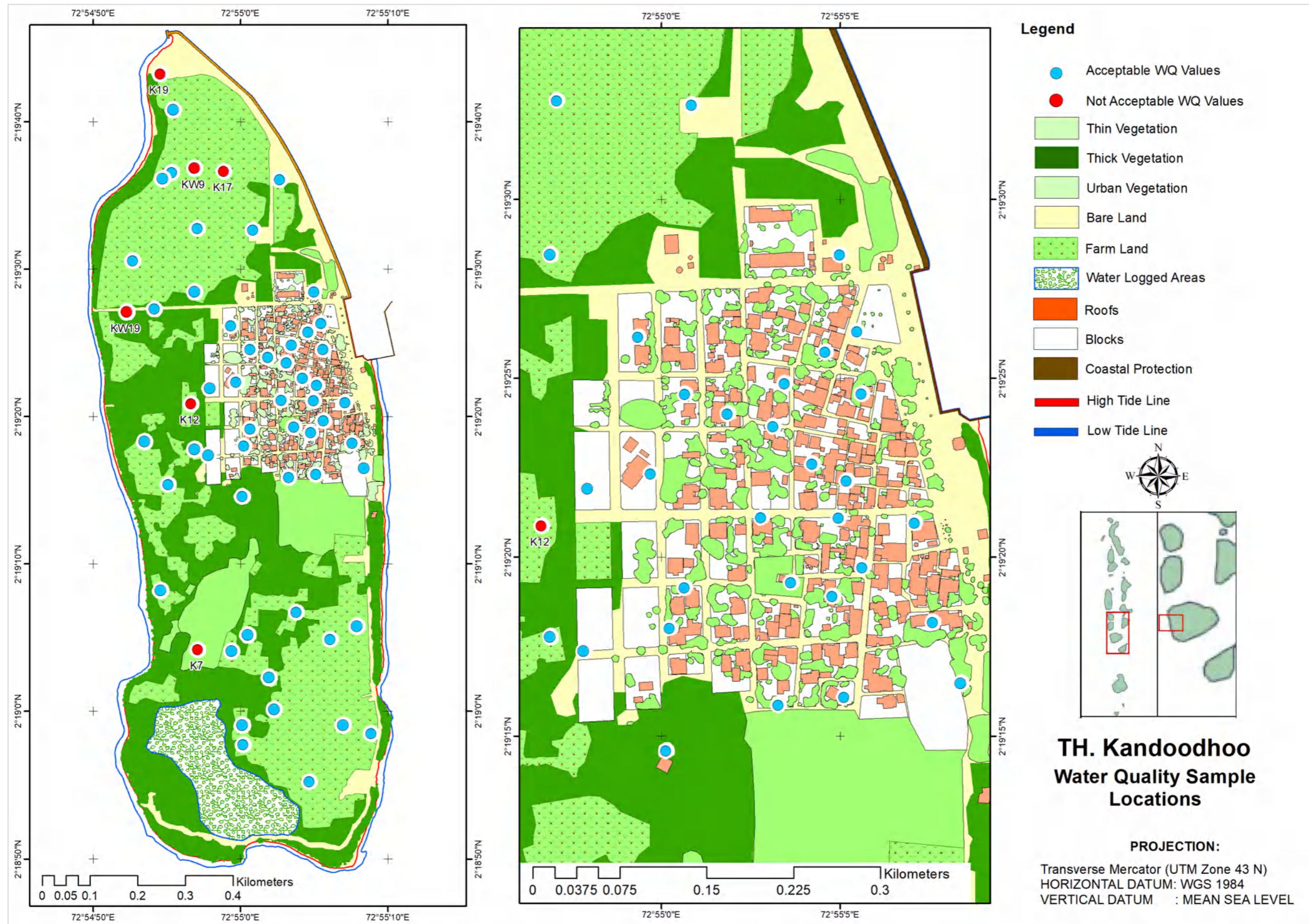


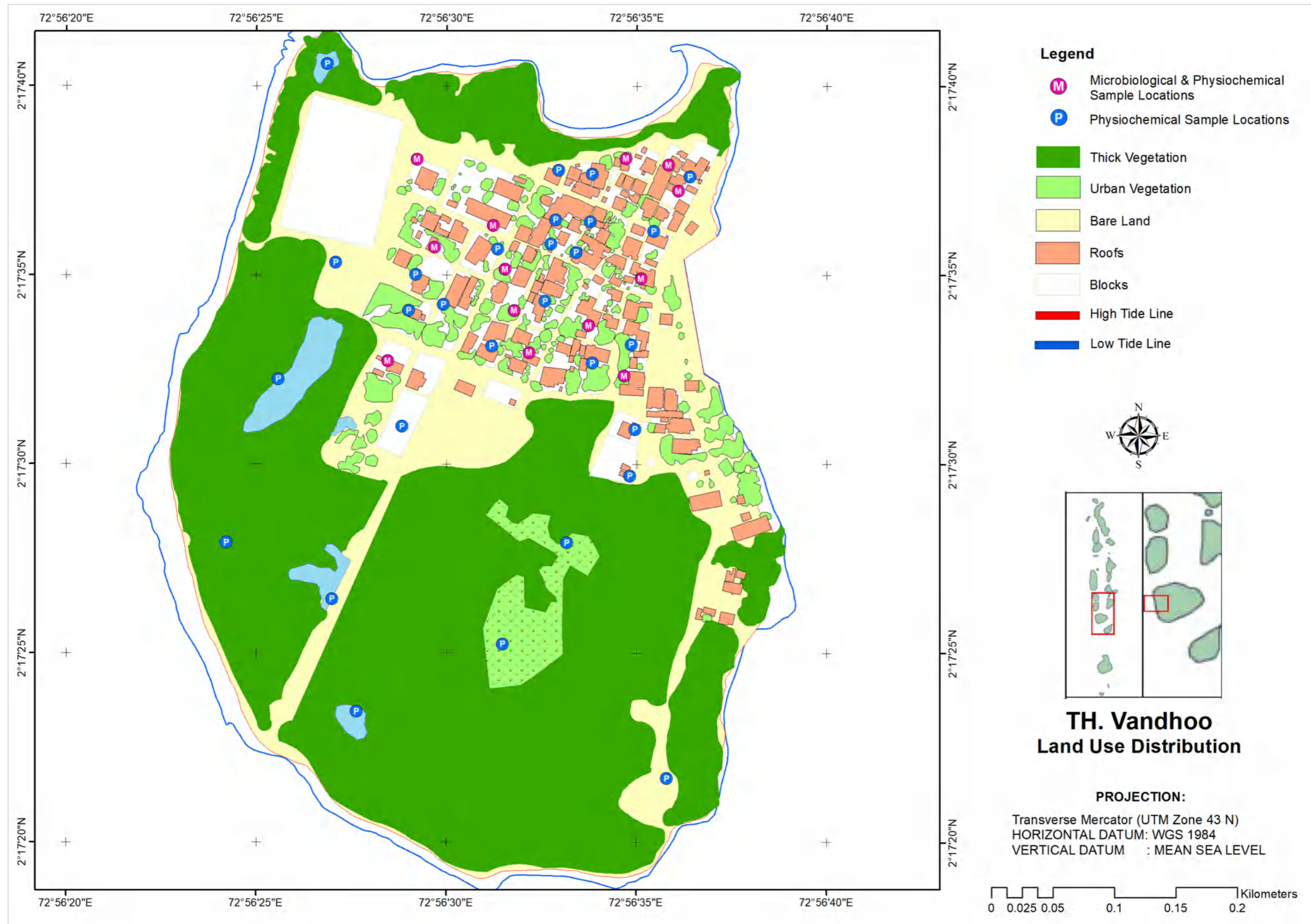


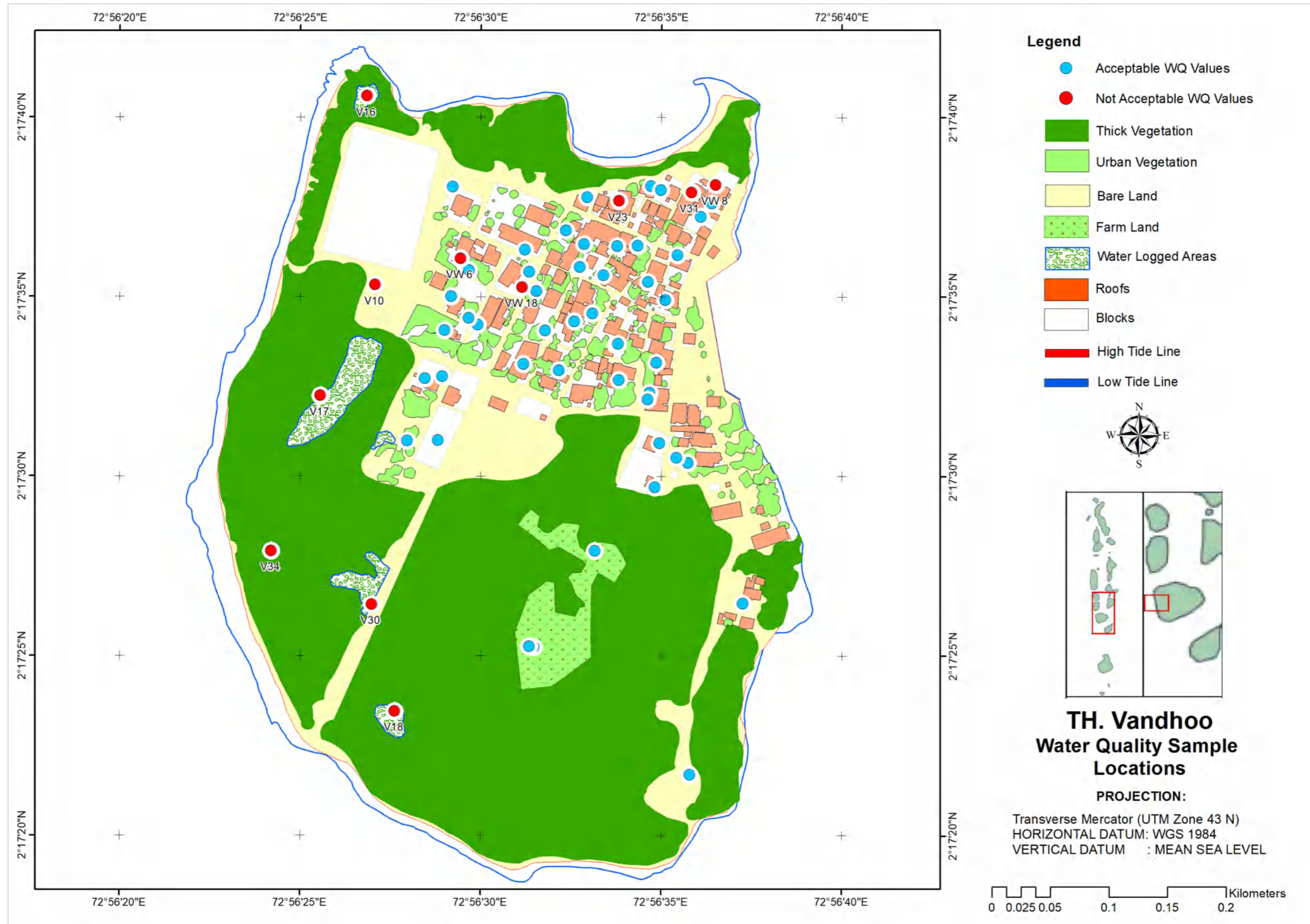


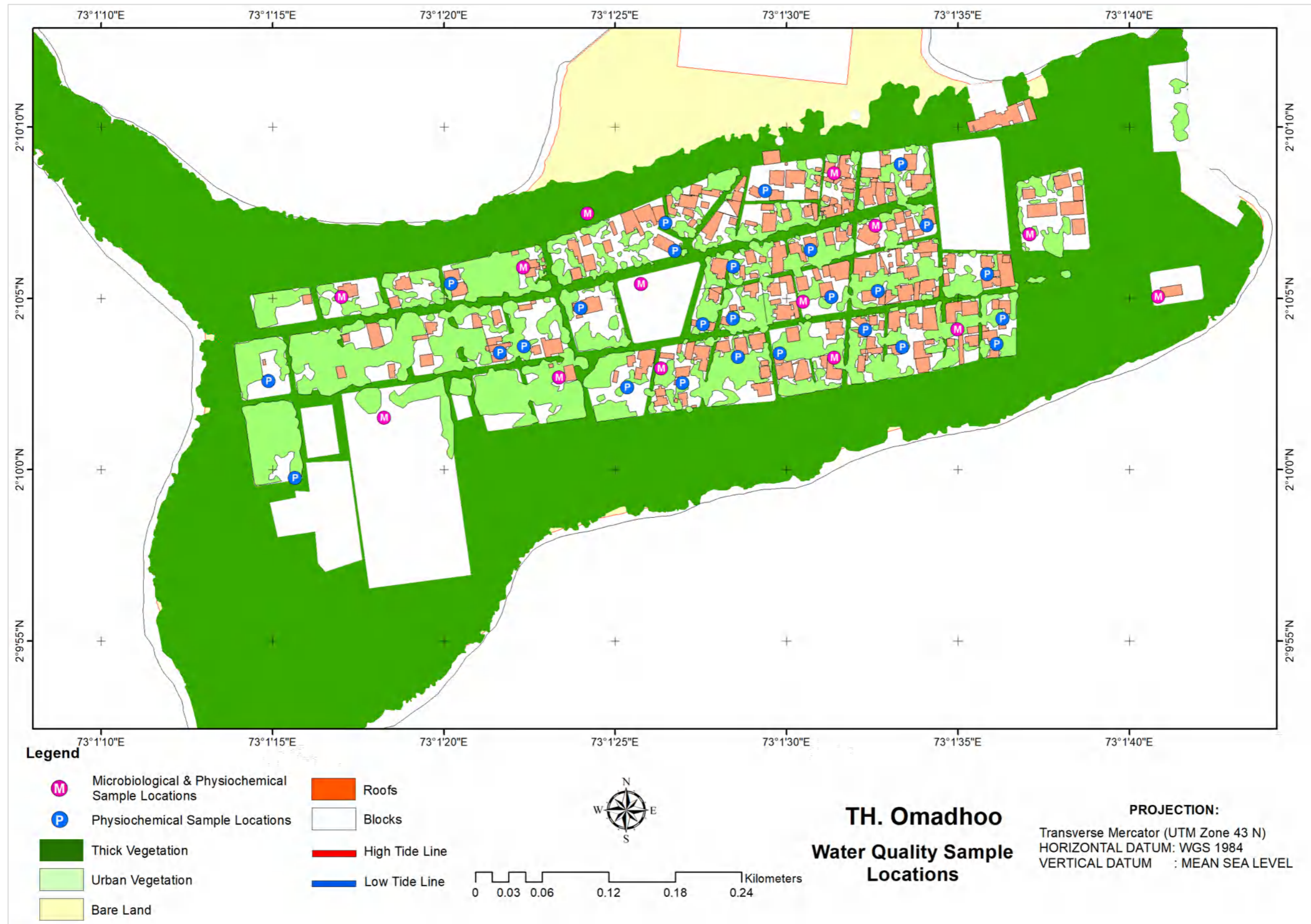
Annex III: Water Quality Sample Locations of the Islands

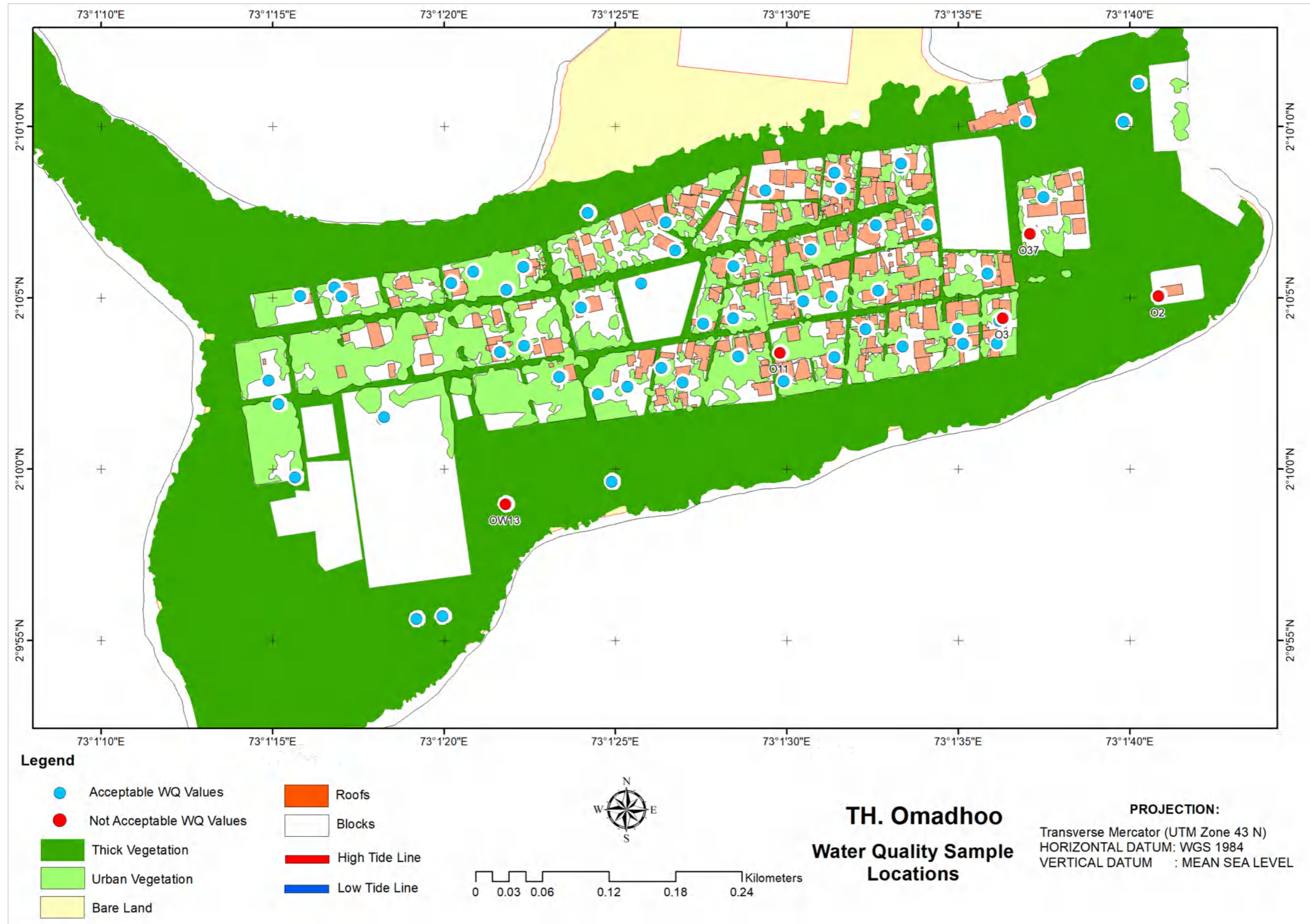


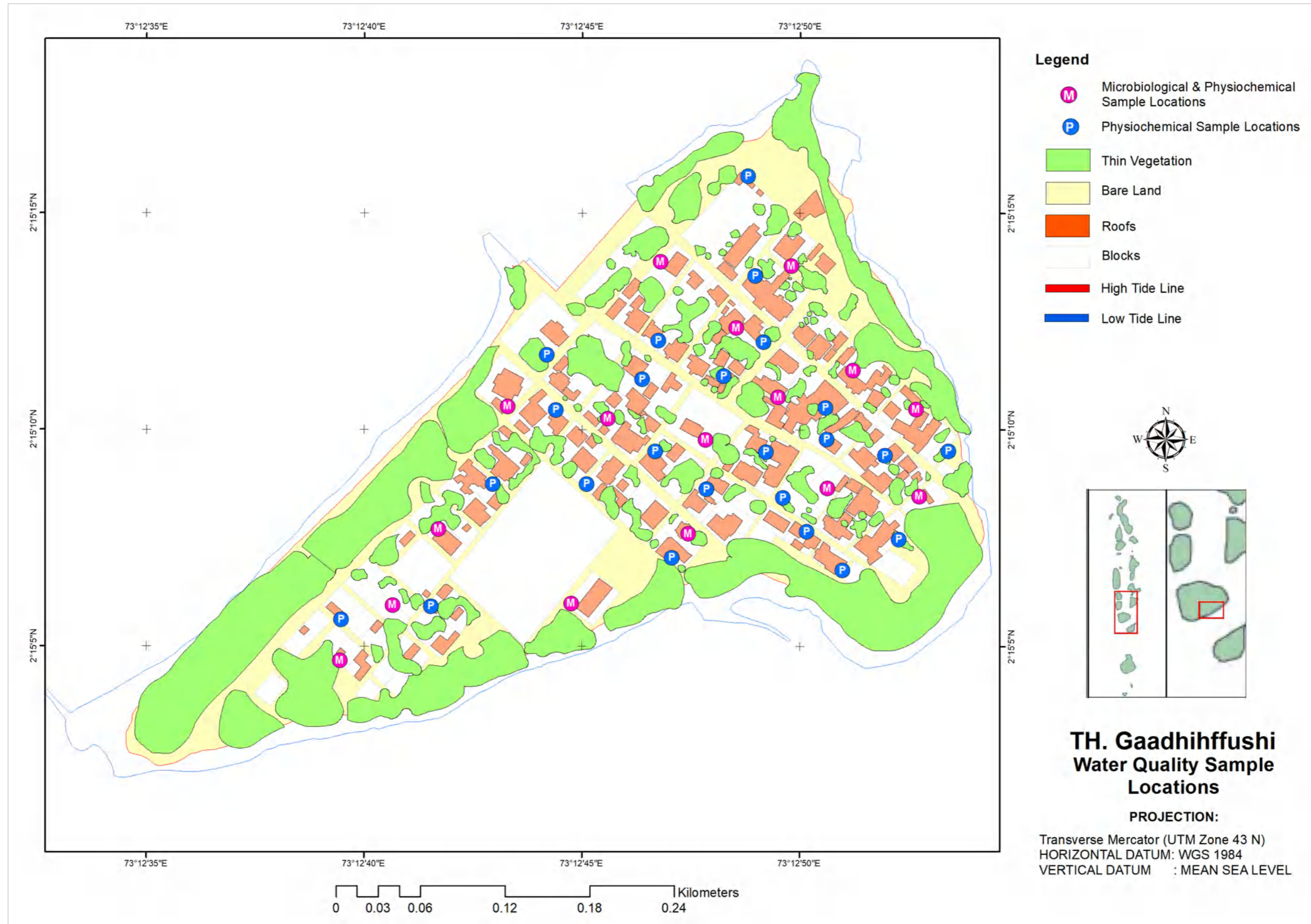


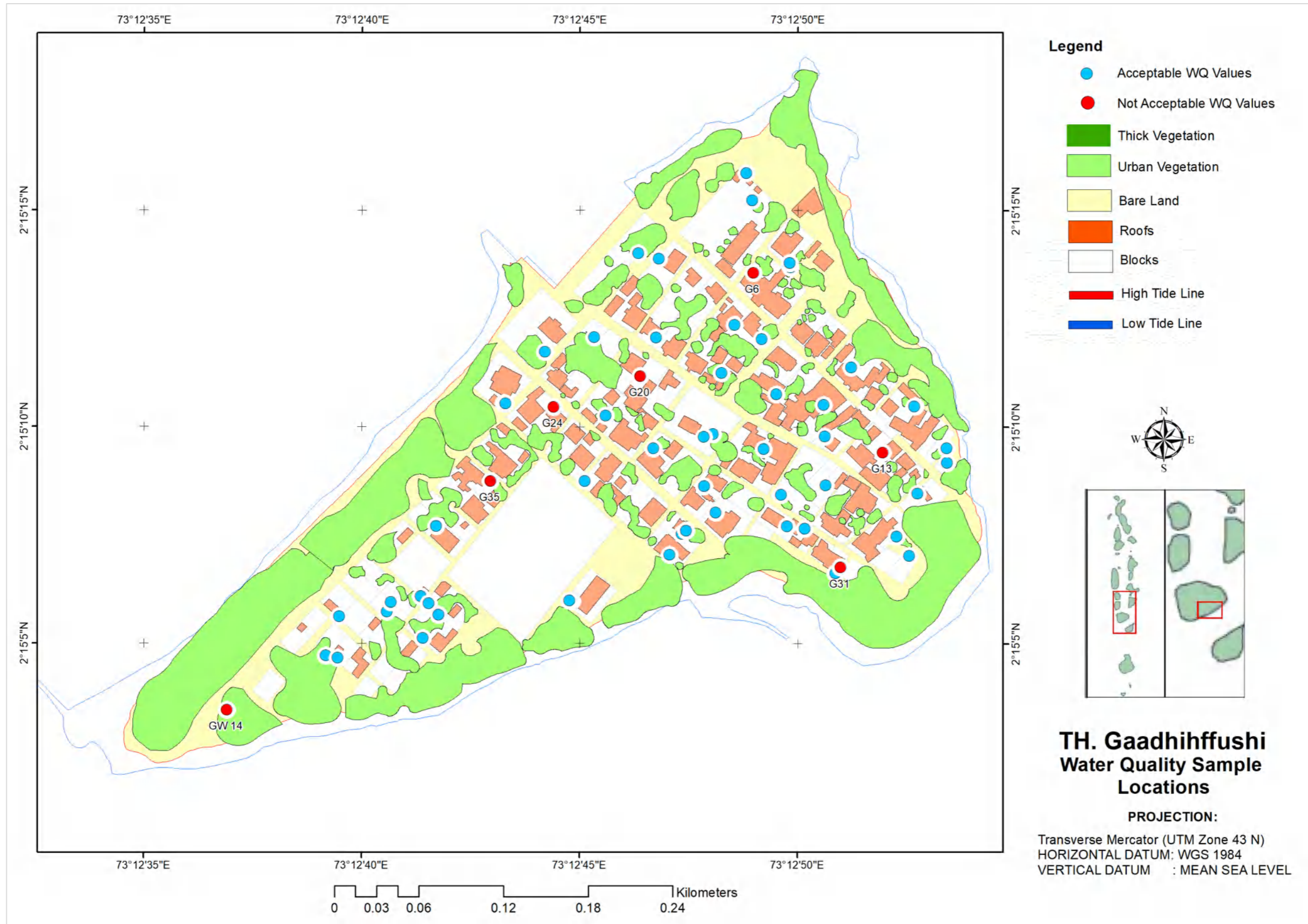


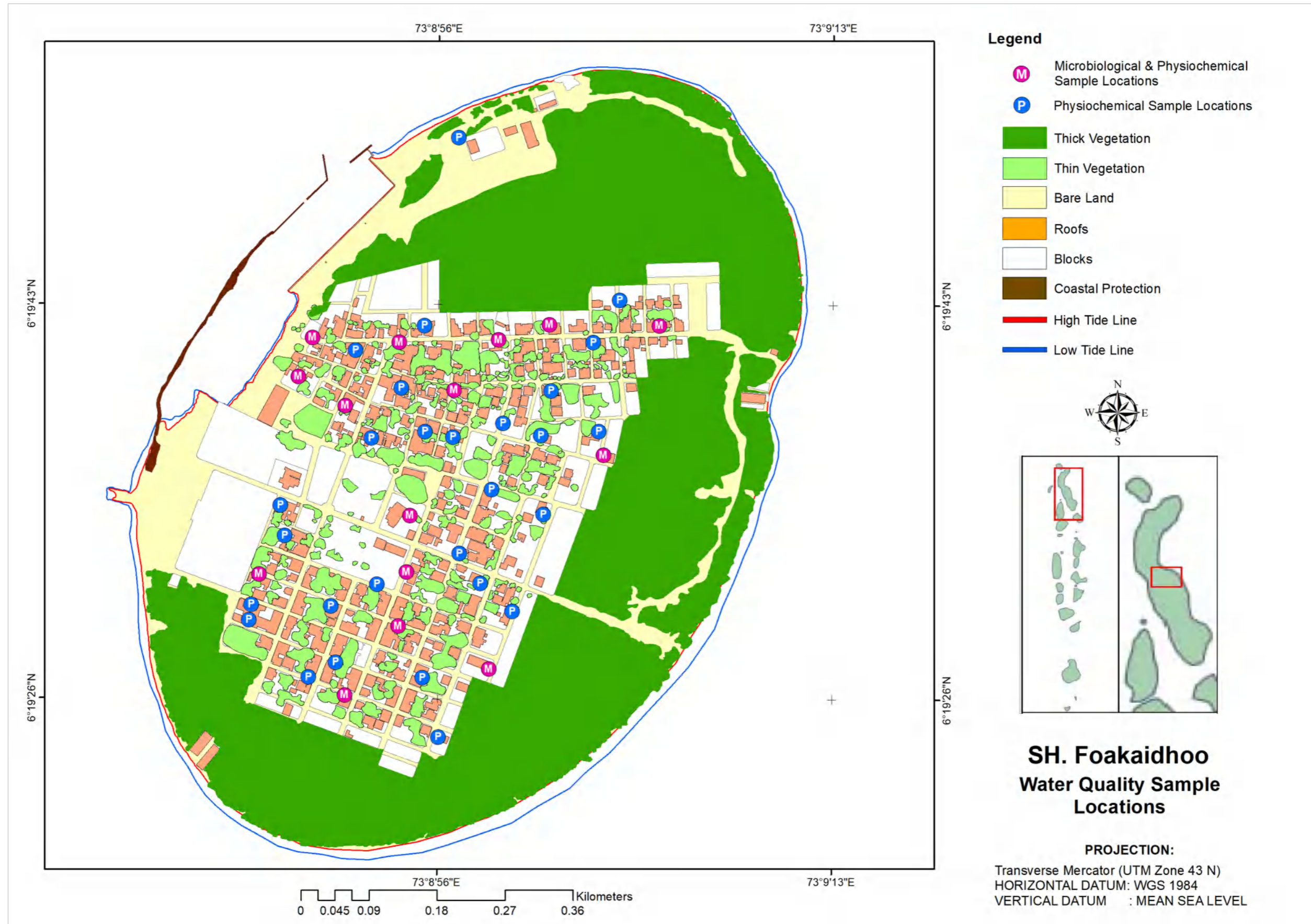


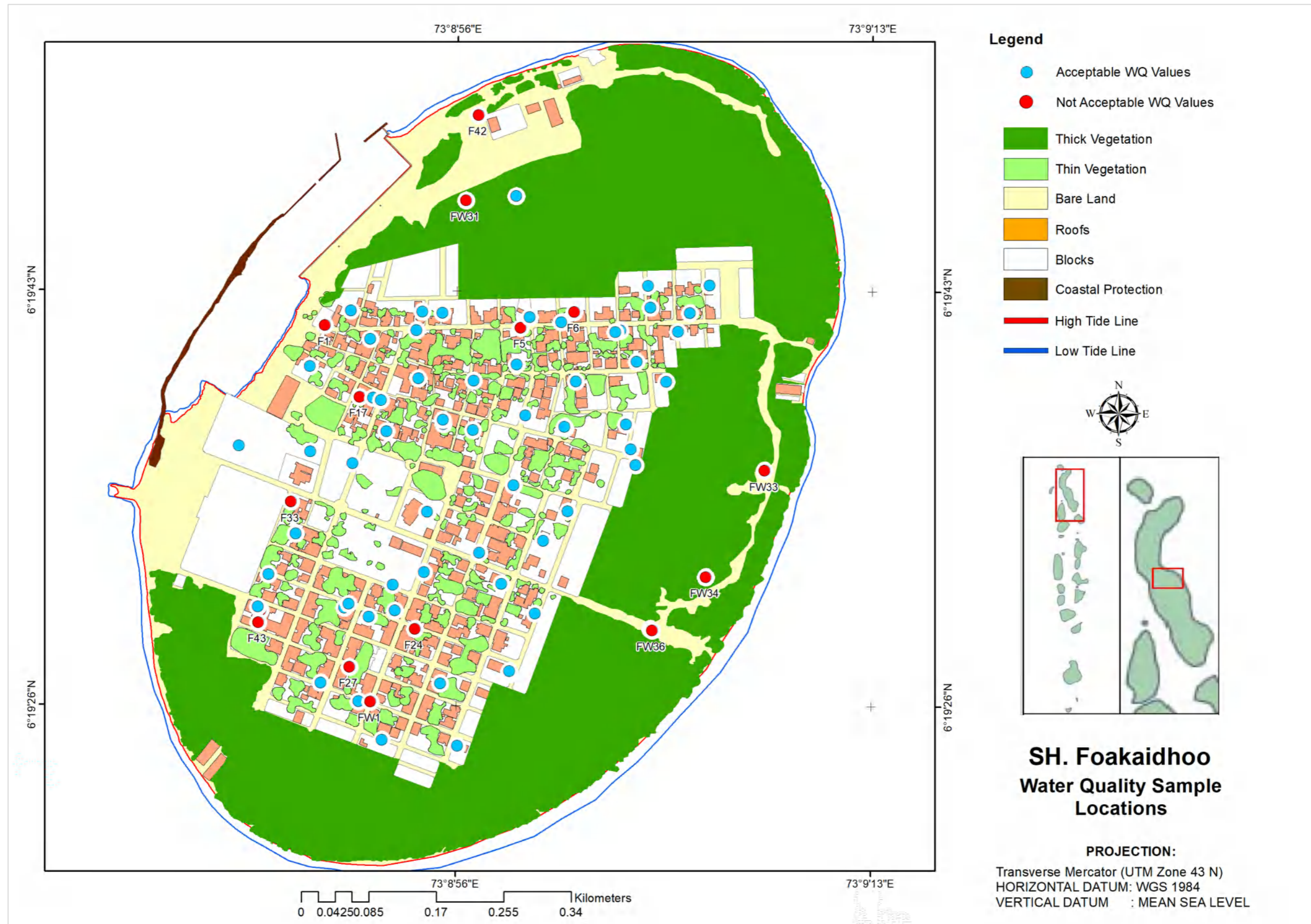




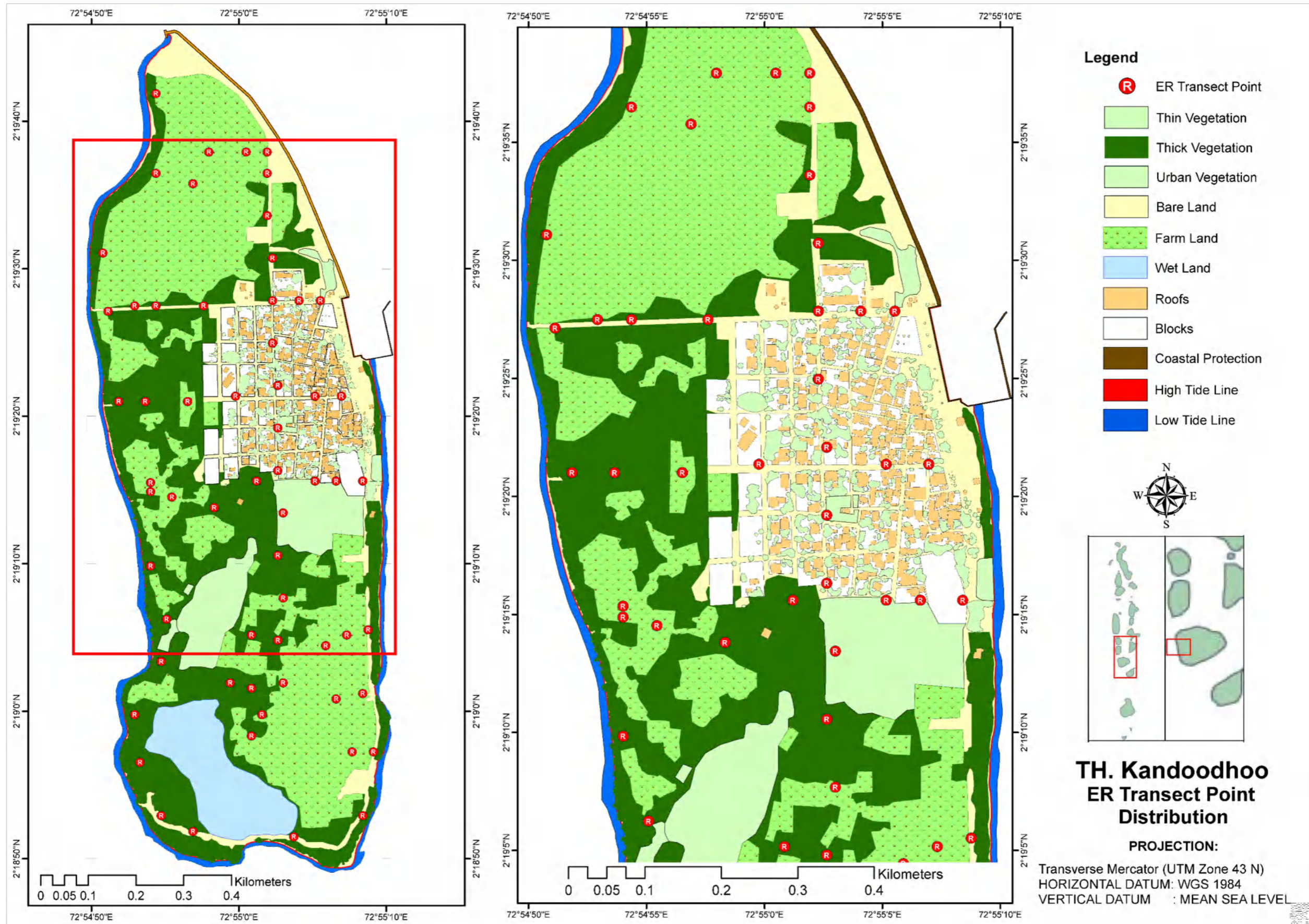


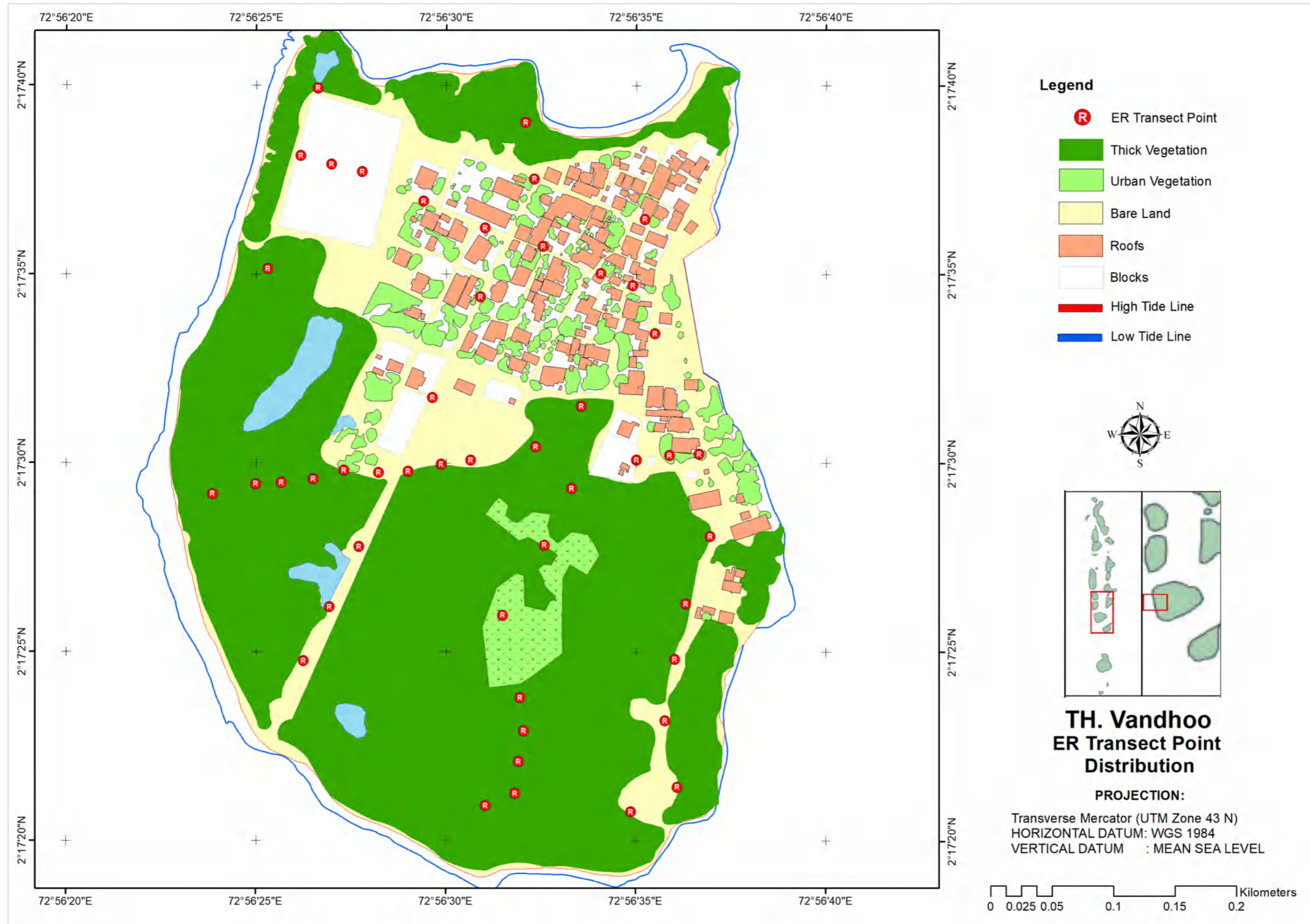


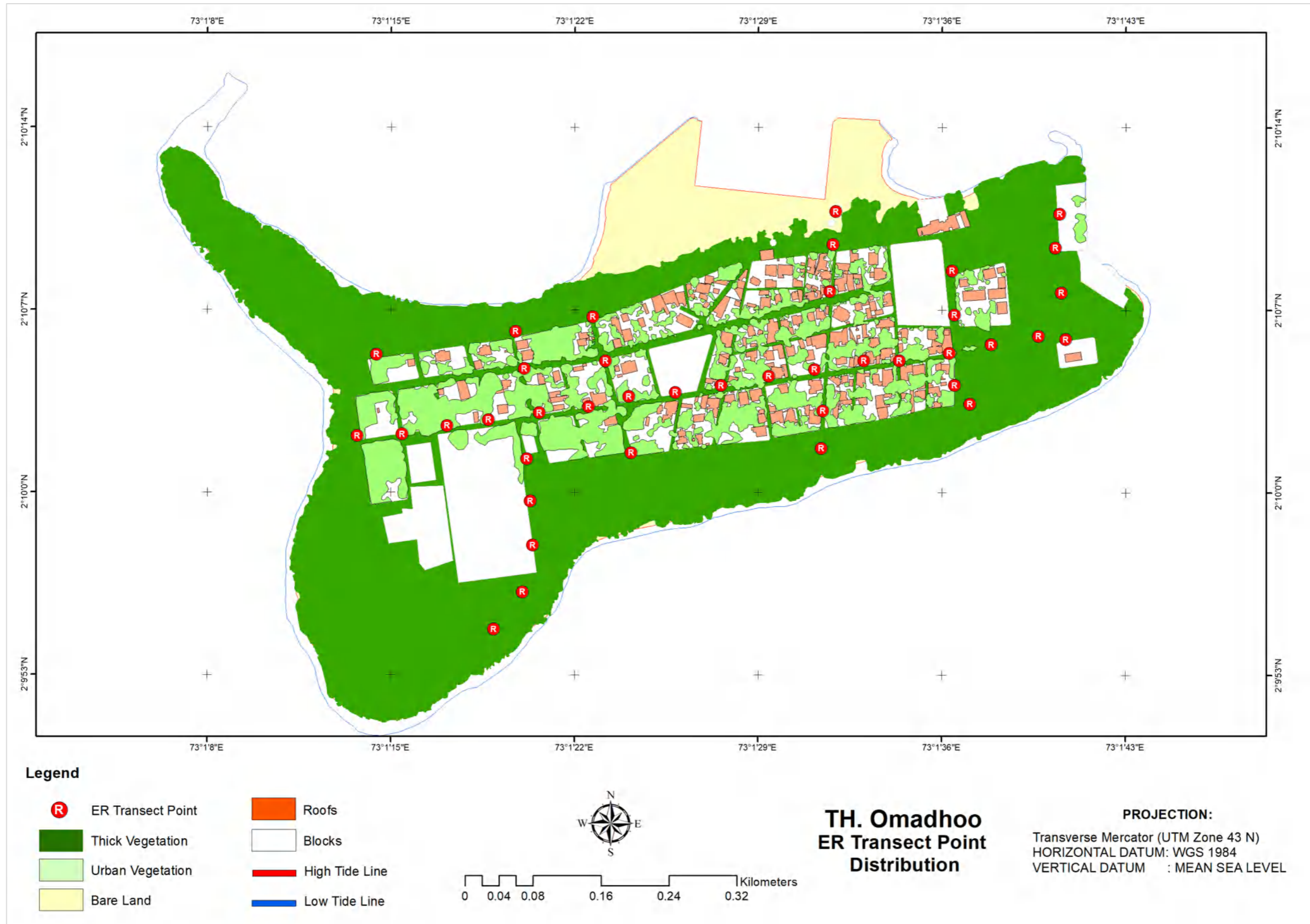


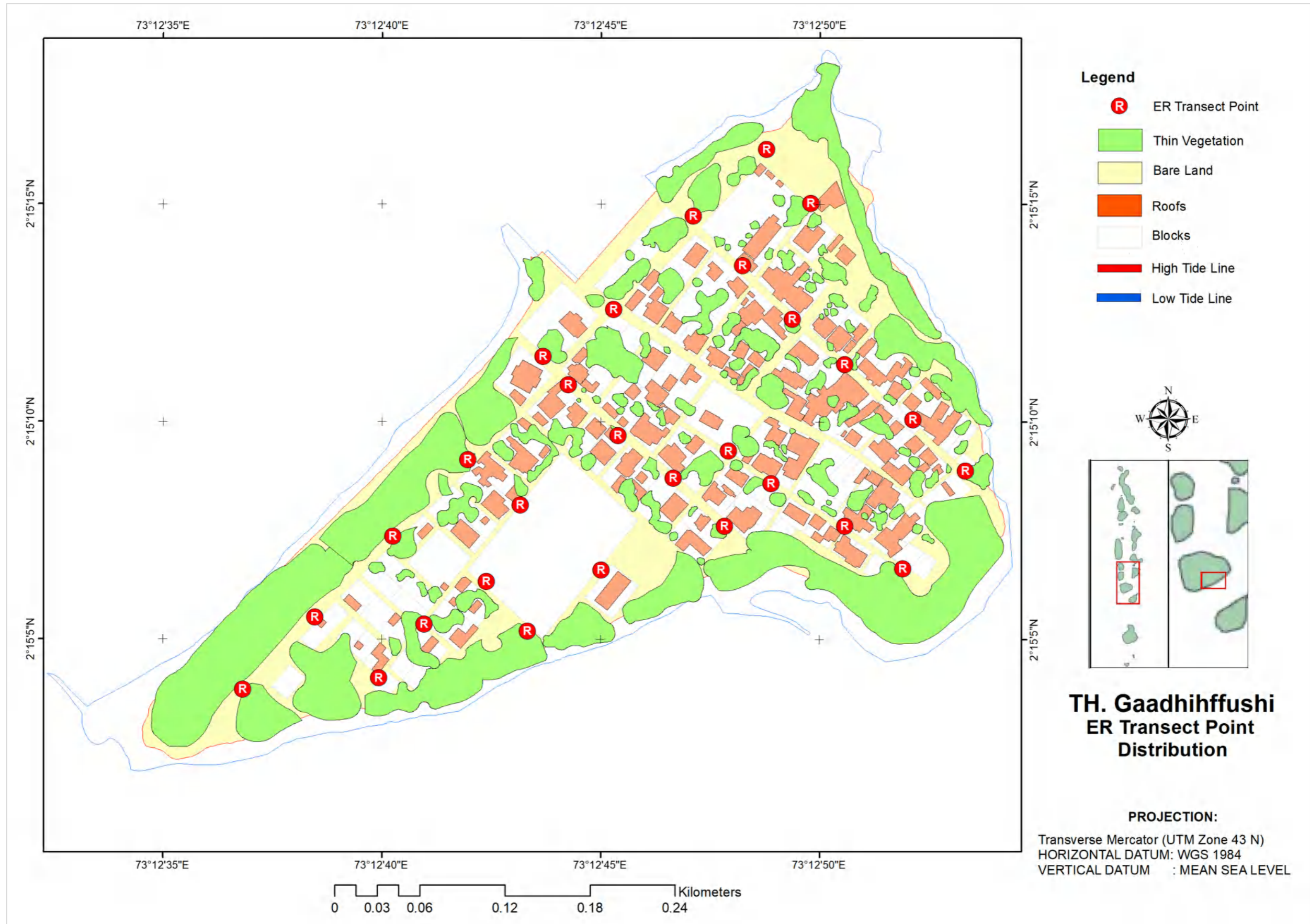


Annex IV: ER Transect Point Locations of the Islands



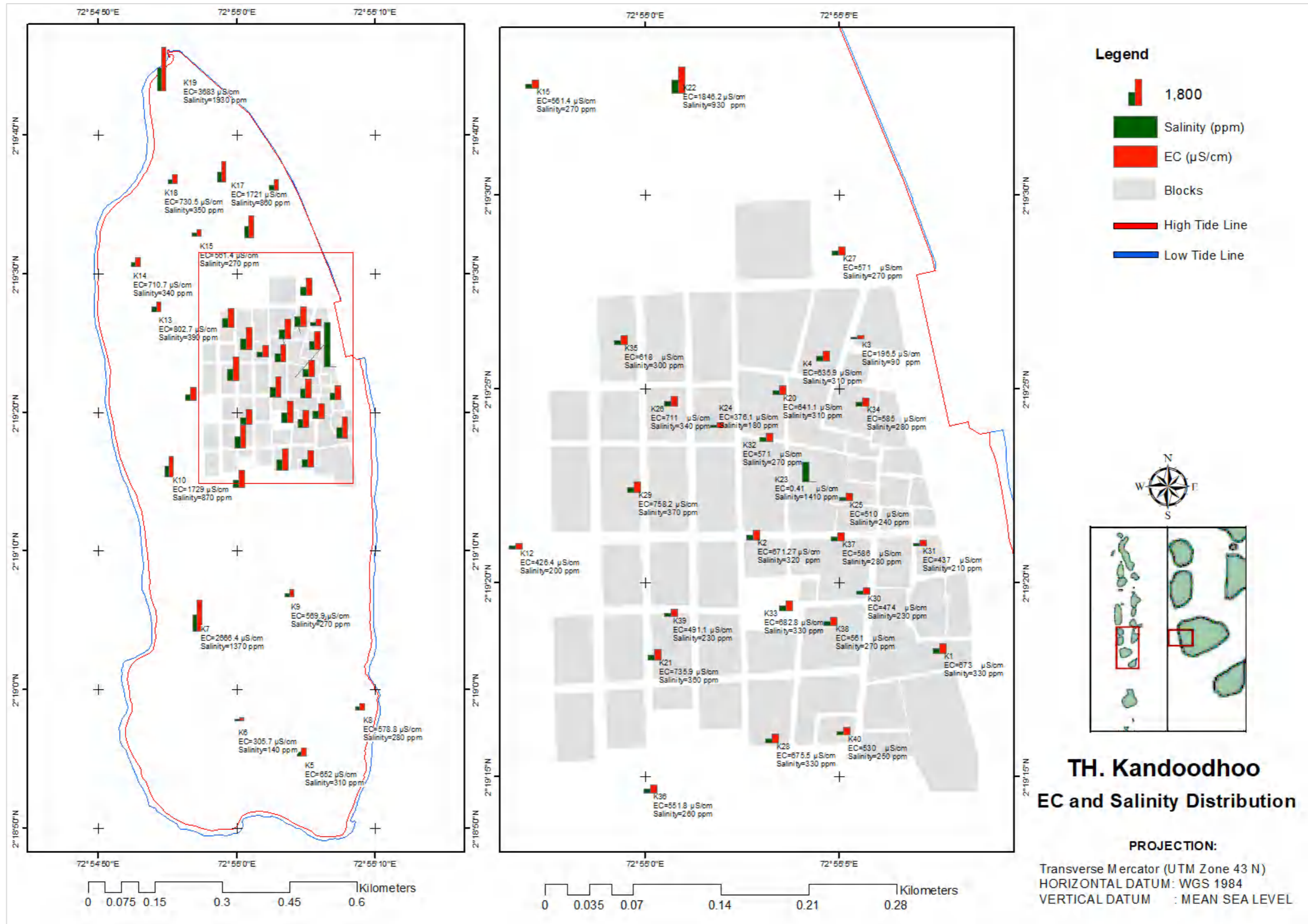


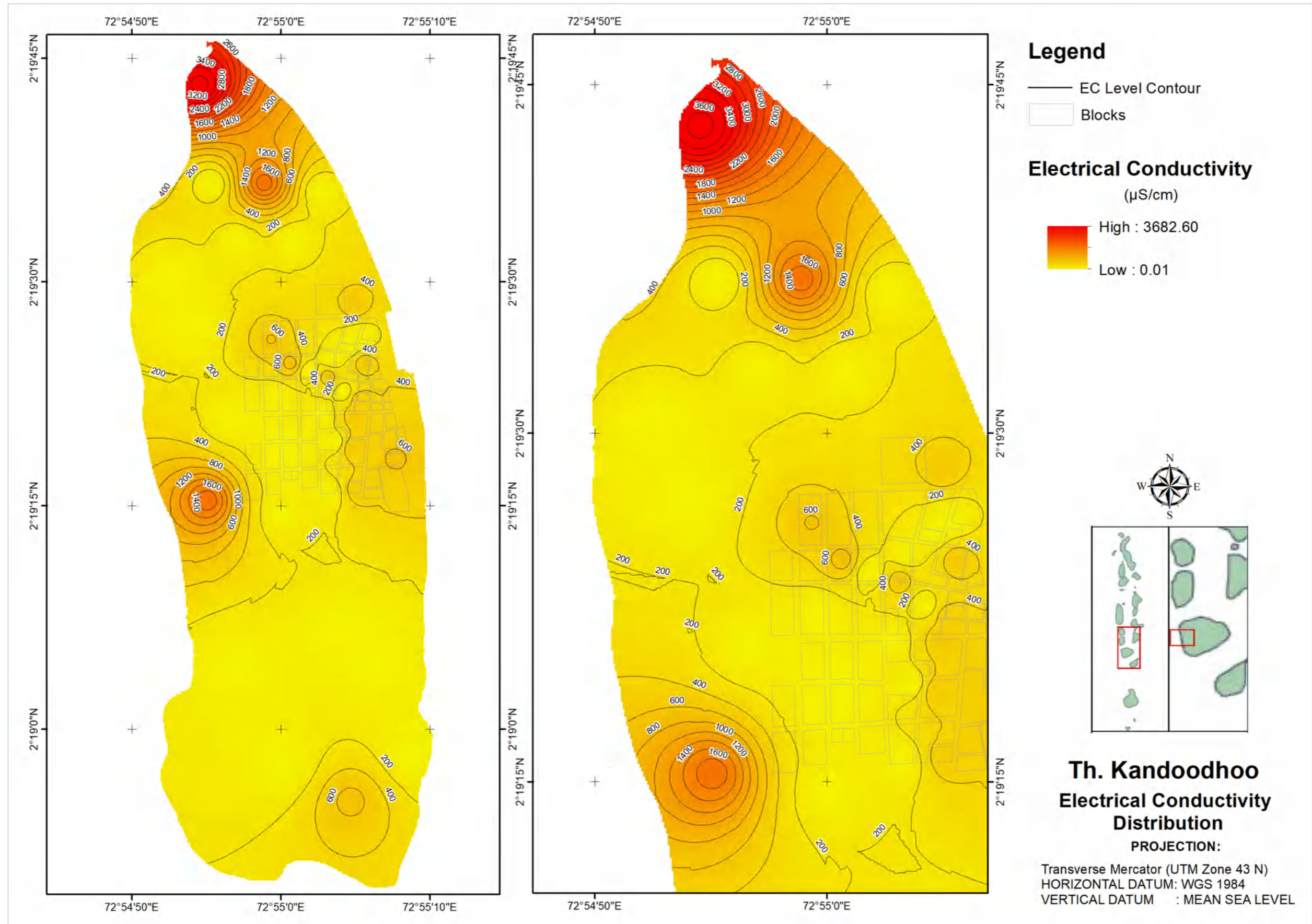


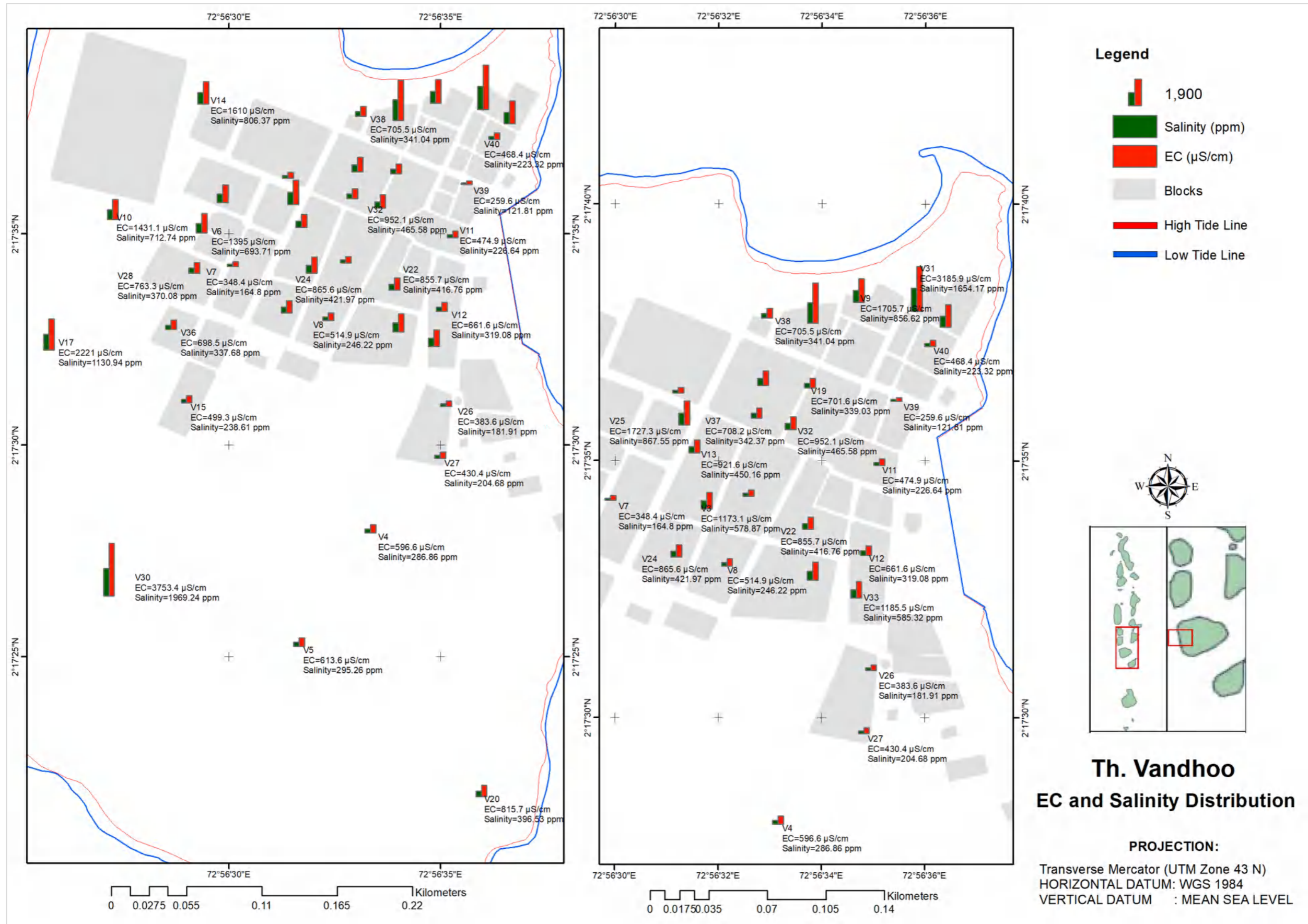


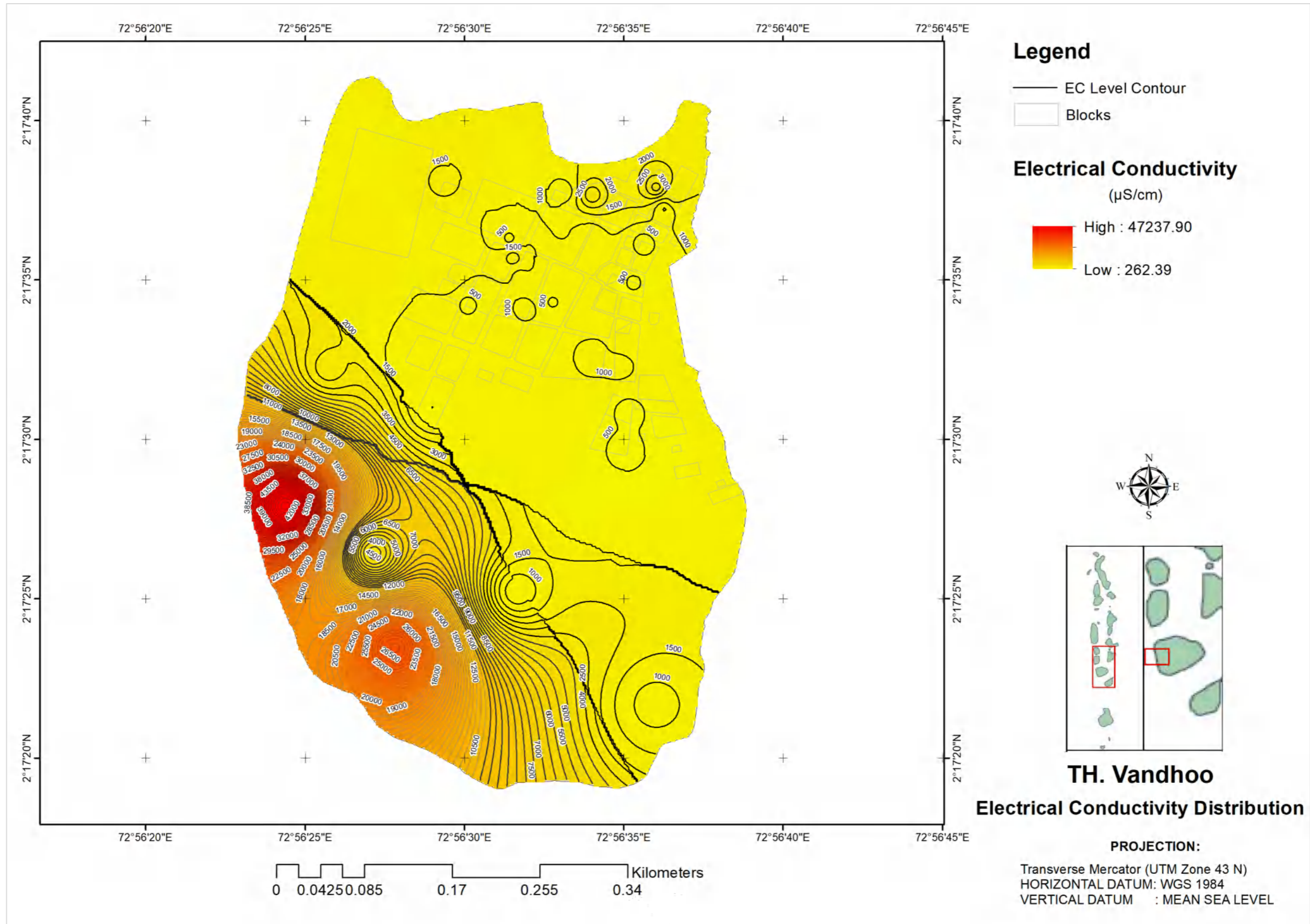


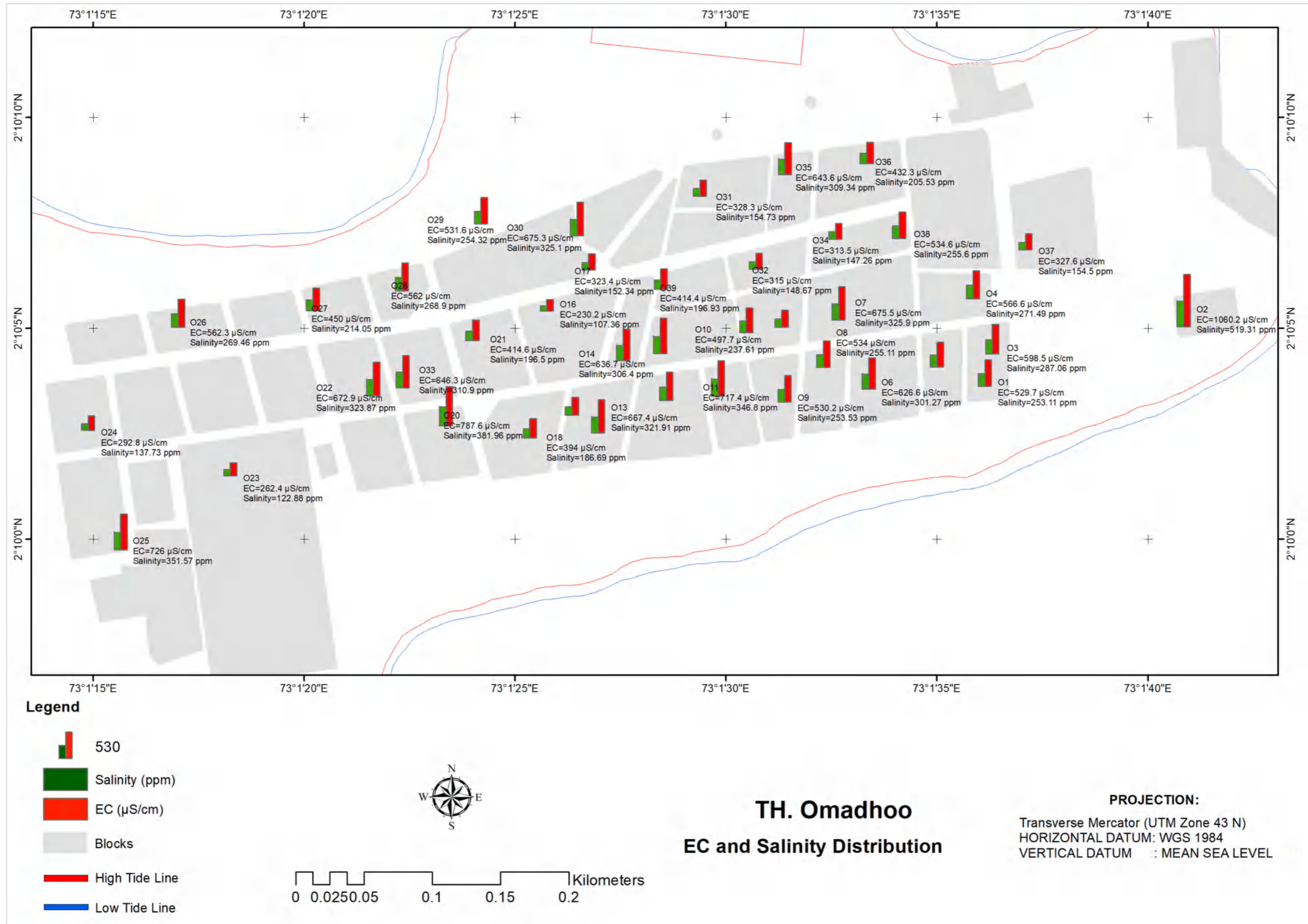
Annex V: EC and Salinity Distribution of the Islands

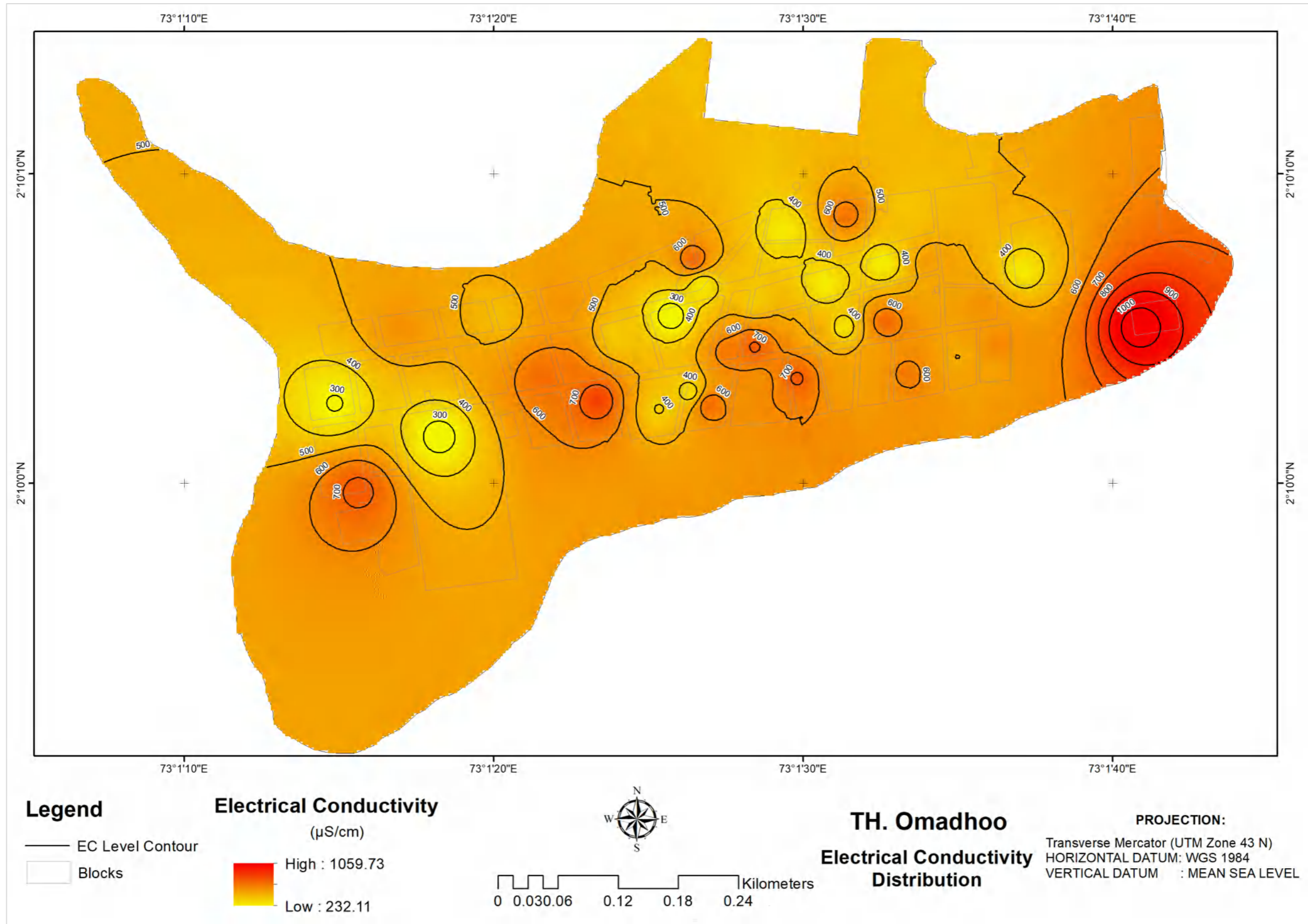


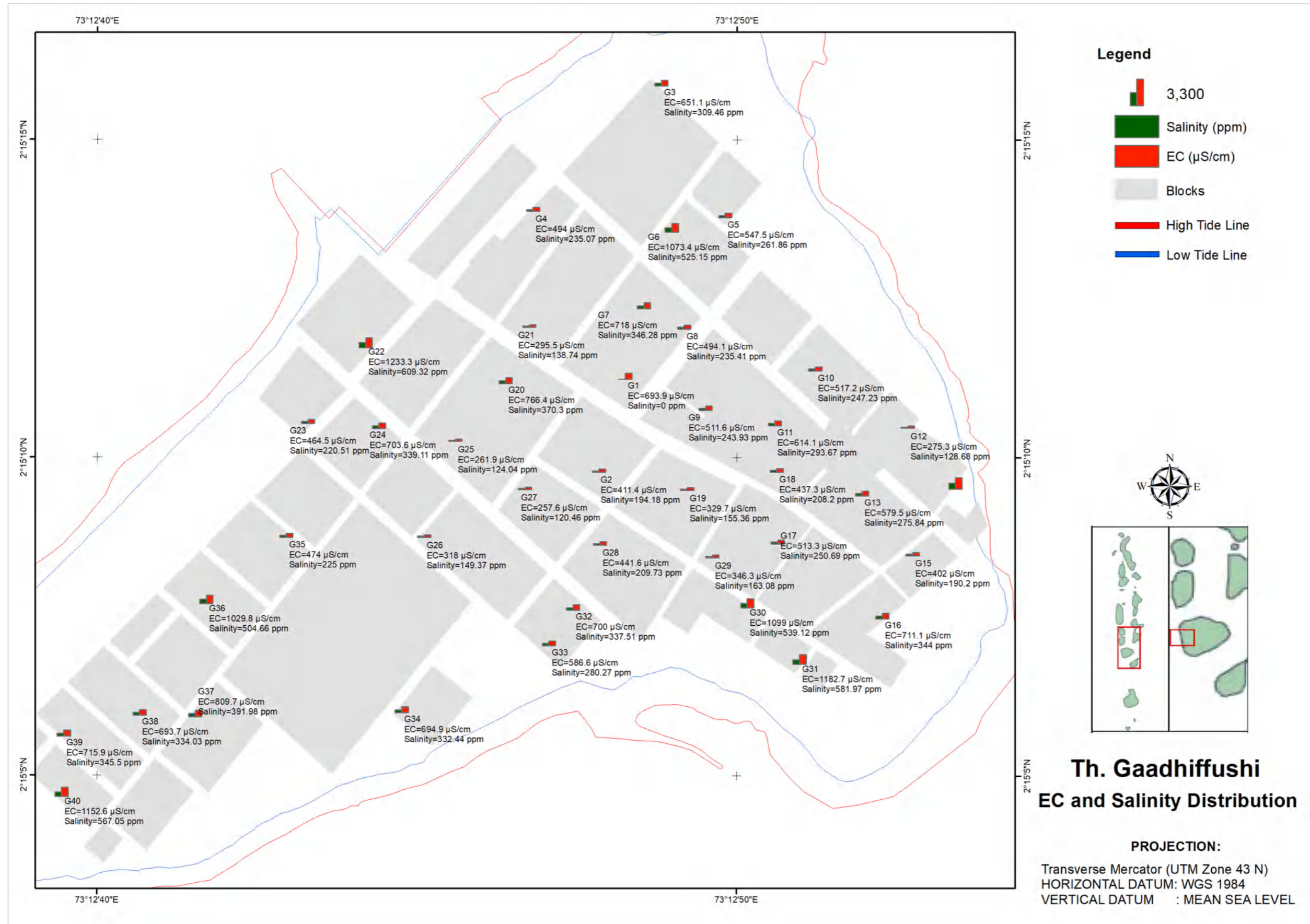


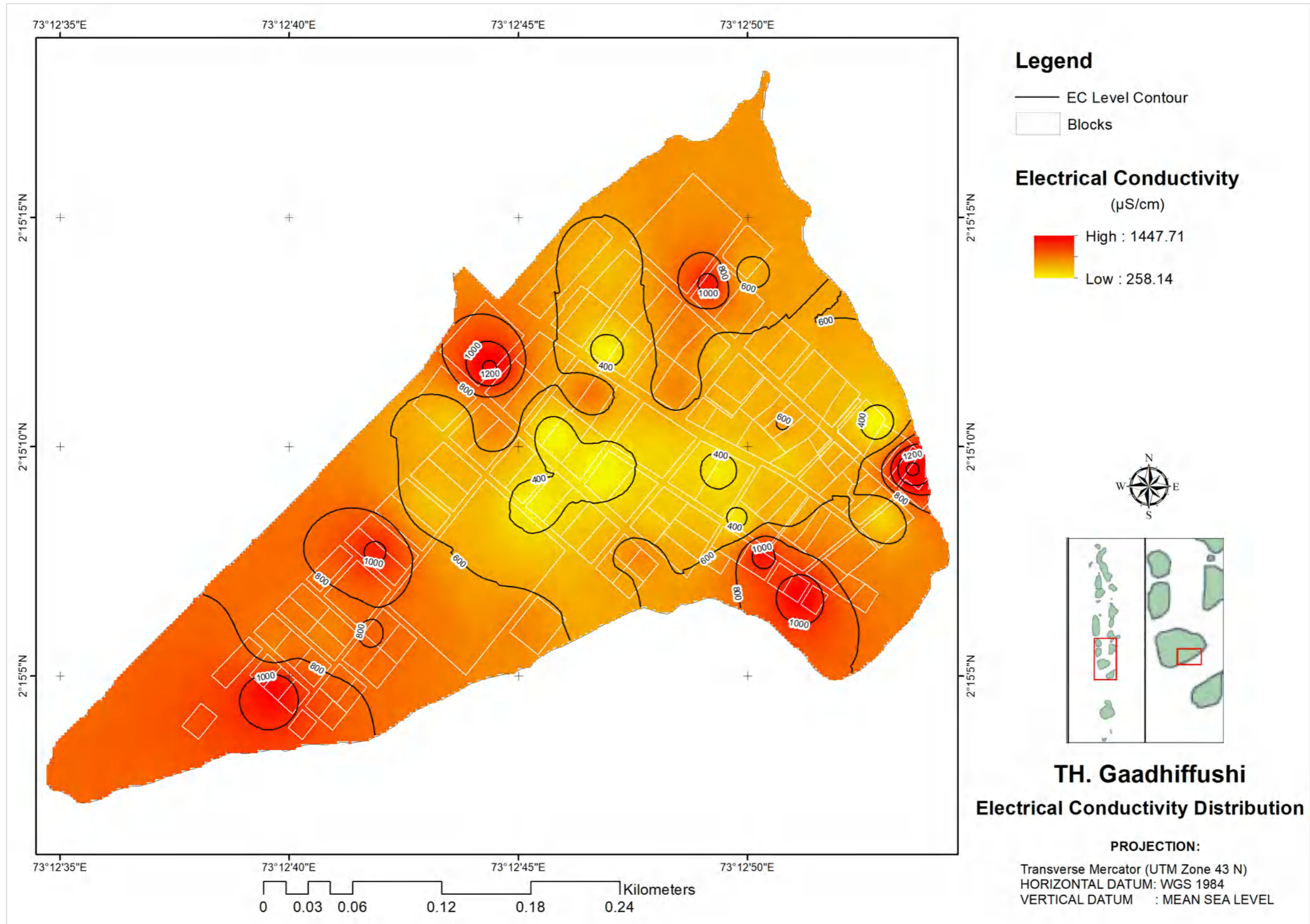




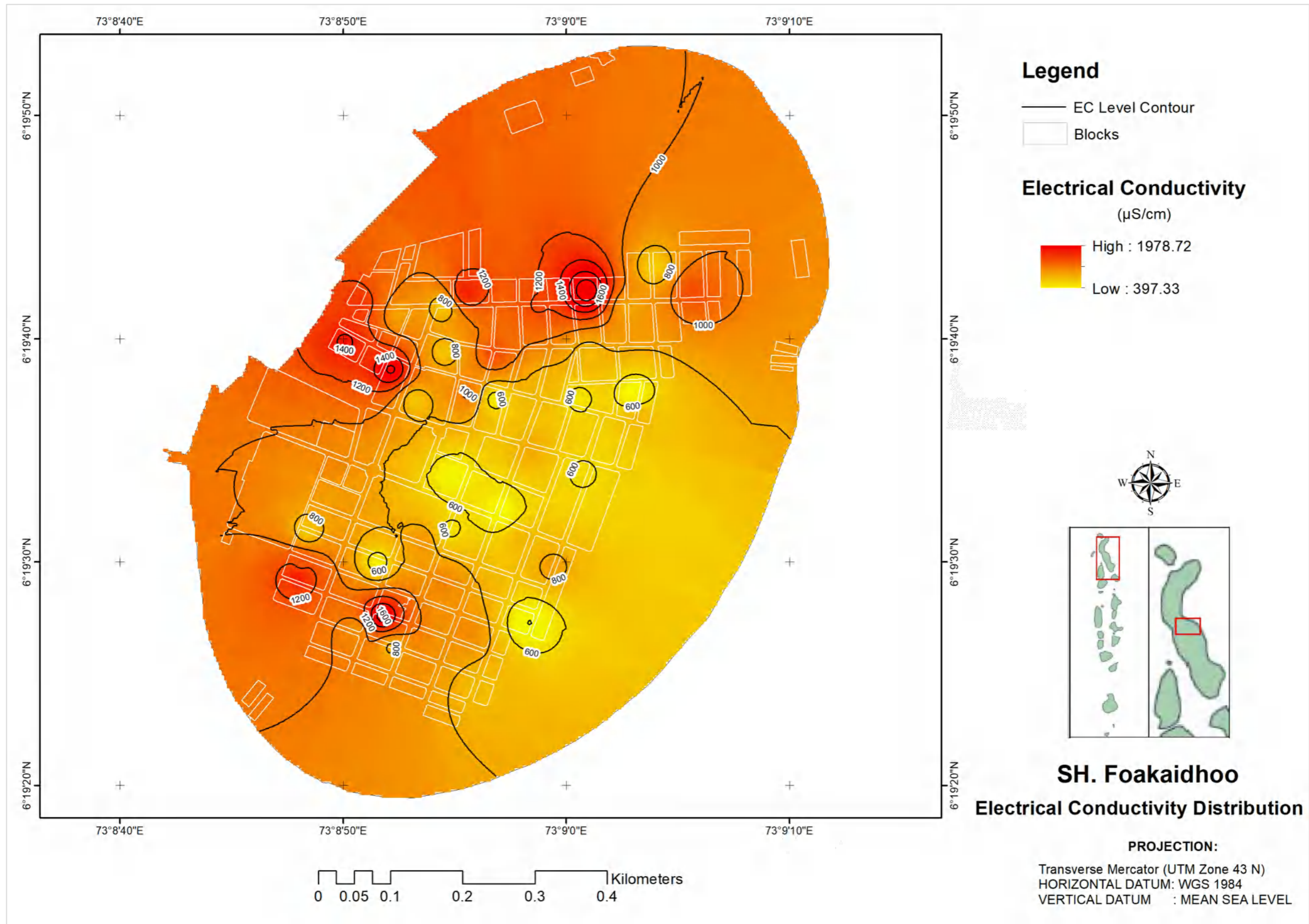




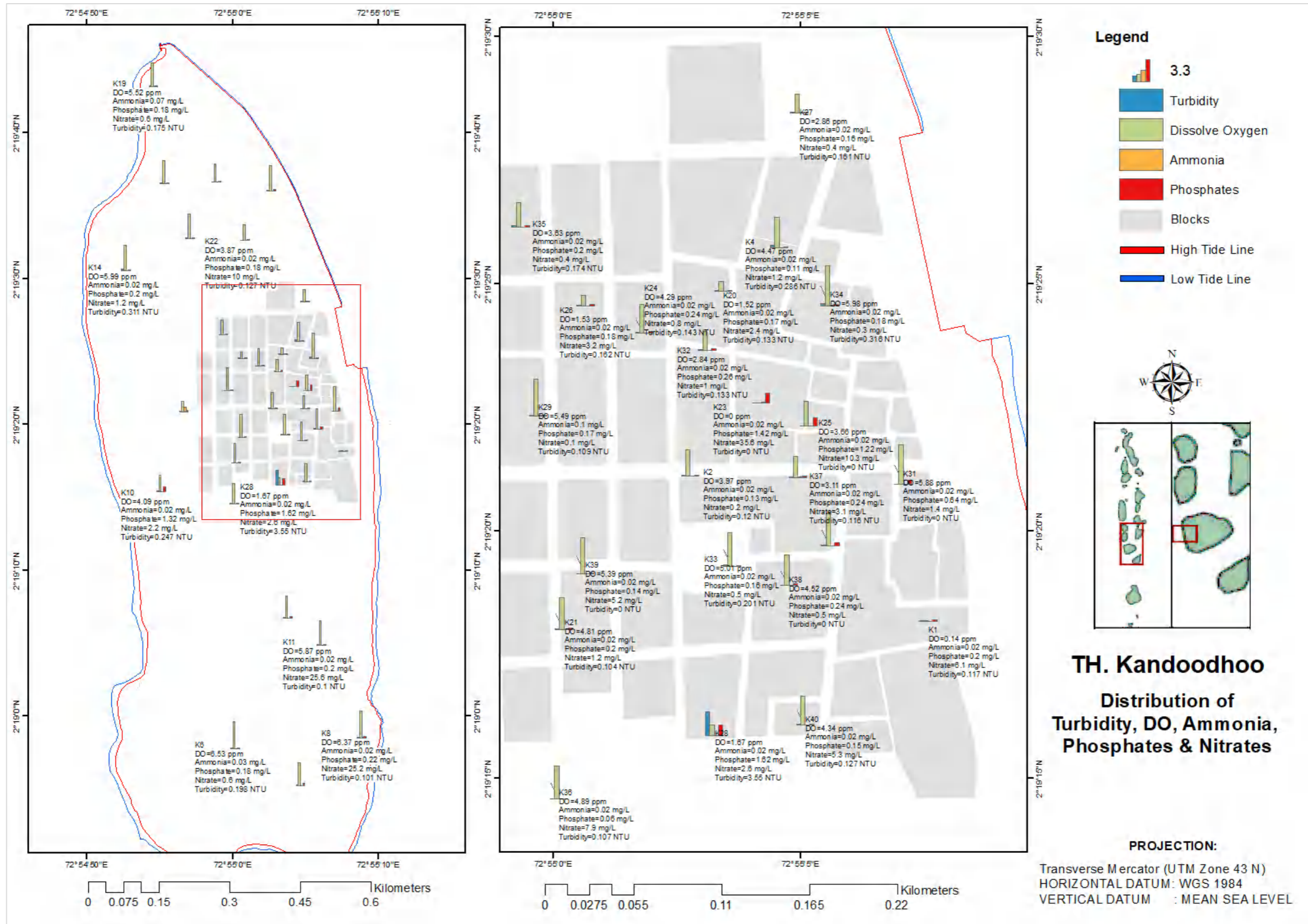


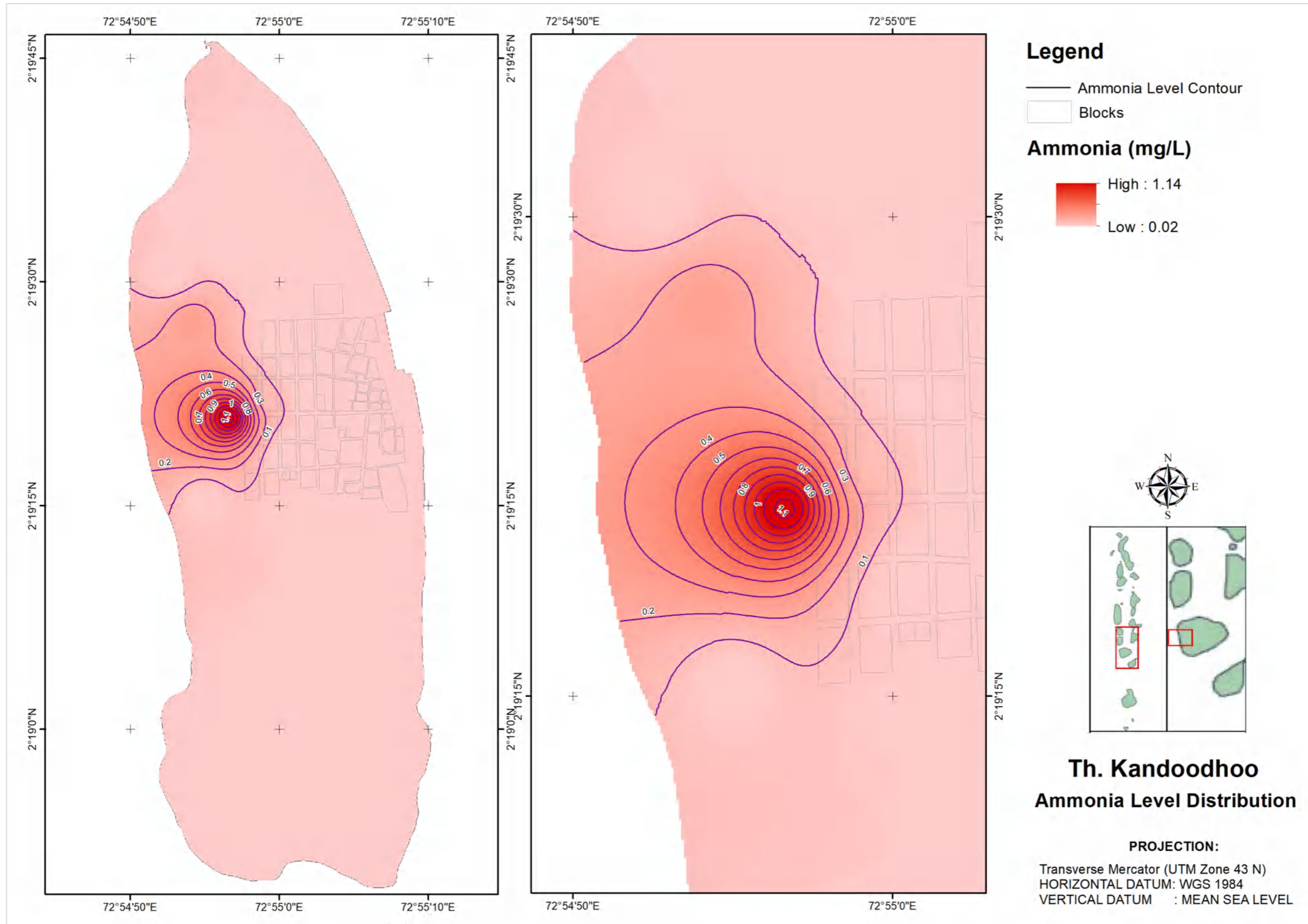


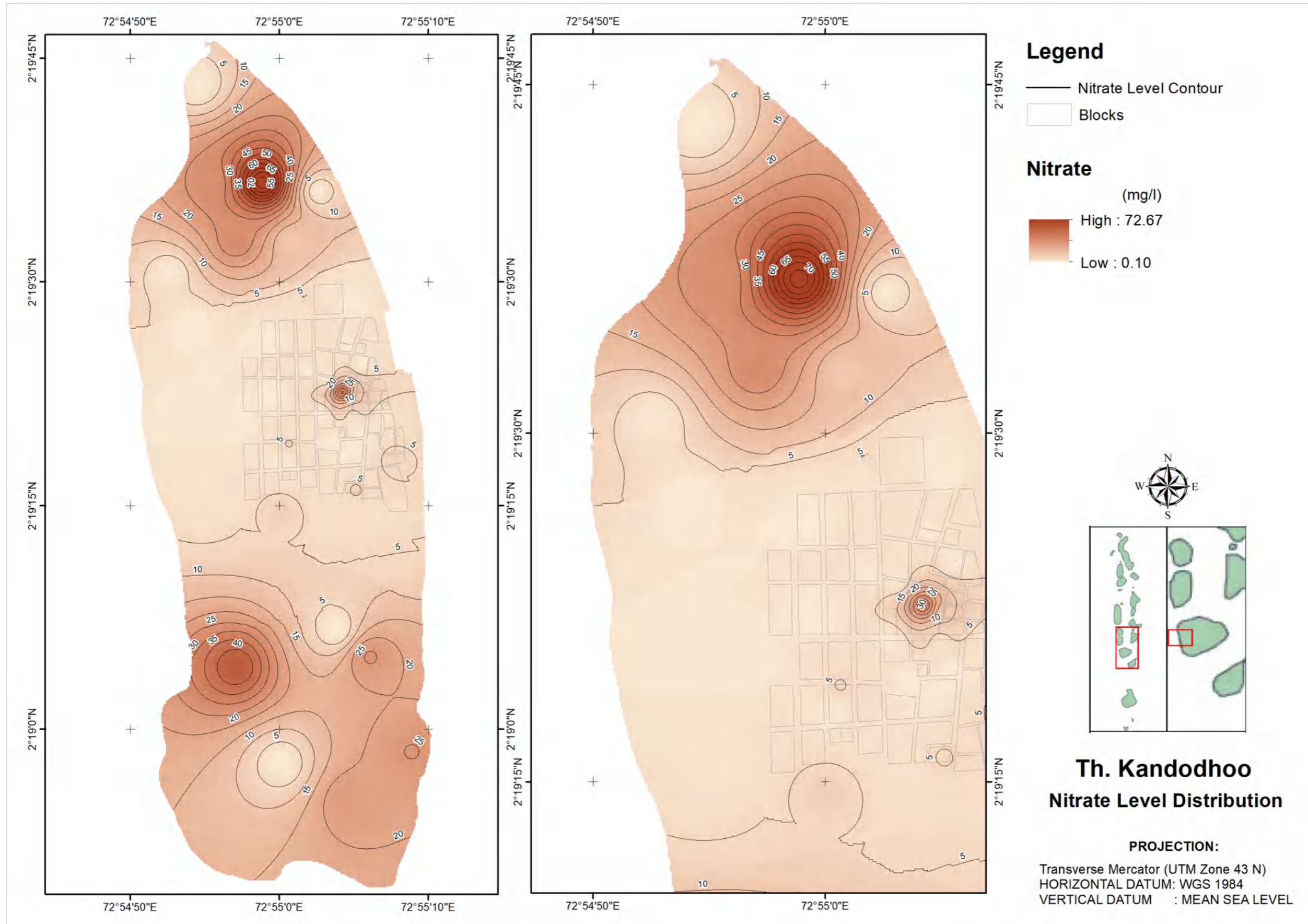


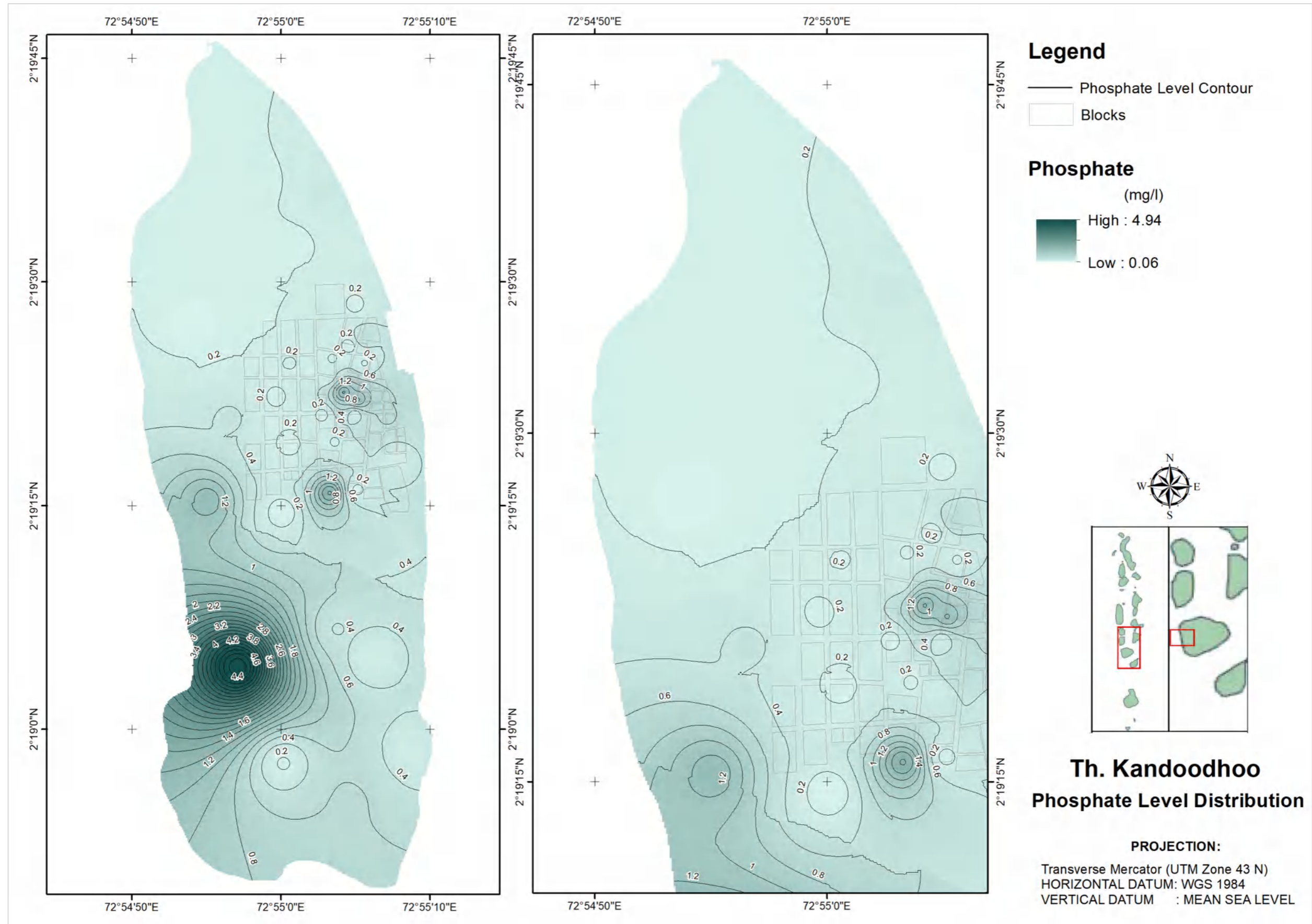


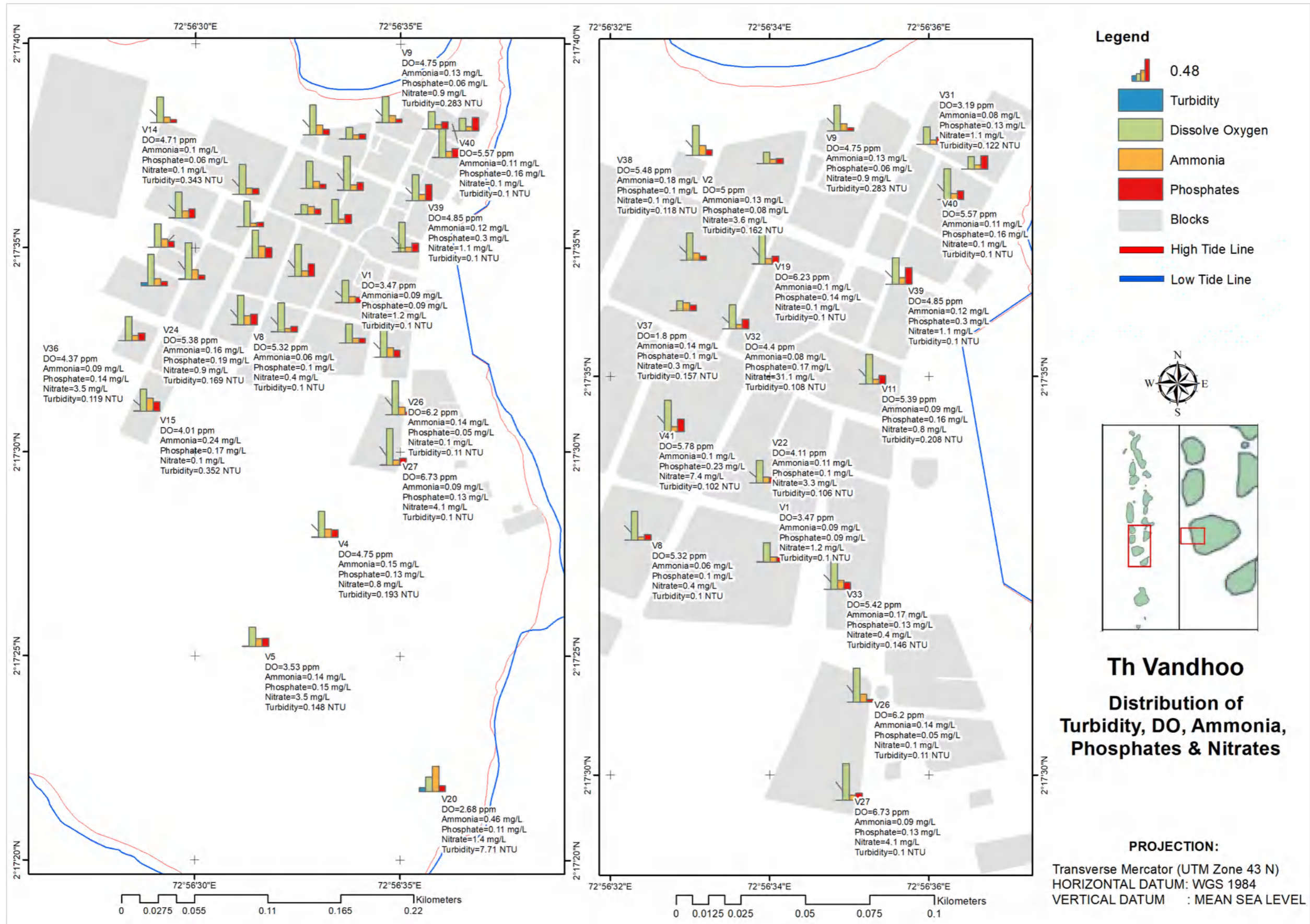
Annex VI: Distribution of Turbidity, DO, Ammonia, Phosphates & Nitrates in the Islands

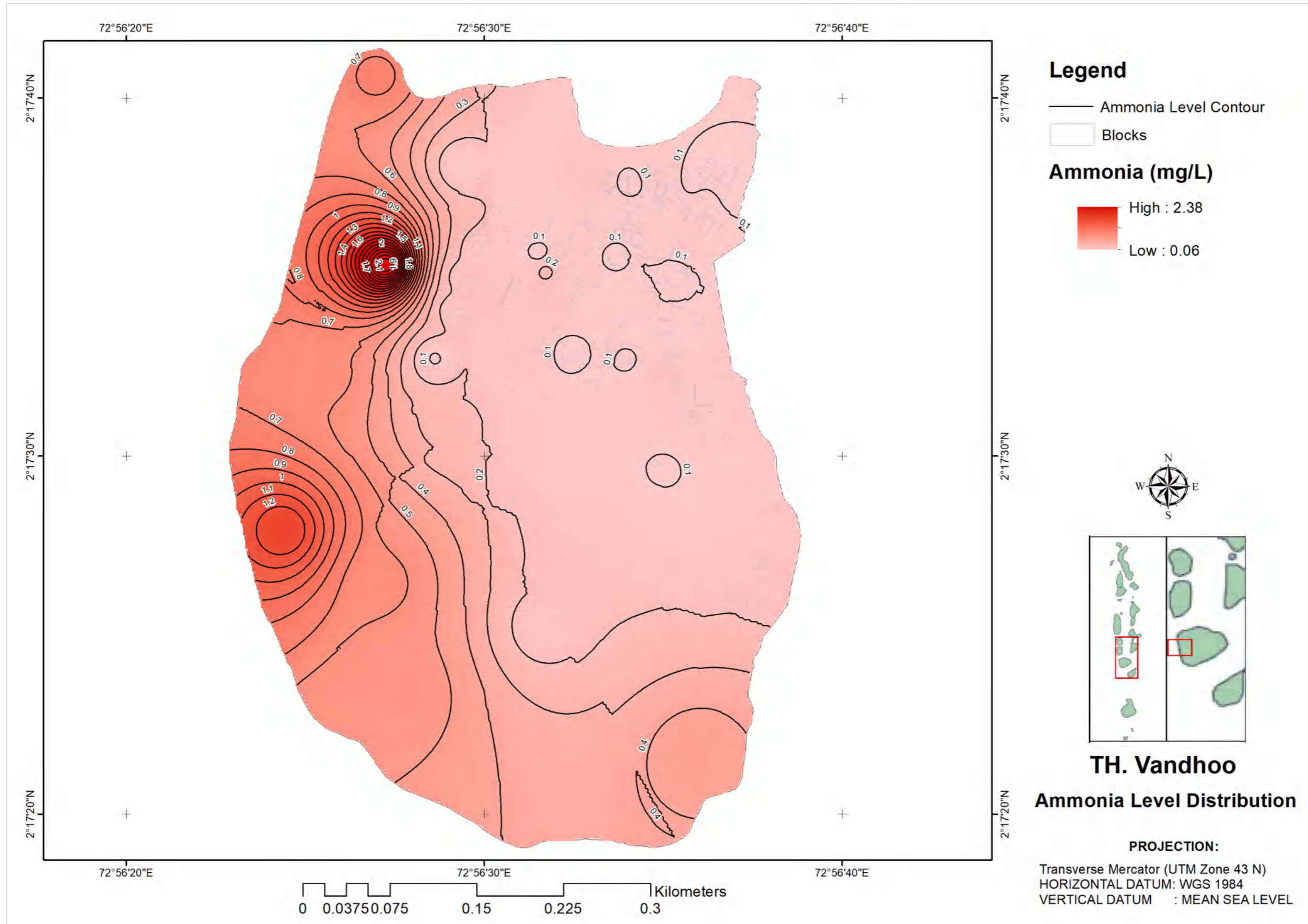


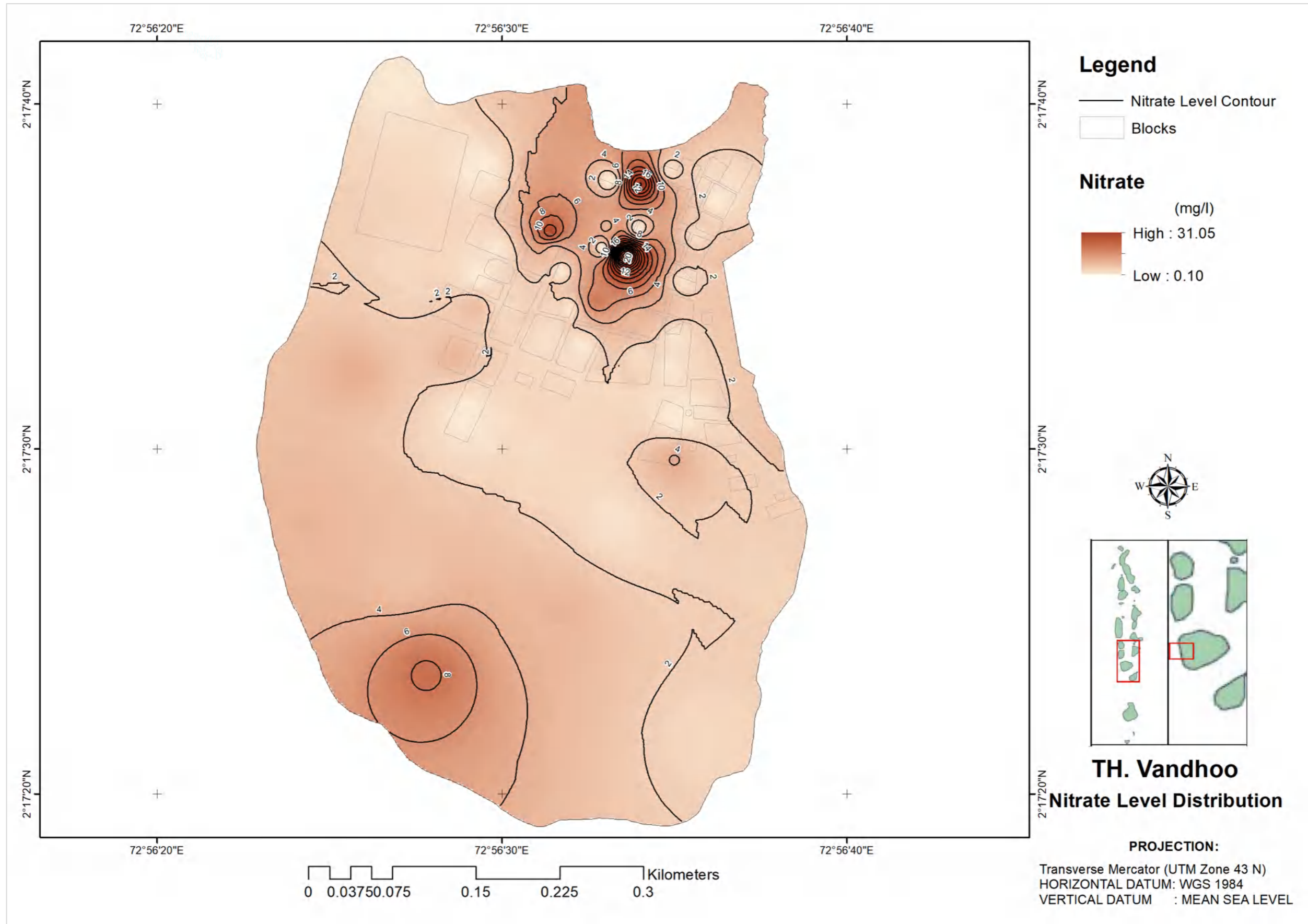


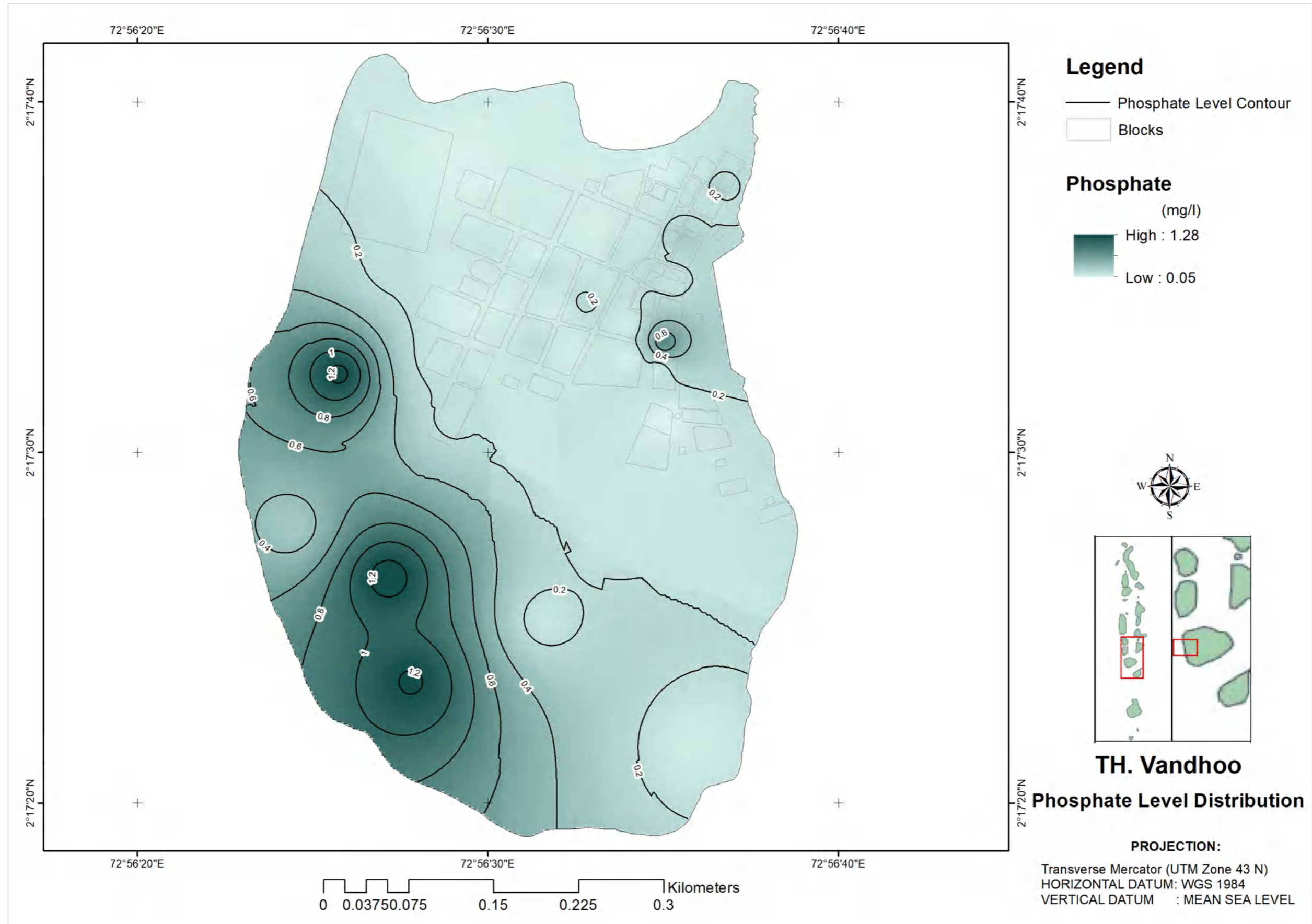


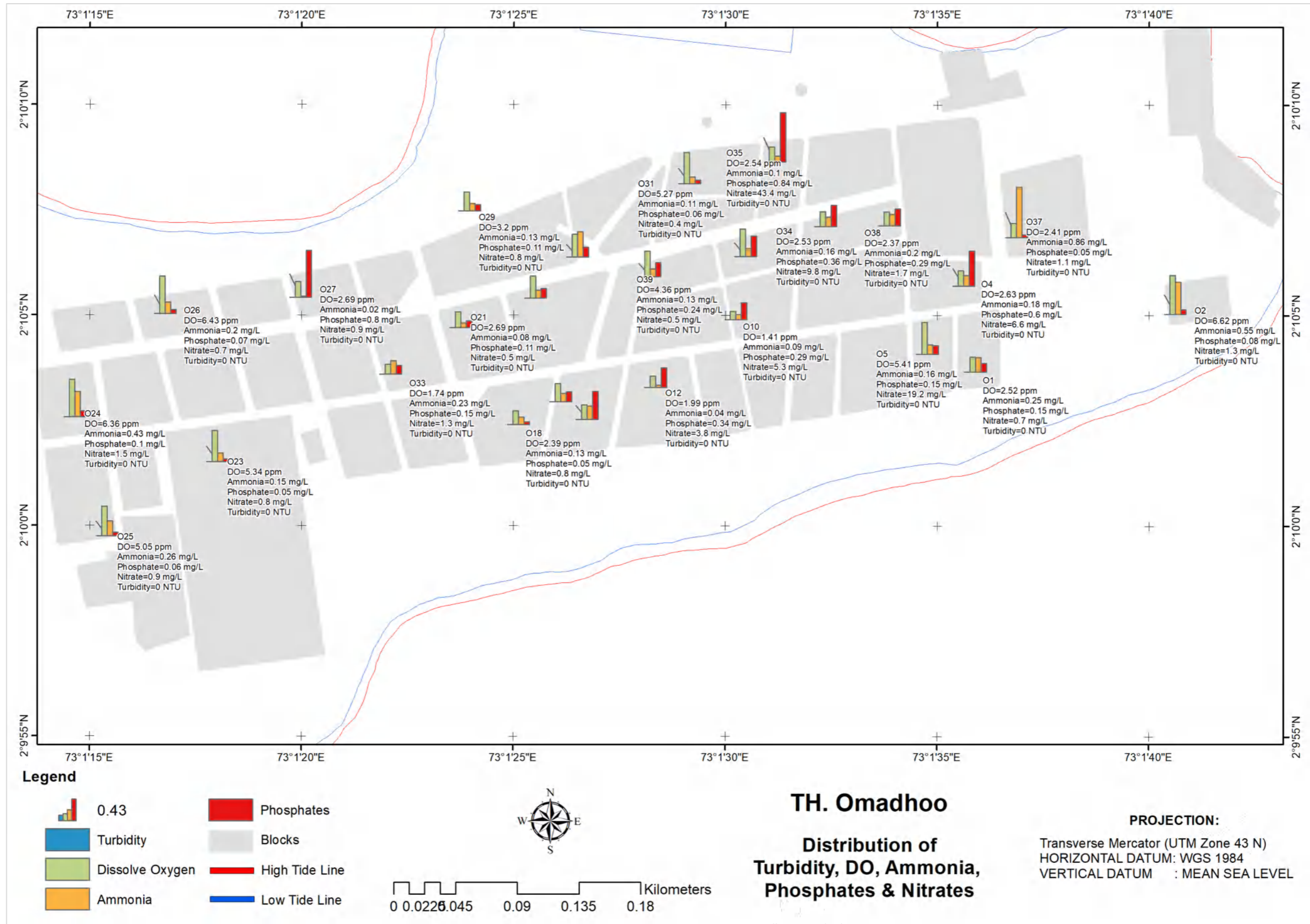


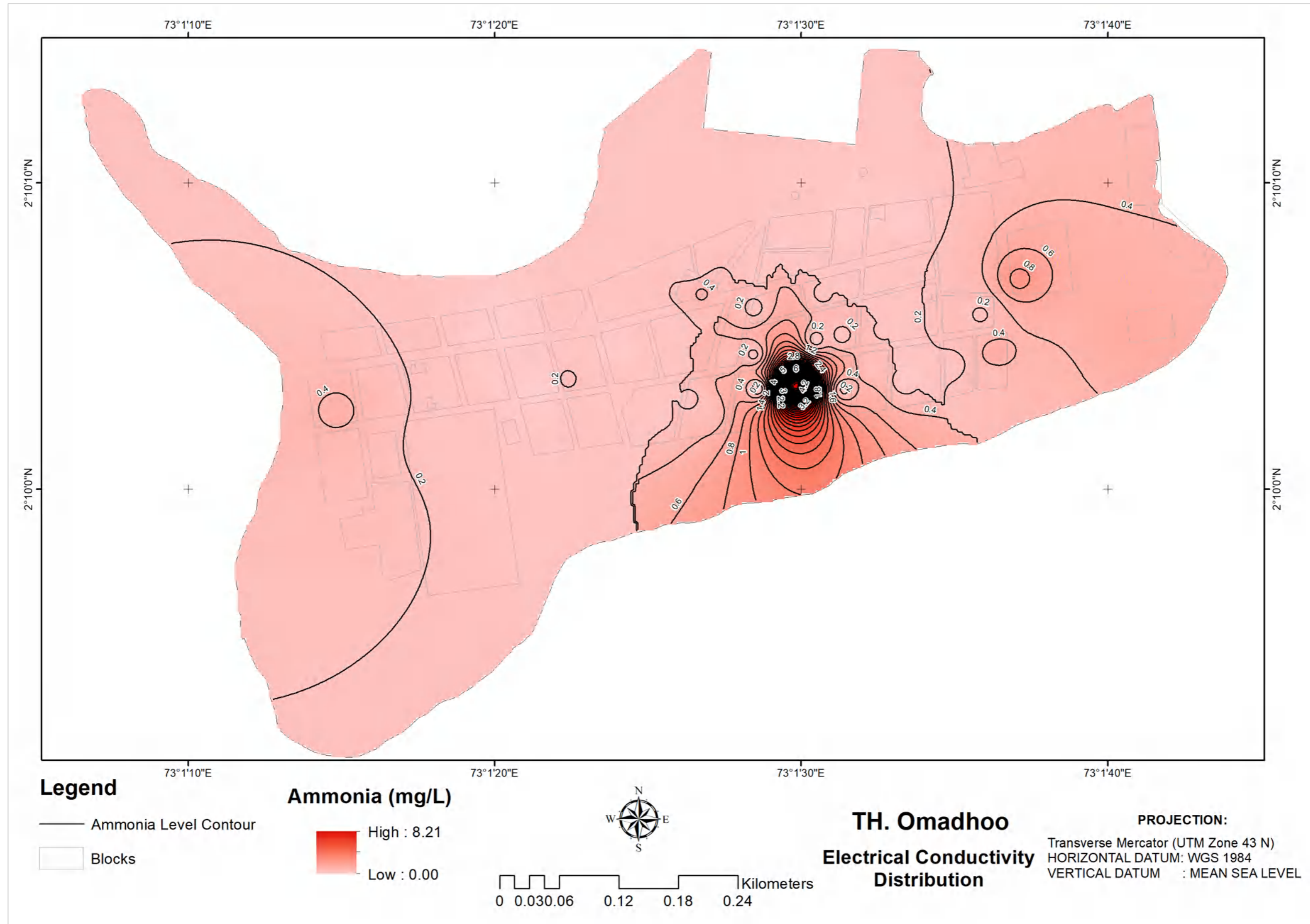


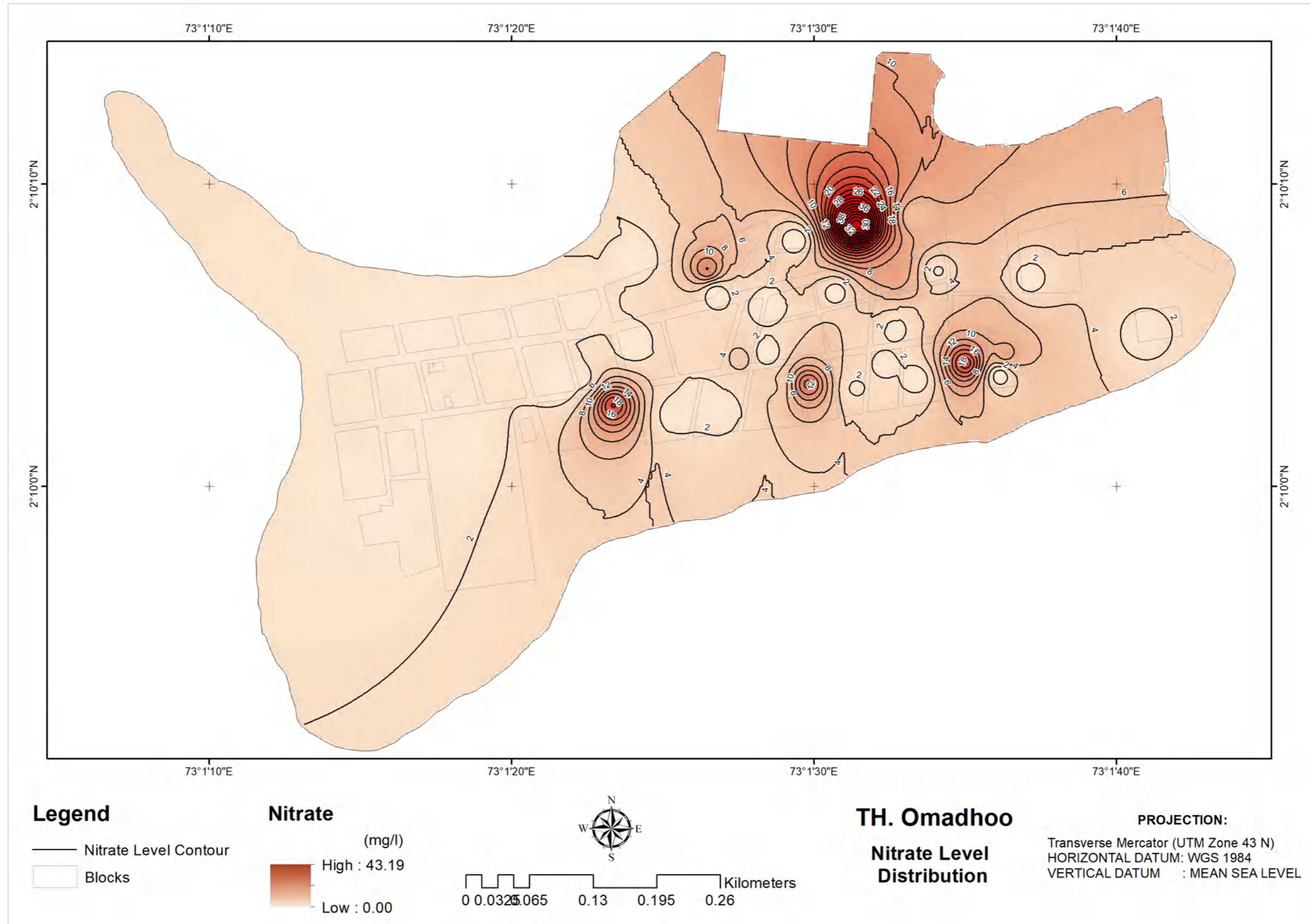


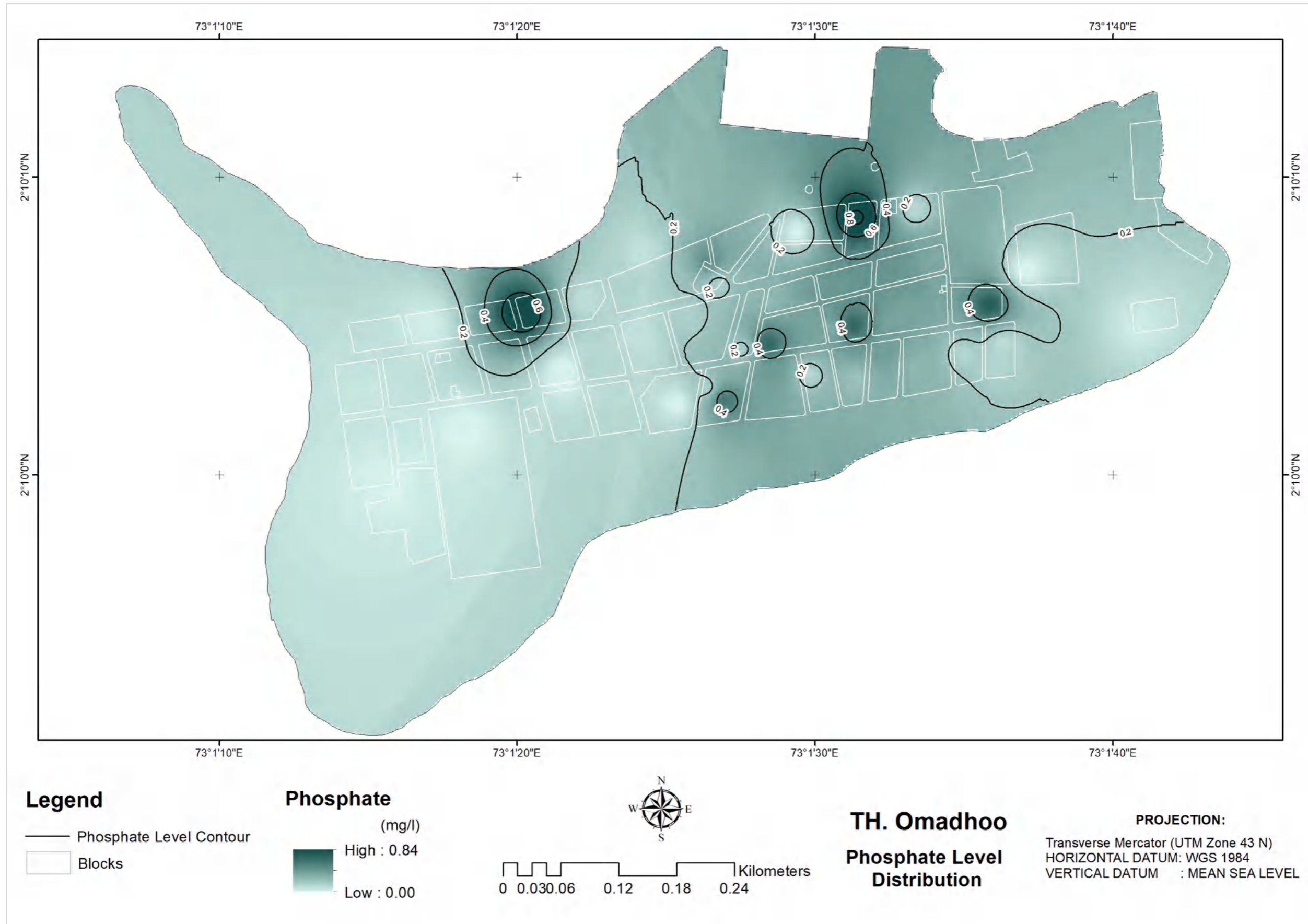


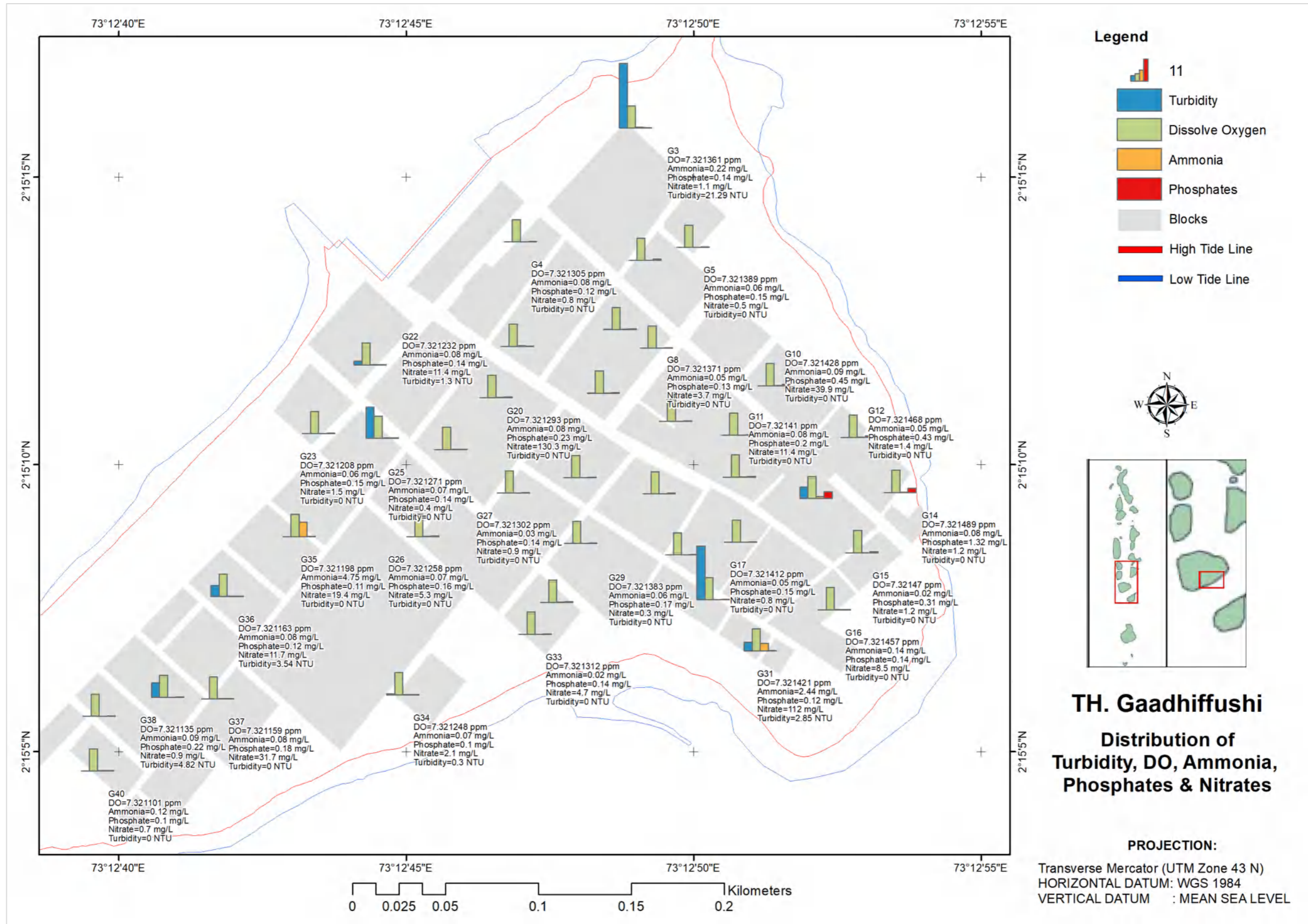


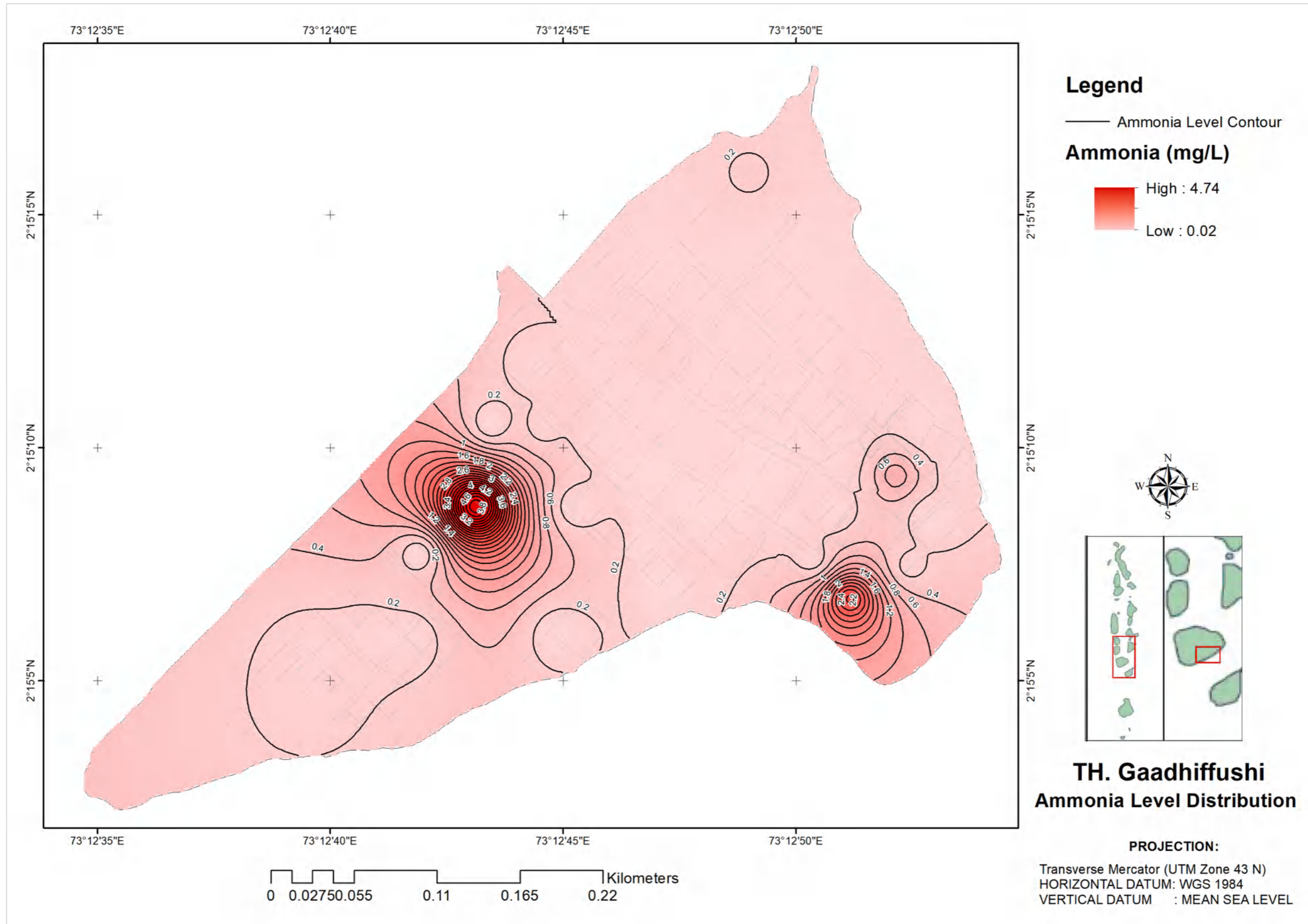


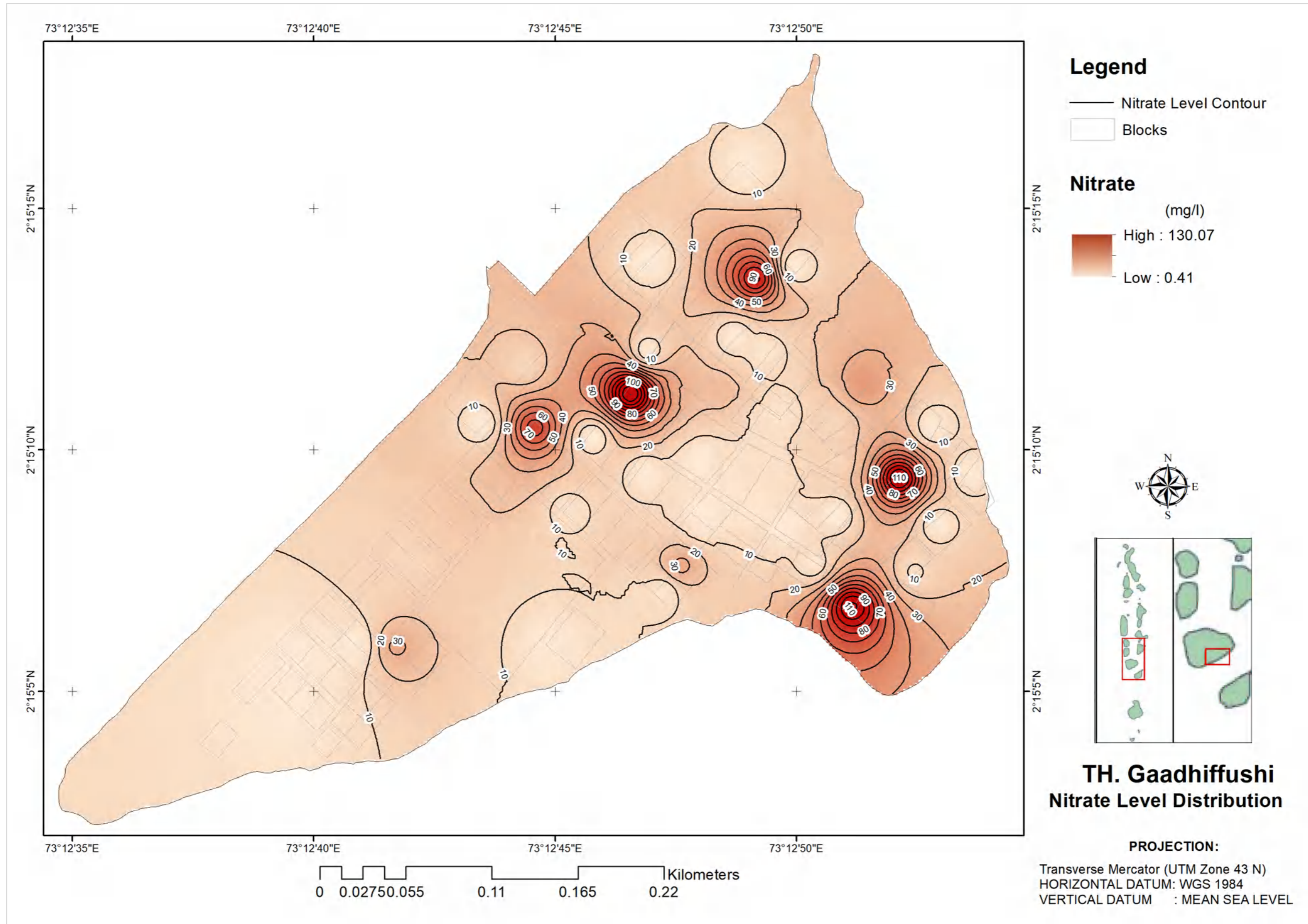


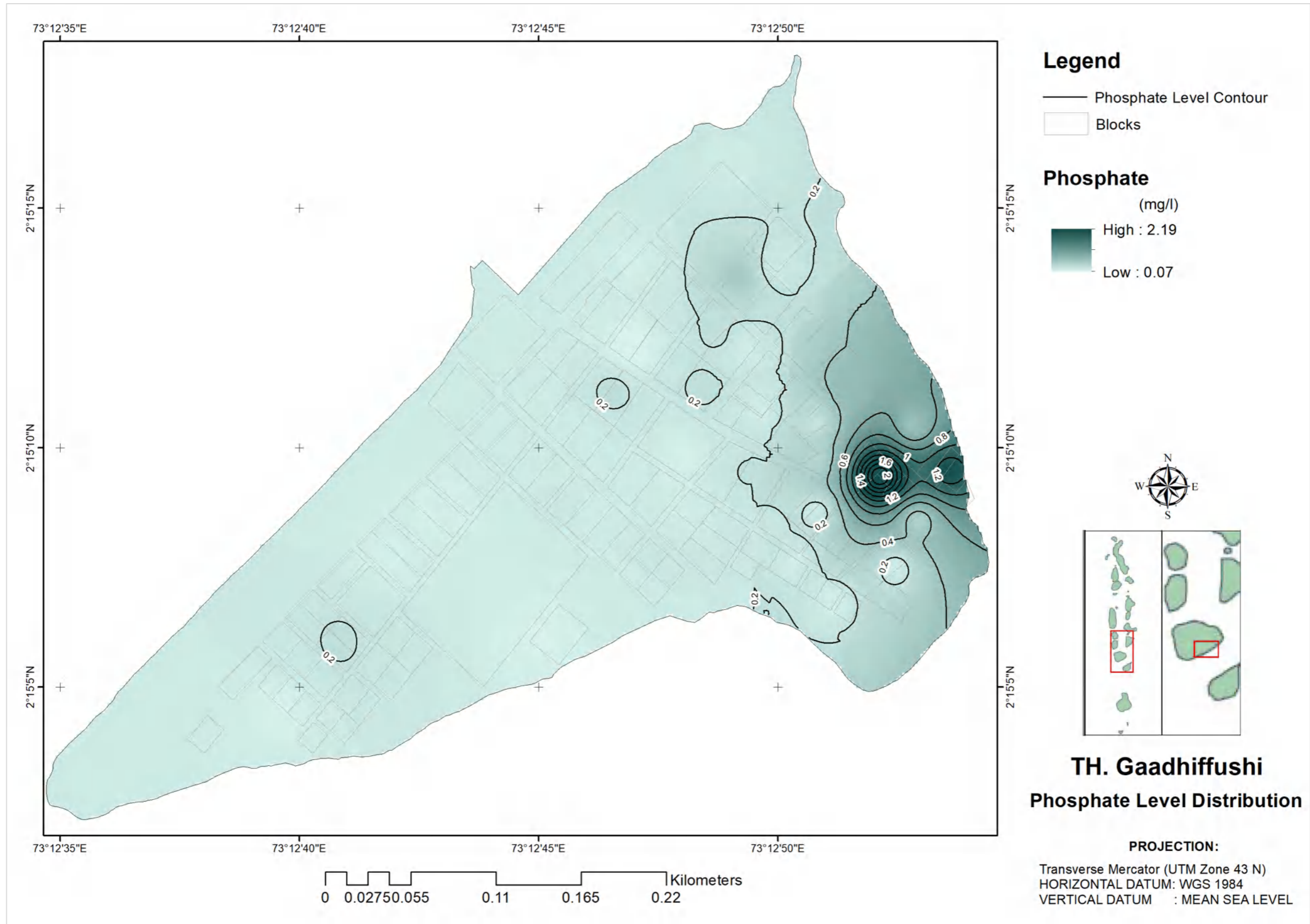


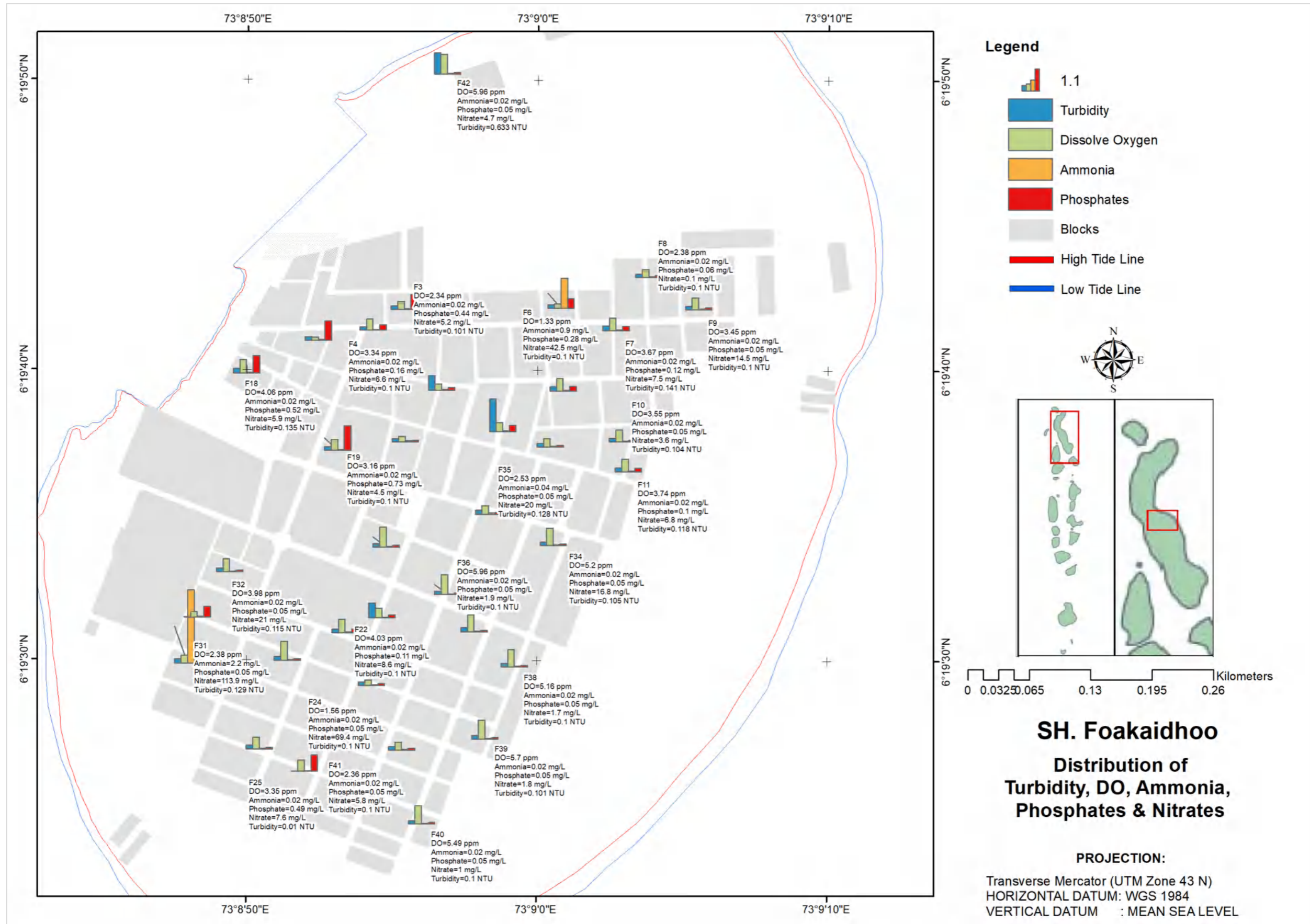


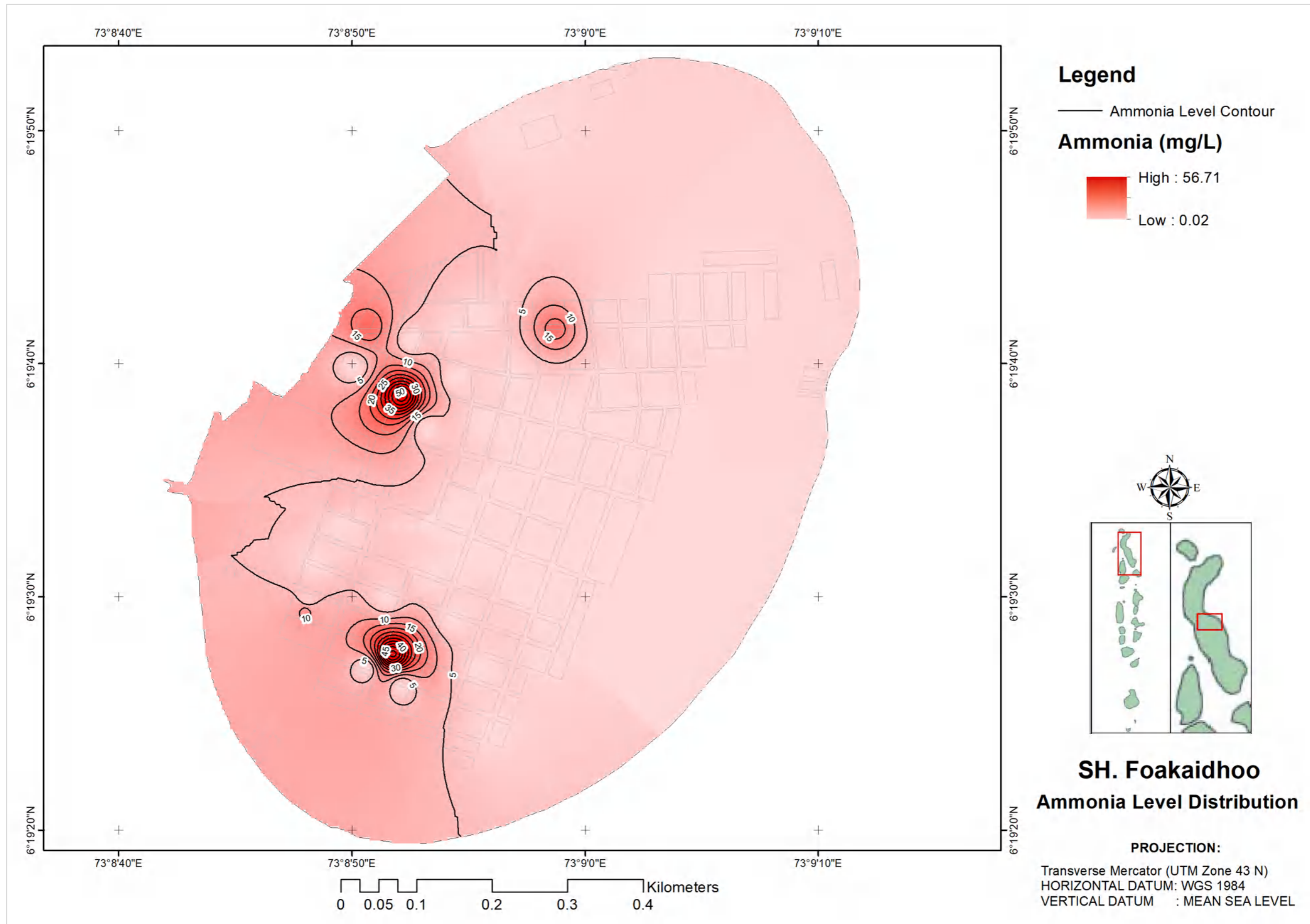


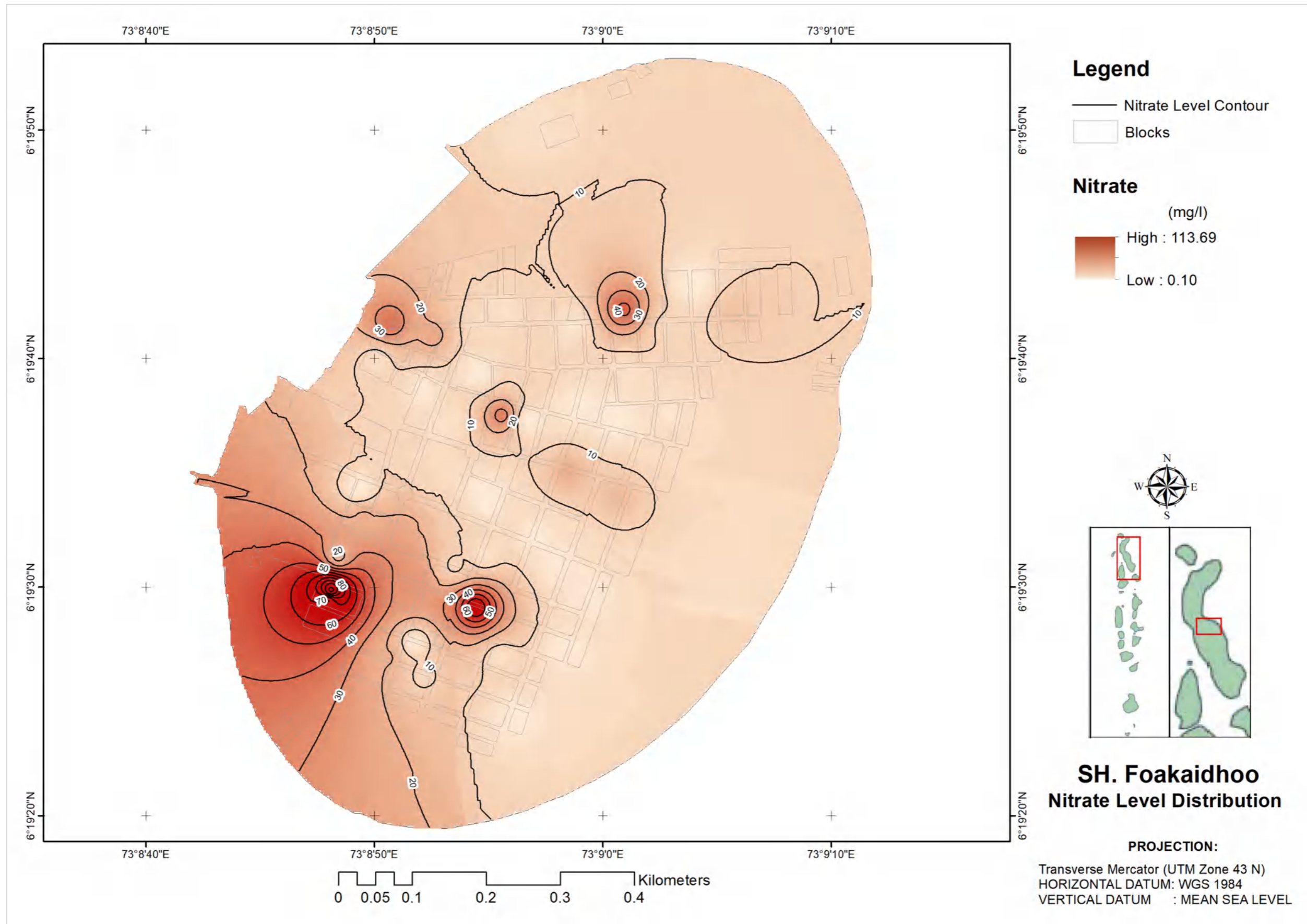


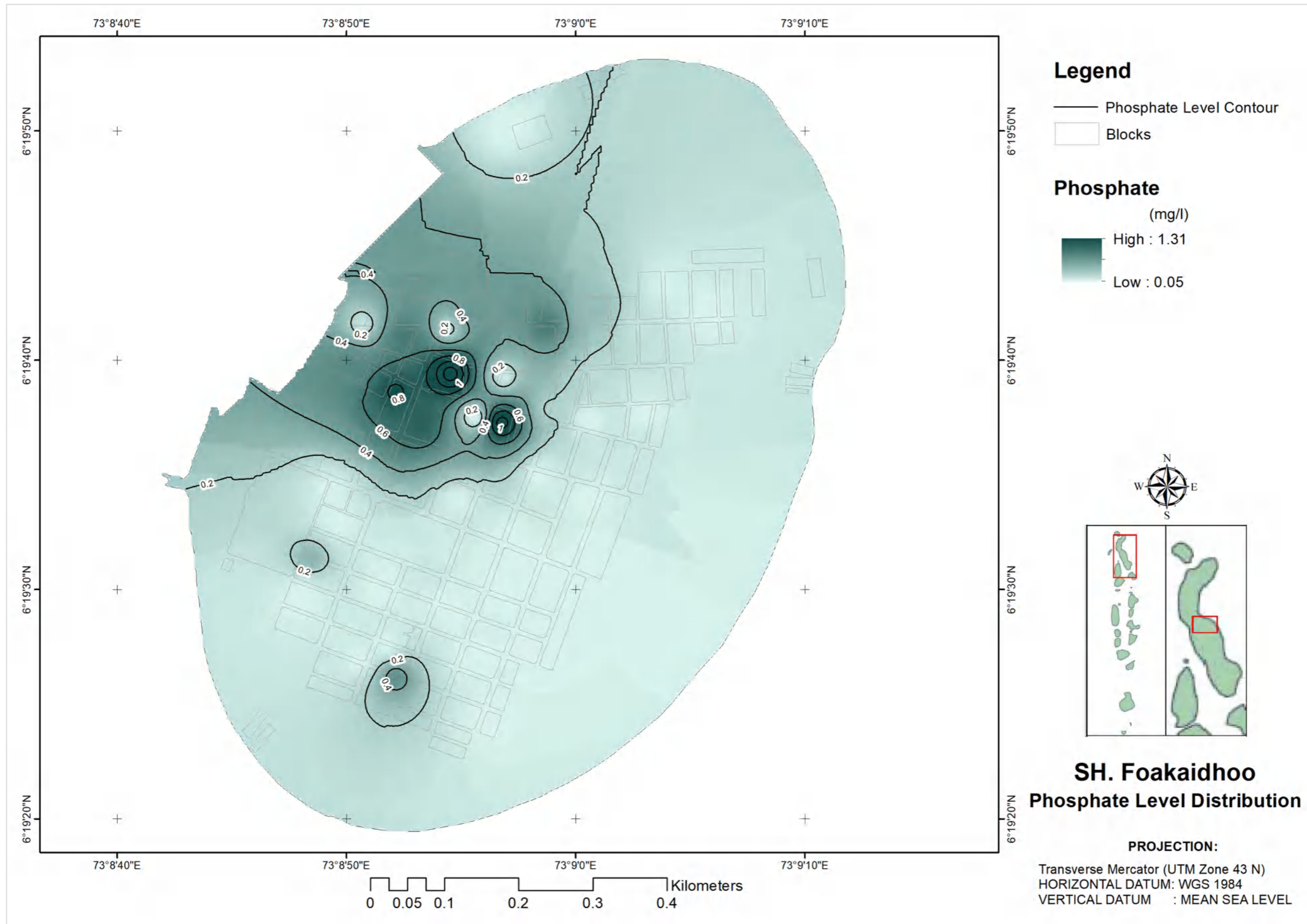




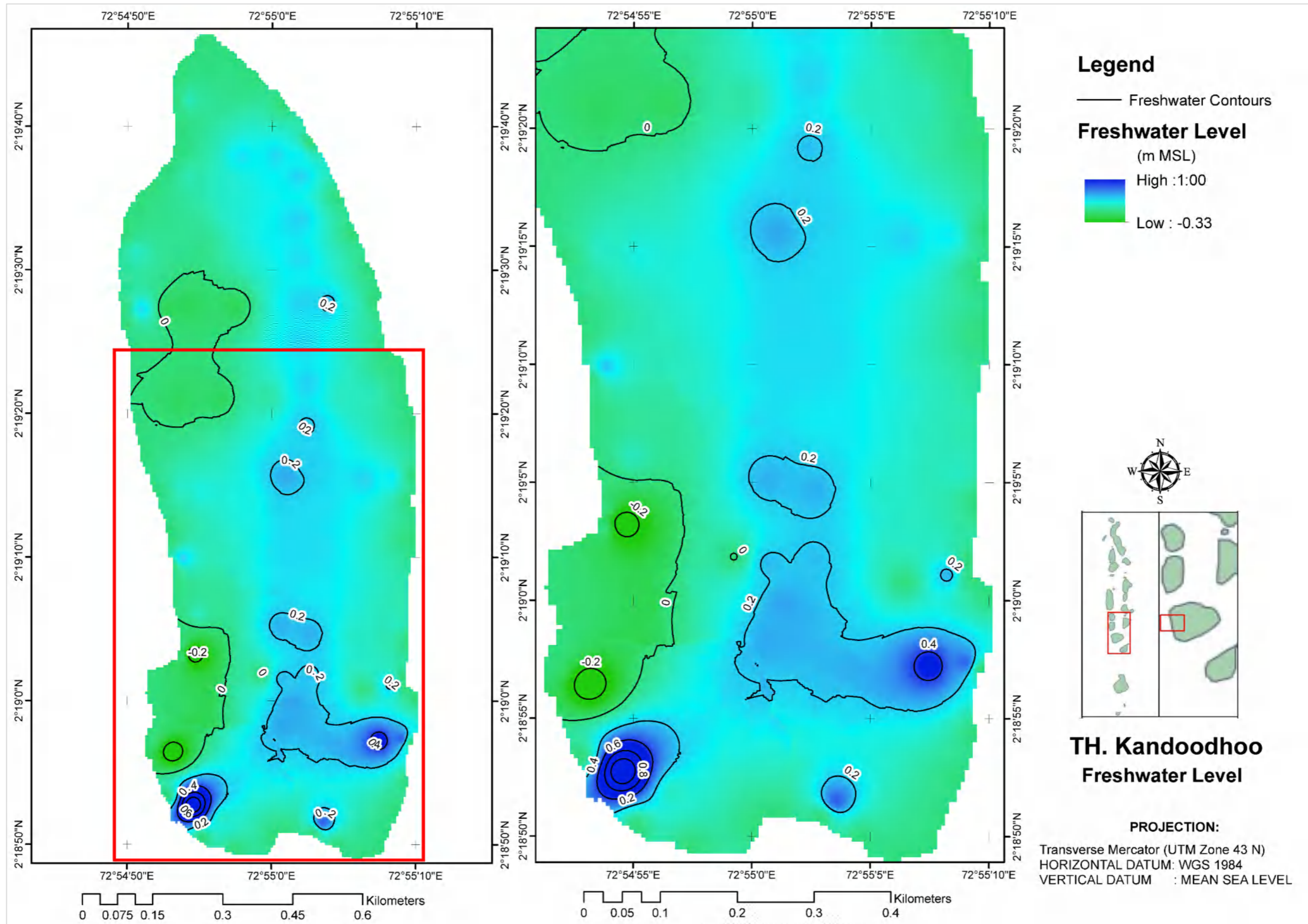


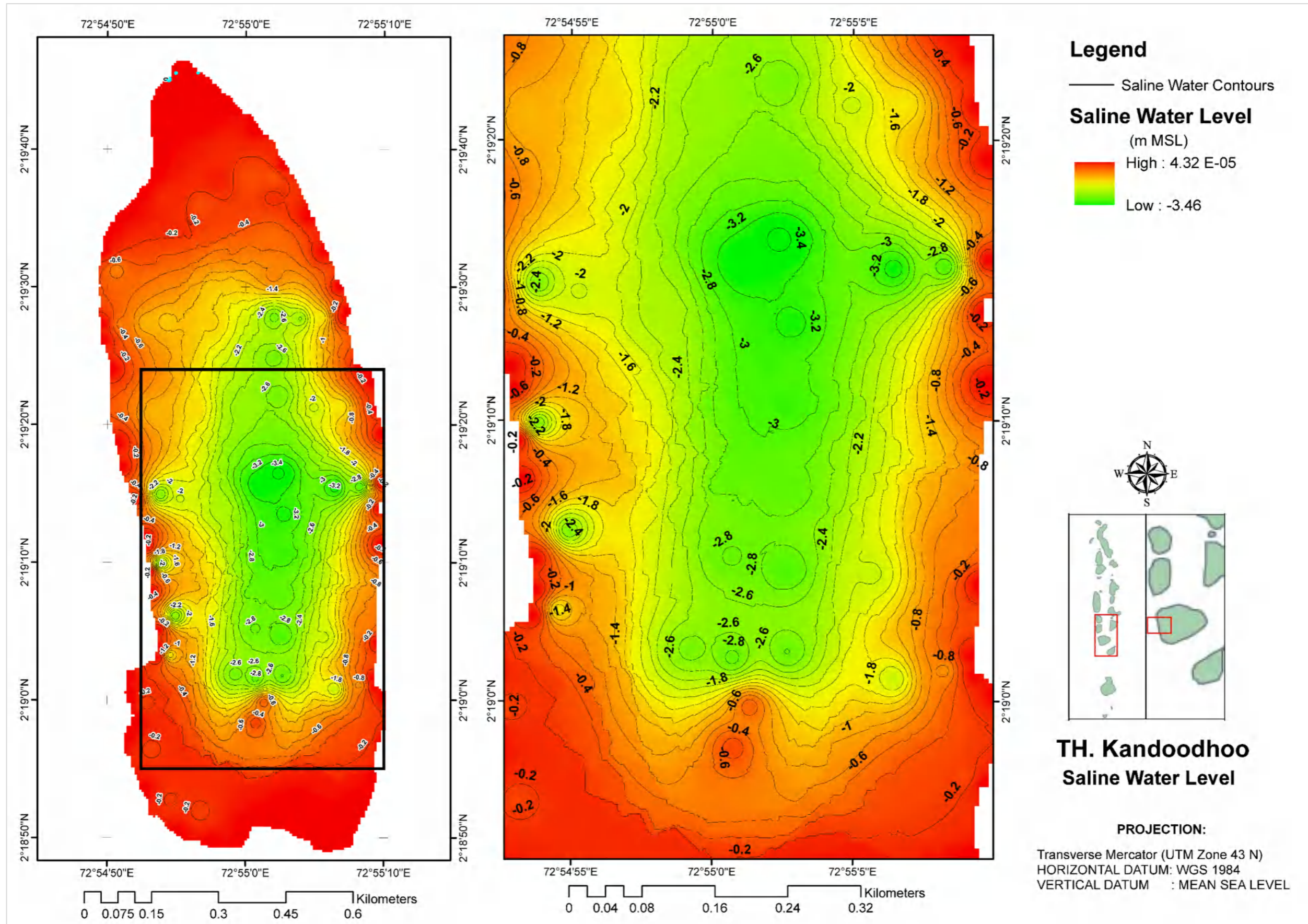


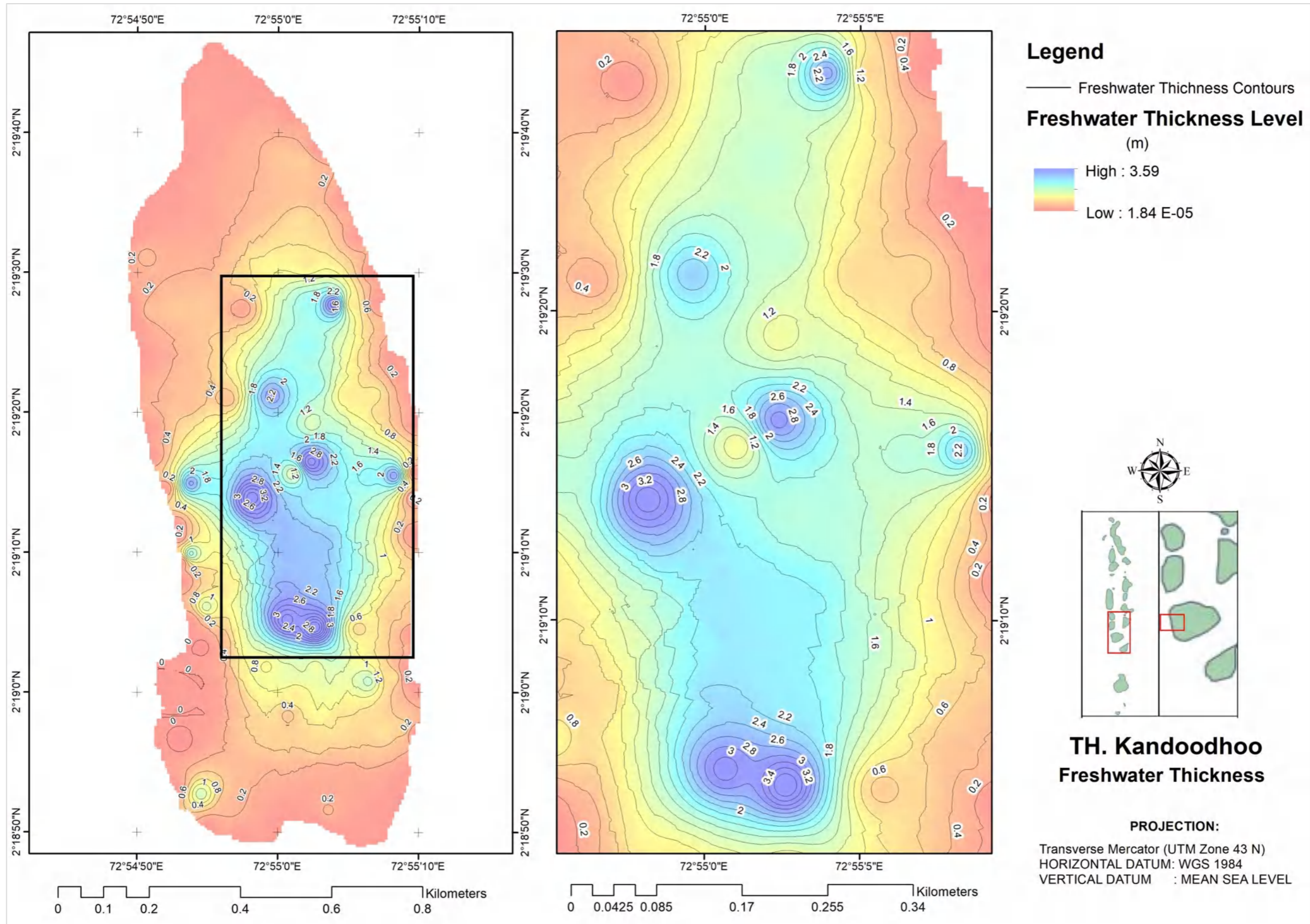


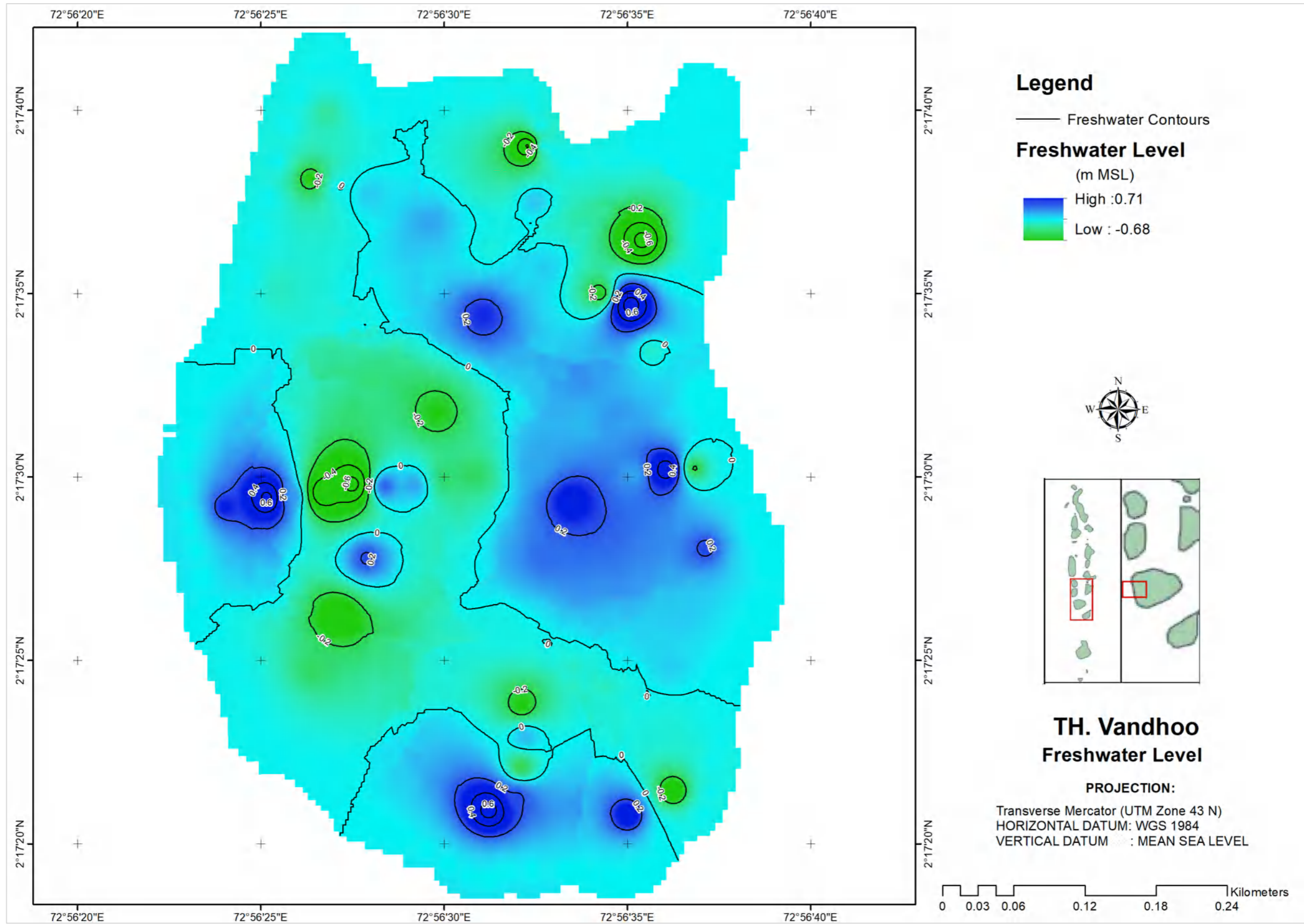


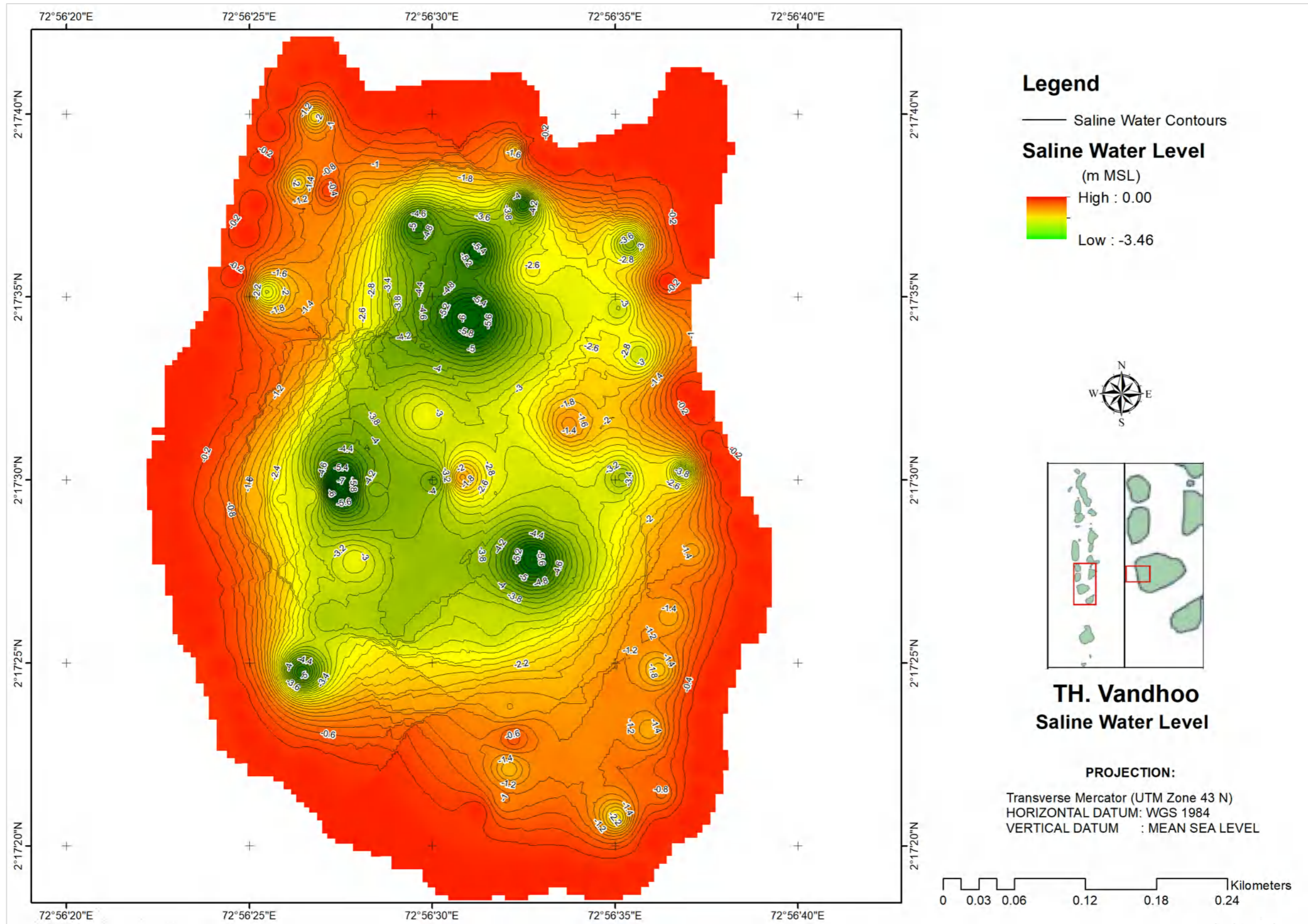
Annex VIII: Freshwater level, Saline Water Level and Freshwater thickness of the Islands

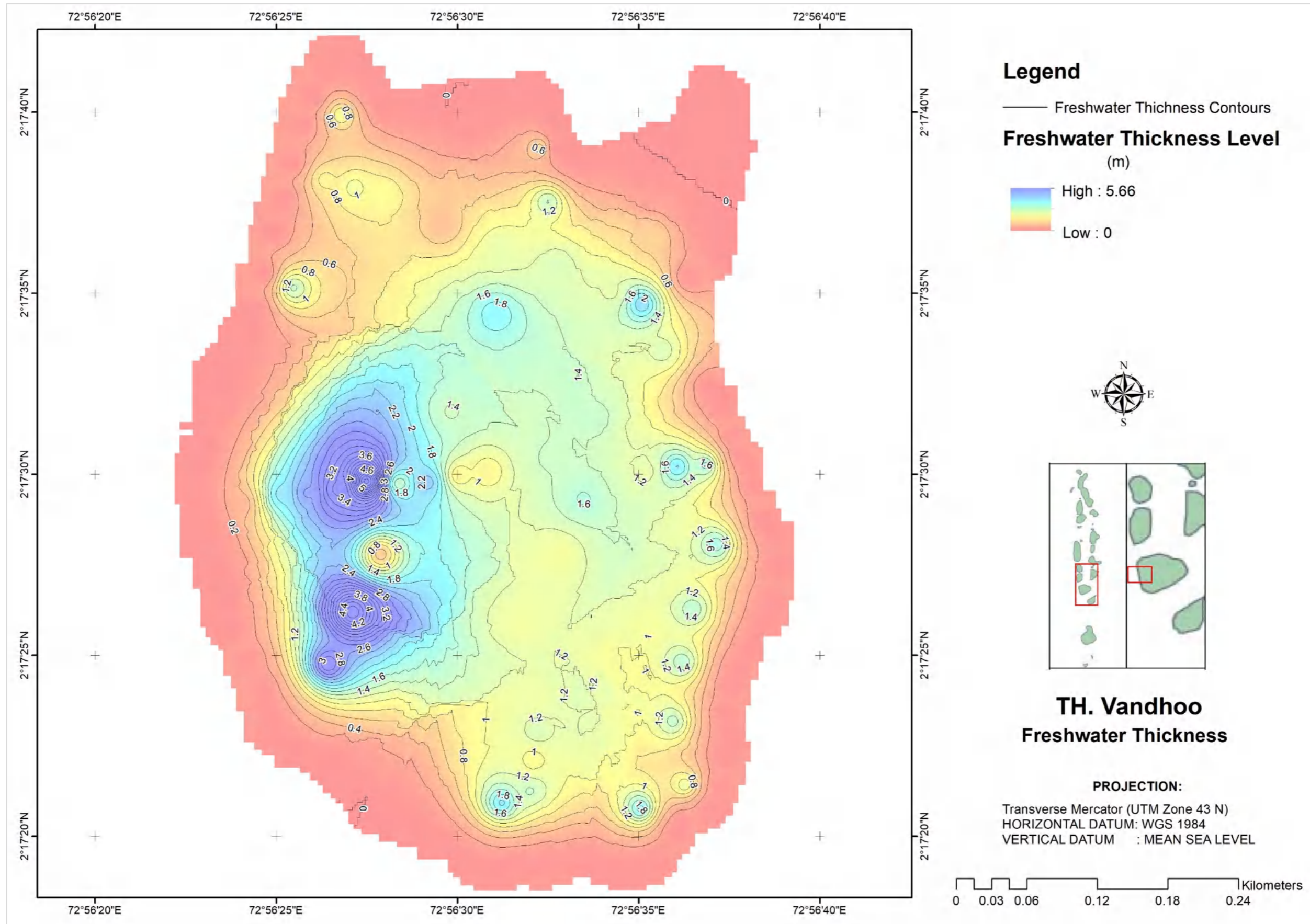


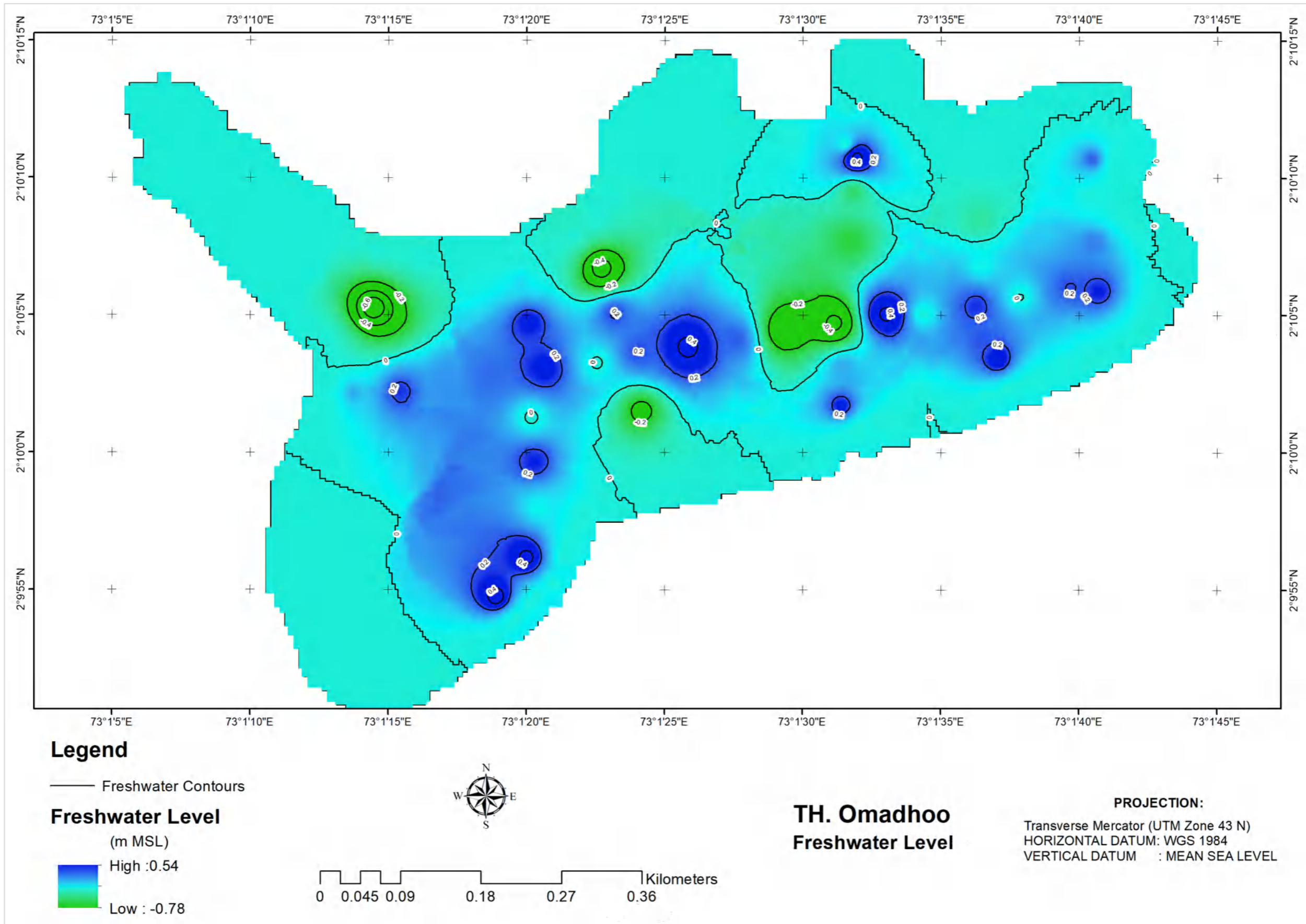


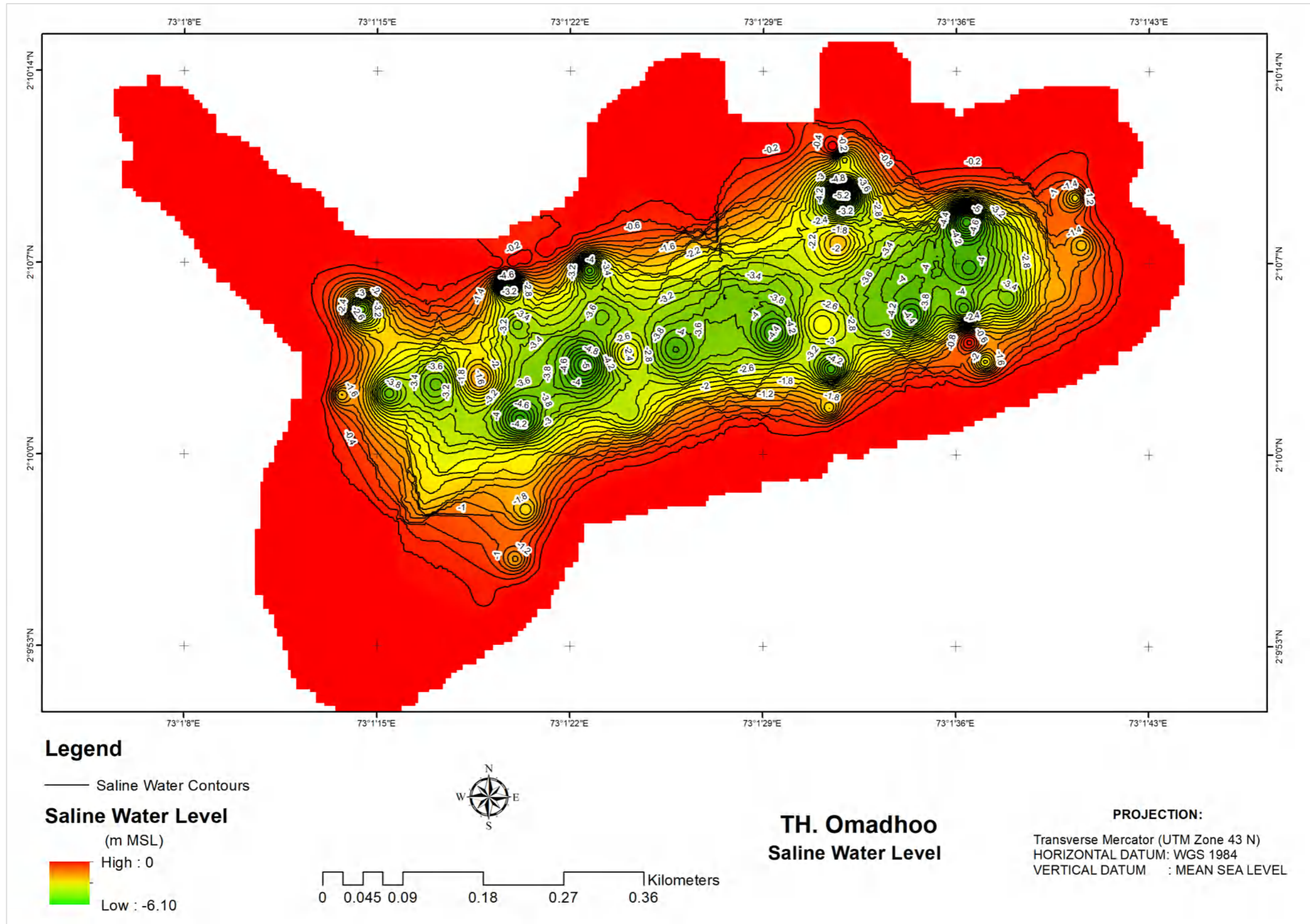


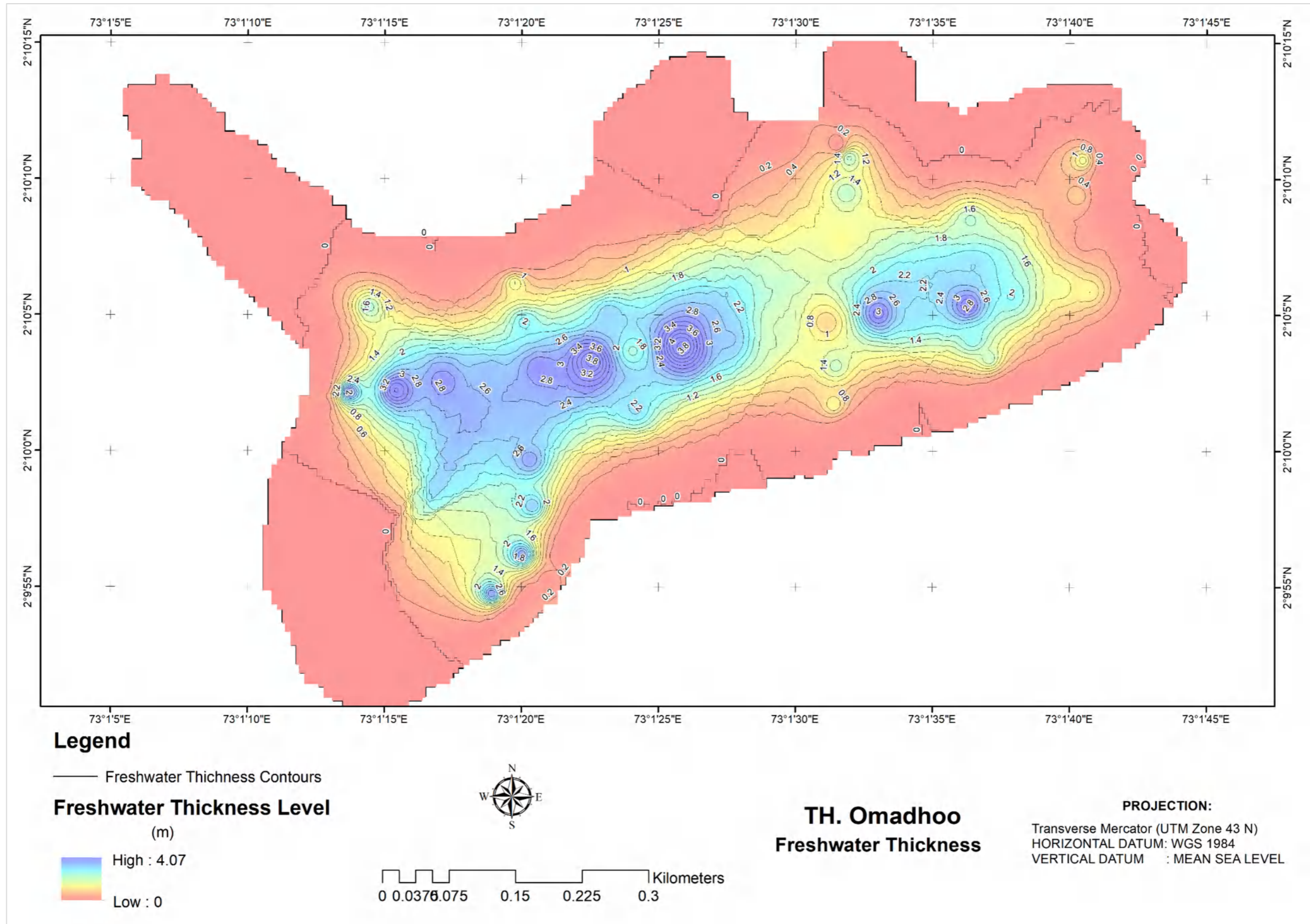


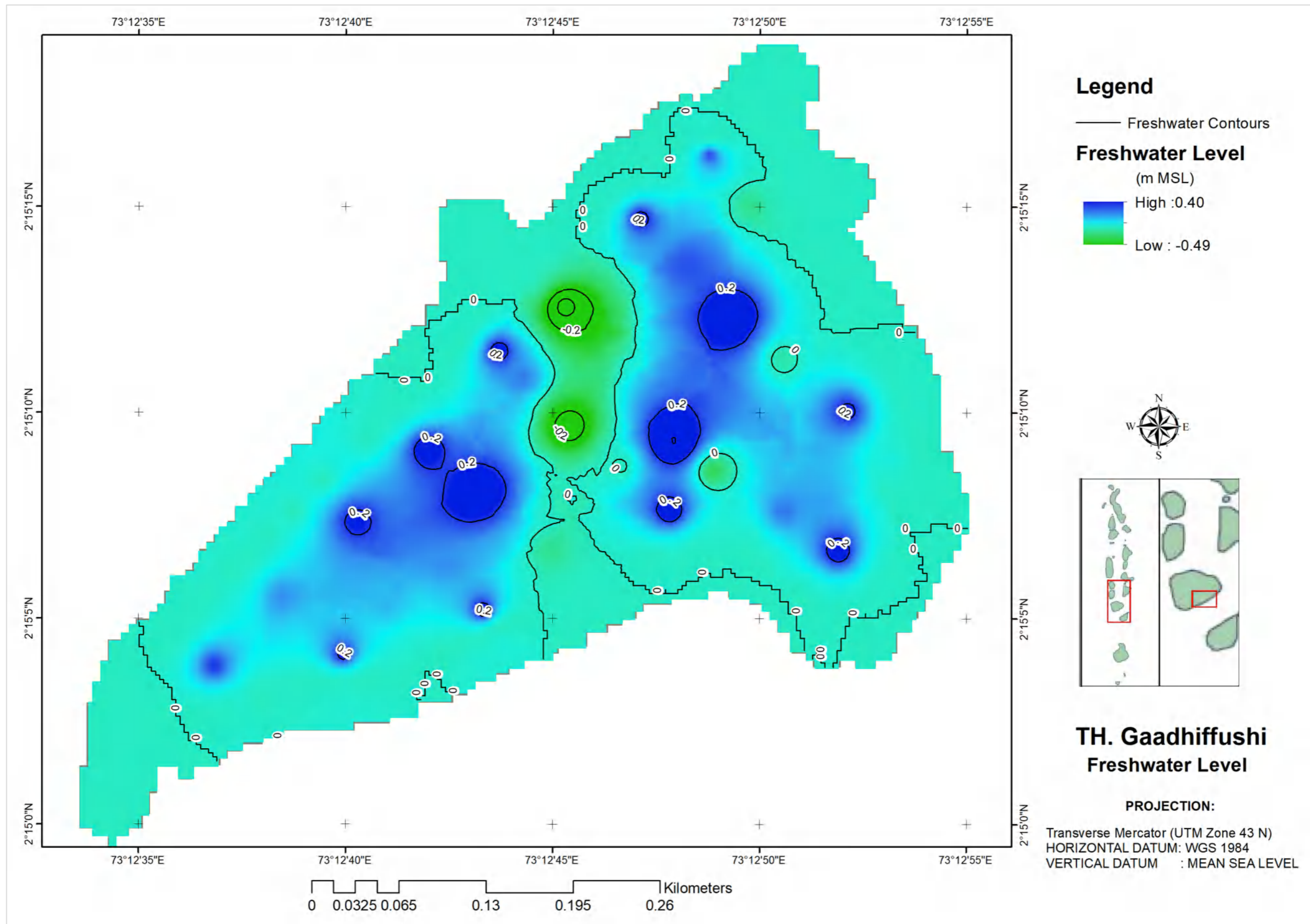


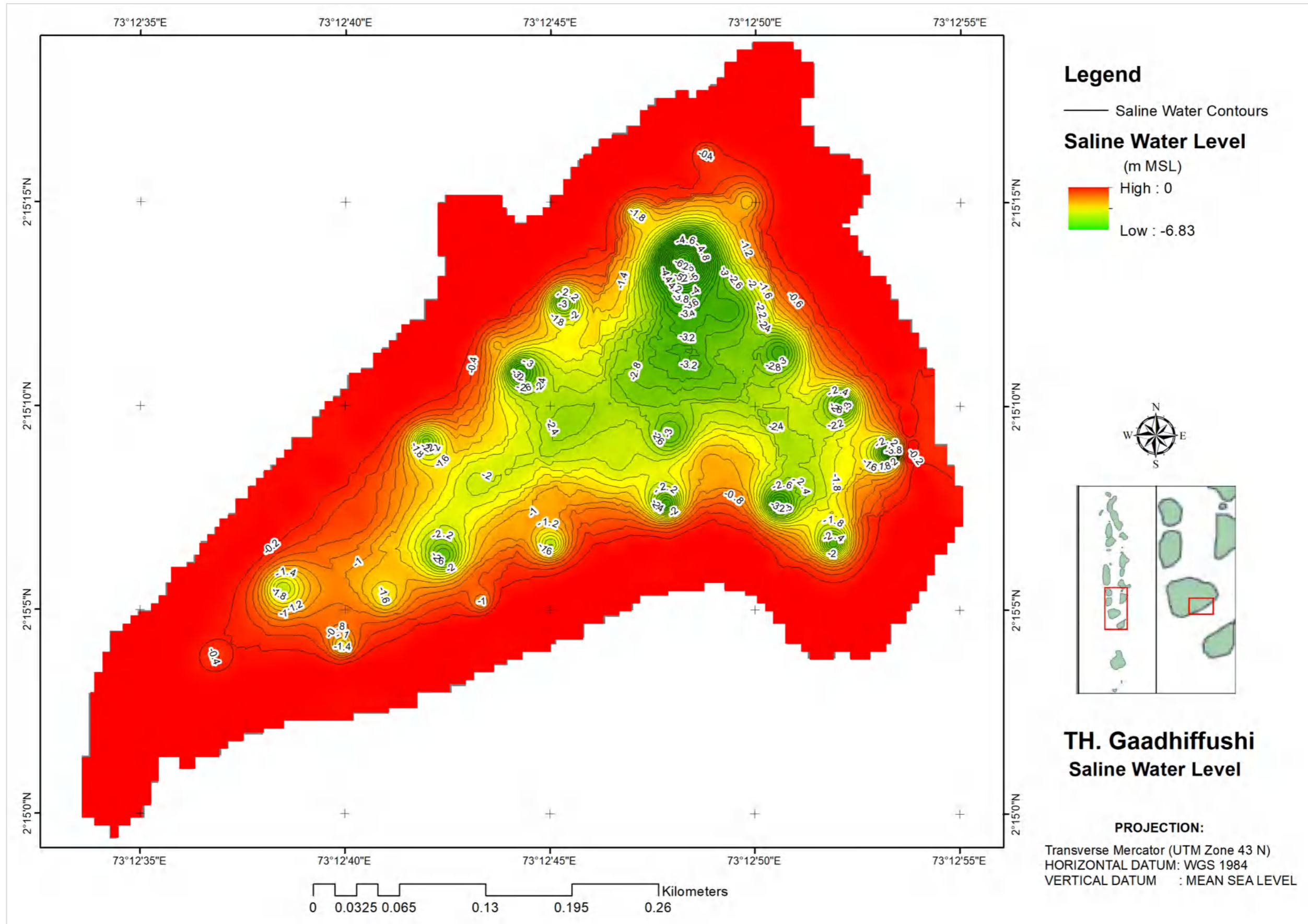


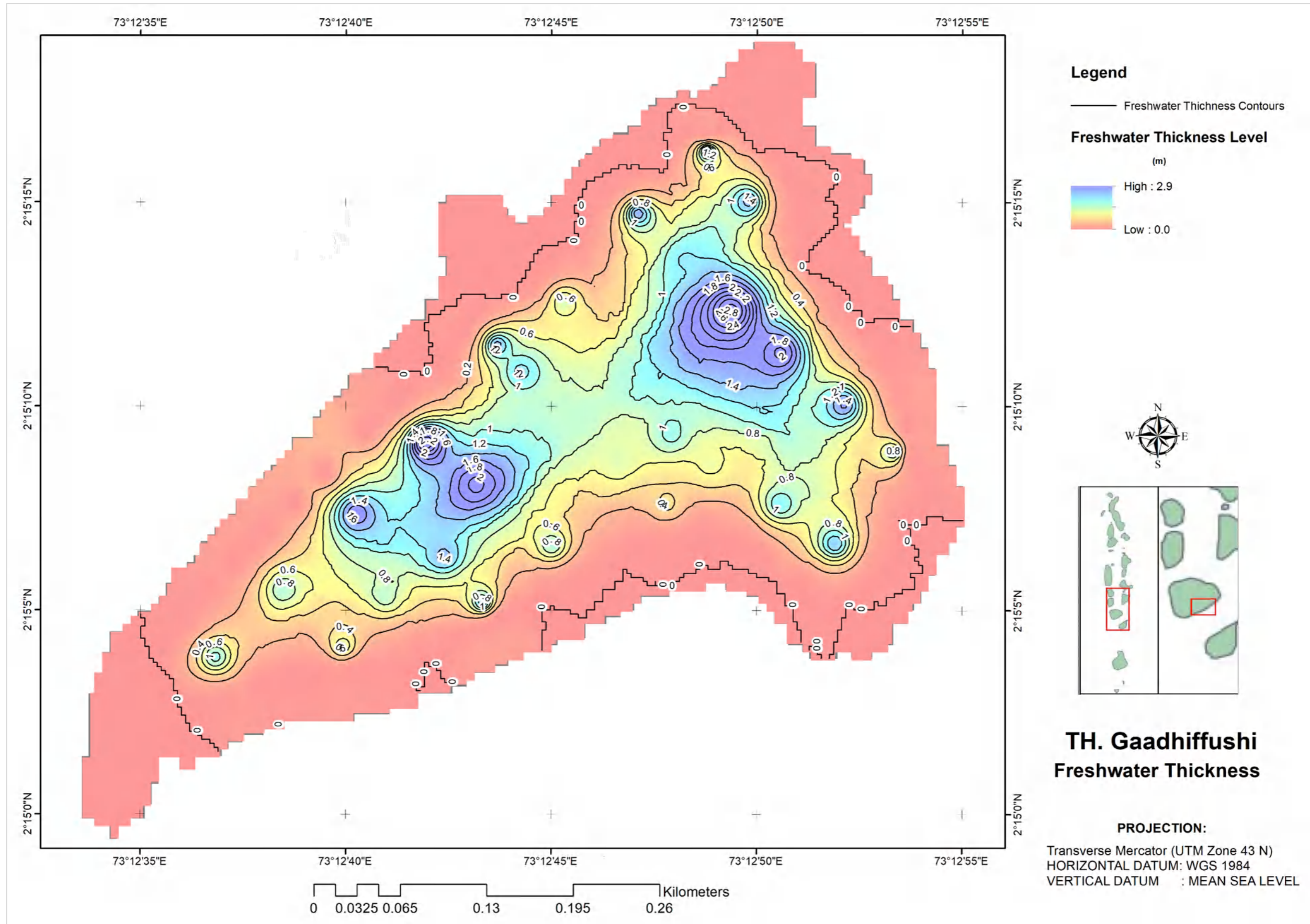


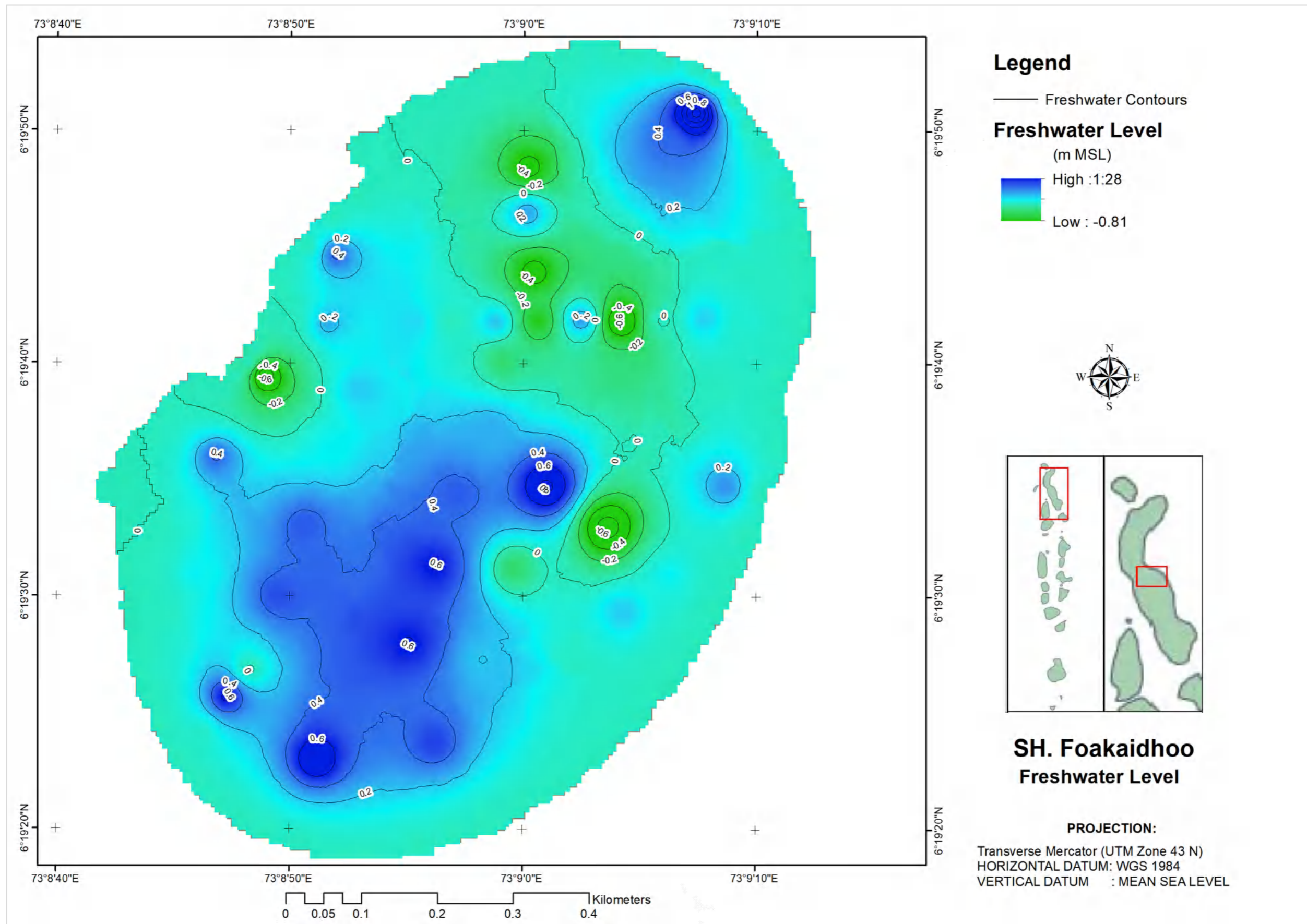


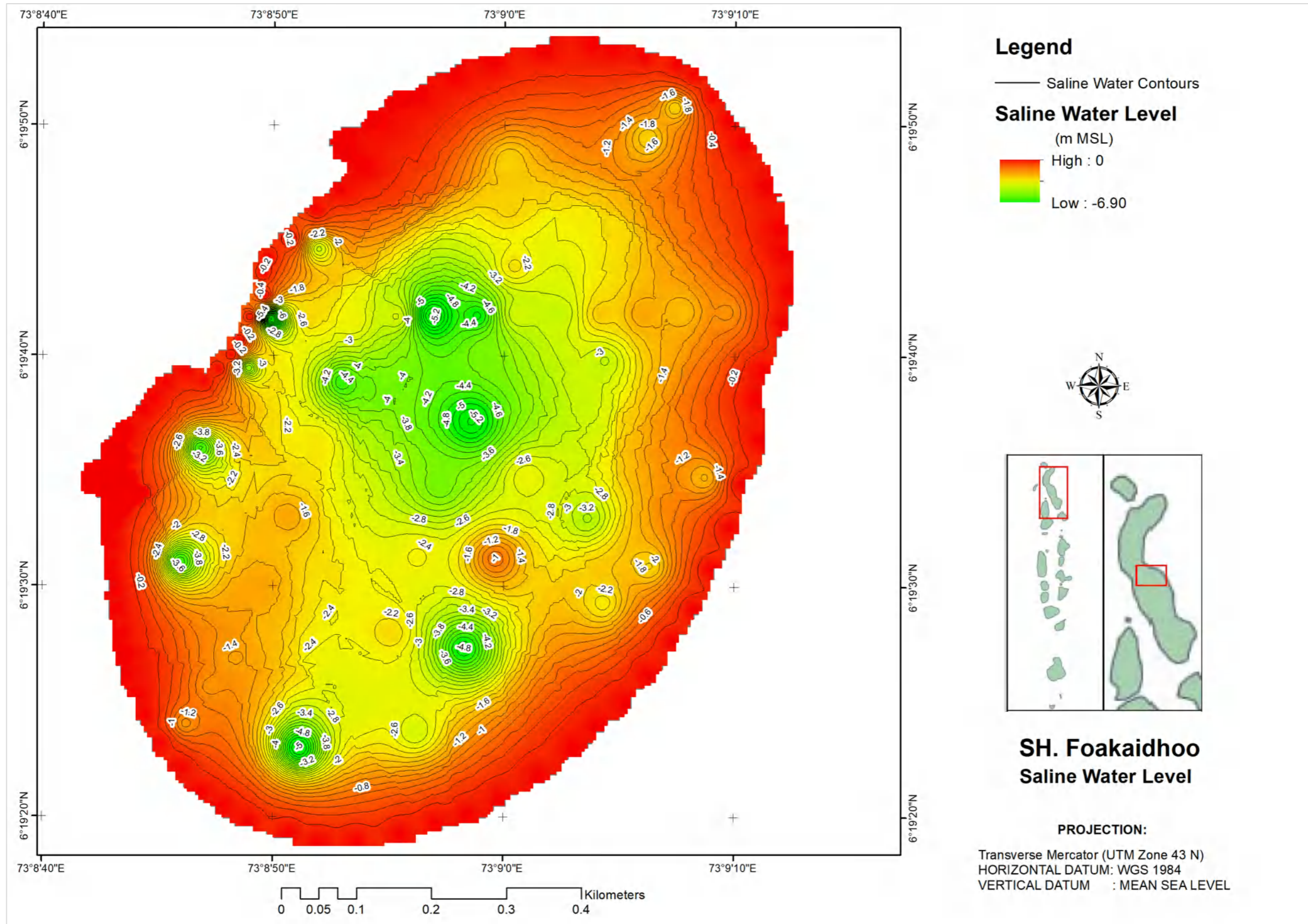


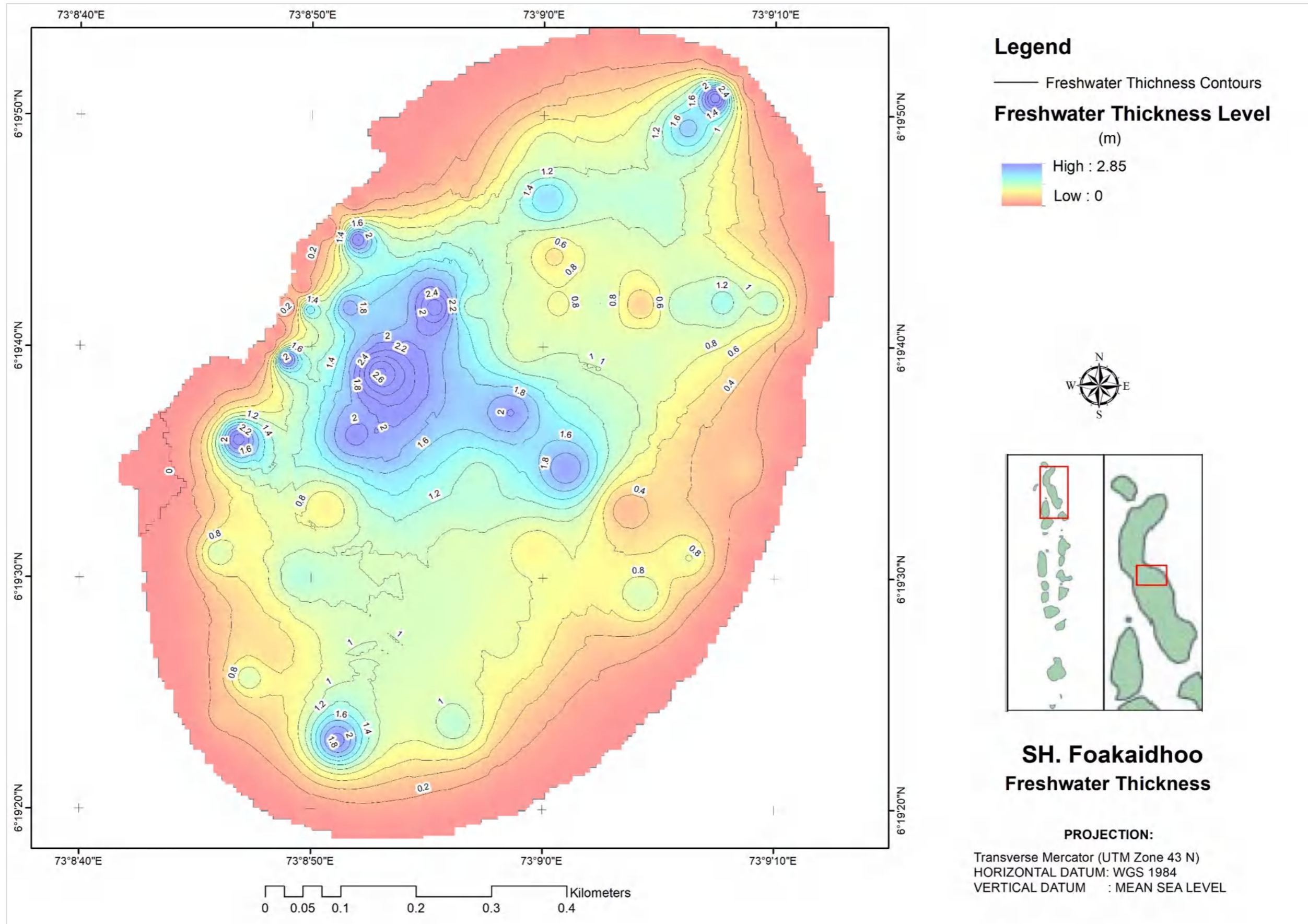












Annex IX: Stakeholder Meeting Details and Meeting Minutes



**Consultancy Service to Assessing Groundwater Resources and Design of
Aquifer Recharge Systems in Selected Islands of Maldives – Lot 2**

Contract no: (IUL)438-GCF/438/2020/199
RIYAN in JV with MHEC

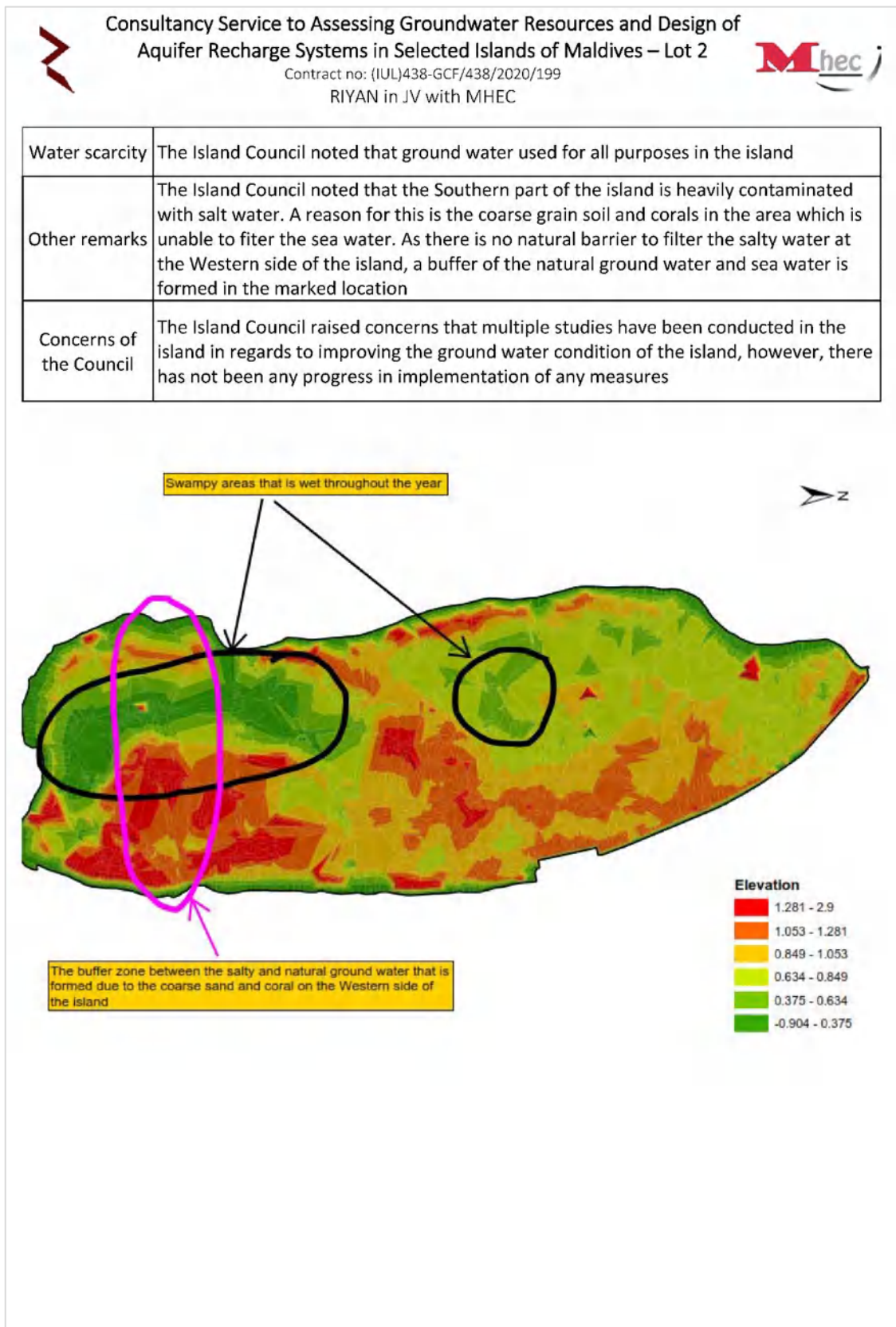


MINUTES OF MEETINGS:

MEETING WITH KANDOODHOO ISLAND COUNCIL (25/SEP/2021)



Introduction	Field team made the introducing remarks of the meeting with a brief introduction of the project
	Field team explained that the purpose of the trip is to collect data of the current status of the island's ground water (aquifer) and design a ground water recharging mechanism which can be used throughout the year. The data collected will be used to design an ground water recharging system that captures the water during the monsoon season and makes the best use of it for later when the water table level gets depleted. Further, after the implementation of the system, it will help to maintain the ground water with better properties such as the smell, taste, color and etc.
Flooding zones	The Island Council marked two major locations prone to flooding mostly throughout the year
	According to the council, these two locations marked are always swampy and does not get fully dried even during the dry season After a heavy rainy day, the water could stagnate and remain for a duration of about 2-3 days
Water quality	The Island Council noted that after the Tsunami, the water quality of the island has been drastically effected
	After Tsunami, the ground water has become salty to the extend that the agricultural fields are commonly damaged due to the increased salt quantity after the monsoon season The Island Council also noted that they find a huge difference in the smell and taste of the water during the dry season





Consultancy Service to Assessing Groundwater Resources and Design of Aquifer Recharge Systems in Selected Islands of Maldives – Lot 2

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MINUTES OF MEETINGS:

MEETING WITH VANDHOO ISLAND COUNCIL (29/SEP/2021)



Introduction	Field team made the introducing remarks of the meeting with a brief introduction of the project
	Field team explained that the purpose of the trip is to collect data of the current status of the island's ground water (aquifer) and design a ground water recharging mechanism which can be used throughout the year.
	The data collected will be used to design an ground water recharging system that captures the water during the monsoon season and makes the best use of it for later when the water table level gets depleted. Further, after the implementation of the system, it will help to maintain the ground water with better properties such as the smell, taste, color and etc.
Flooding zones	The Island Council marked 3 major locations prone to flooding mostly throughout the year. These 3 areas are swamps
	The Island Council noted that there are no major wet or flooding zones in the habitat area.
Water quality	The Island Council noted that throughout the year, there is a foul smell of the ground water. This is severe near the households that uses more ground water such as households that use automatic washing machines.

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	<p>The Island Council noted that irrespective of the foul smell, the water is always clear in all the areas and seasons.</p>
	<p>The Island Council noted that they have not observed a difference in smell and taste of the ground water during the wet and dry season</p>
	<p>The water in the swamp has high salinity</p>
Water scarcity	<p>The Island Council noted that ground water is used for all purposes except cooking and drinking</p>
	<p>The Island Council noted that due to the shallow water table level of the island, they do not have any difficulty in obtaining the groundwater during dry seasons</p>
Other remarks	<p>The Island Council noted that the island has an existing sewerage system made by the themselves which 95% of the households are connected. The outfall of this system is diverted to the ocean through a gravity system</p>
	<p>As the existing sewerage system was laid by the locals of the island, the house connections (lateral connections) to the main sewerage line could be very shallow, therefore, precaution must be taken during the Electrical Resistivity test. The locals with the team would help to identify the areas that are with shallow lines and if there are further queries or concerns, the team can contact the Island Council for more clarification</p>
	<p>The island council noted that the Northern left corner of the island (the swamp area) is prone to ocean waves through the year and the Eastern part faces flooding during the severe rainy days (with high wind)</p>



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MINUTES OF MEETINGS:

MEETING WITH OMADHOO ISLAND COUNCIL (02/OCT/2021)



Introduction	Field team made the introducing remarks of the meeting with a brief introduction of the project
	Field team explained that the purpose of the trip is to collect data of the current status of the island's ground water (aquifer) and design a ground water recharging mechanism which can be used throughout the year. The data collected will be used to design an ground water recharging system that captures the water during the monsoon season and makes the best use of it for later when the water table level gets depleted. Further, after the implementation of the system, it will help to maintain the ground water with better properties such as the smell, taste, color and etc.
Flooding zones	The most flooded areas were marked in the map by the Island Council president. The flooded area drains within 1-2 days after heavy rain
	The Island Council also noted that the road Infront of the Island Council office, right next to the reclaimed area for the newly constructed harbor, is prone to flooding during rainy season as the reclaimed area is elevated higher than the natural island level
Water quality	The council noted that as the sewage is discharge to the ground via septic tanks, the groundwater has a foul smell, taste and discoloring. These are noticed throughout the year in some of the households of the island and samples have been collected by the previous survey team of the project.
	No noticeable water scarcity is noticed throughout the year, but the quality of the groundwater is better during the rainy season. However, there is a foul smell, taste and unclarity is noticeable even during the rainy season. It was further noted that almost all households use oxygen tanks while using groundwater
	Groundwater has not been used for drinking for a very long time, approximately for 30 years. The main source of drinking water is rain water and recently the use of mineral water is increasing. The groundwater is mainly used by only food processing areas

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Water scarcity	There is no scarcity noticed throughout the year.
Septic tanks and sewerage system management	All the houses use septic tanks and each household is given permission to discharge the waste to a septic tank built on the road if needed and some households do that.
	The Island Council agreed that they suspect the groundwater to be contaminated due to septic tanks, but as no specific studies are made to test the exact pollution contents, they cannot confirm that the pollution is from the septic tanks
	The council informed that the sewerage system is at the final concept design stage and they hope to get the project completed at the earliest. No tentative date was mentioned for the implementation of the system
Other remarks	The marked area in the map is the area marked by the Island Council as the soil erosion and susceptible to flooding during the rainy season
	The Island Council noted that the salinity of the water at the Southern side is more after the Tsunami. As a result, the metals used in the houses in the area is easily corroded.
	The Island Council estimated that for the fish processing works in the island will consume not less than 300,000 liters of water per month. This is a rough estimate and the actual consumption will be higher than this. And all the water is discharged to the sea as they contain blood and other impurities



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MINUTES OF MEETINGS:

MEETING WITH GAADHIFUSHI ISLAND COUNCIL (03/OCT/2021)



Introduction	Field team made the introducing remarks of the meeting with a brief introduction of the project
	Field team explained that the purpose of the trip is to collect data of the current status of the island's ground water (aquifer) and design a ground water recharging mechanism which can be used throughout the year. The data collected will be used to design an ground water recharging system that captures the water during the monsoon season and makes the best use of it for later when the water table level gets depleted. Further, after the implementation of the system, it will help to maintain the ground water with better properties such as the smell, taste, color and etc.
Flooding zones	The Island Council showed the area in the map (as marked). Major swell waves occur usually twice a year during the rainy season and when the sea level is higher.
	The Island Council showed the area in the map (as marked).
Water quality	Some areas with septic tanks have noticeable differences in the water quality with foul smell and taste. It is even more prominent during swell waves. There is a noticeable difference in groundwater in general after the Tsunami.
	Ground water used for all purposes except cooking and drinking There are differences in the water lens. However, they are not sure which areas are better or worse. But as noted before, there are specific areas near septic tanks which are found to have worse condition

 Consultancy Service to Assessing Groundwater Resources and Design of Aquifer Recharge Systems in Selected Islands of Maldives – Lot 2 Contract no: (IUL)438-GCF/438/2020/199 RIYAN in JV with MHEC 	
Water scarcity	Does not notice a significant scarcity in ground water, however the quality of water degrades with the seasonal (wet and dry season) changes.
Septic tanks and sewerage system management	All the houses will be connected to the sewerage system when it's complete and the existing septic tanks will be decommissioned
Other remarks	During the rainy season, the level of water table is not noticed to differ from other times of the year. However, it is observed that the water table level fluctuates with the tidal differences. The difference is estimated around 6-8 inches
	The council informed that there are plans for land reclamation by the government, however, they cannot give a tentative date on the project. Currently, shore protection works are in progress by MTCC at the area subjected to swell waves (as shown in the map)



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MINUTES OF MEETINGS:

MEETING WITH FOAKAIDHOO ISLAND COUNCIL (09/OCT/2021)



Introduction	Field team made the introducing remarks of the meeting with a brief introduction of the project
	Field team explained that the purpose of the trip is to collect data of the current status of the island's ground water (aquifer) and design a ground water recharging mechanism which can be used throughout the year. The data collected will be used to design an ground water recharging system that captures the water during the monsoon season and makes the best use of it for later when the water table level gets depleted. Further, after the implementation of the system, it will help to maintain the ground water with better properties such as the smell, taste, color and etc.
Flooding zones	Water stagnation is rarely observed dur to rain. It happens only in severe cases one or twice in a year where rainfall is excessive.
	Water stagnation is observed during swell waves in the monsoon season. It backflows to the ocean only if the level of inflow exceeds the ocean level.
Water quality	The quality of water at different areas are found to be different. A foul smell and odour is present generally in all areas. The areas near Bodu Miski & childrens park are found to have better water quality than other areas. A reason for this could be that this area is less densly populated than other areas.
	During the rainy season, the ground water quality is found to improve noticeably in all the araes. The worse areas still has the foul smell and odour however, it improves during the rainy season.
	It's observed that areas with good groundwater condition deteriorated with the habitation in those areas (Southern area). And houses near the swamps are found to have worse ground water conditions

 Consultancy Service to Assessing Groundwater Resources and Design of Aquifer Recharge Systems in Selected Islands of Maldives – Lot 2 Contract no: (IUL)438-GCF/438/2020/199 RIYAN in JV with MHEC	
Septic tanks and sewerage system management	The septic tanks are found to worsen the ground water condition overtime. There are occasions which the water wells are changed due to pollutions observed by the septic tanks
	There are no rules for the constructions of the septic tanks inside the household. However, the septic tank and water well area mostly arranged in such a way that it does not align with the naturally observed direction of waterflow. This is observed to give better ground water in the water tanks
Soil erosion	After the construction of the harbour, the southern side of the island appears to erode 10ft annually
Rainwater and RO system	The rainwater harvesting areas are determined by the council where they found it to be most suitable.
	The discharge of excess rainwater is not observed to improve the groundwater condition as there are efforts made to check the difference in groundwater quality due to it
	The capacity of rainwater storage is 200,000 litres, the capacity of the RO storage tank to be checked
	The existing water wells will not be useless after the RO system however, the specific purpose of the existing wells are not confirmed yet
Construction	The foundation of the school new building is 14-15inches below the ground water table at the school location
	Due to construction and dewatering by the pumps, a decrease in water level is observed up to 2ft below the natural level
Other remarks	No waterborne diseases are observed
	The newly planned projects for the nearby future is shifting of the existing garbage to the area next to it. This is to make way for the road
Council's questions and Expert team's recommendation	1- What would be effect of backfilling the swamps with the sea sand? Backfilling the swamps with the sand will cause to release the salt into the groundwater with time. Therefore, the groundwater condition of the area will worsen by backfilling it with sea sand



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RIYAN in JV with MHEC



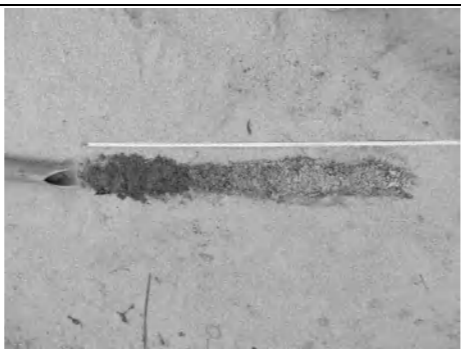

2- What would be best way to dismantle the existing septic tanks? Will backfilling it by sand is a viable option

The best option would be to transfer the sludge in the existing septic tanks to the new sewerage system over a period of 3-6months such a way that it's discharged effectively. If it's not an option, leaving the septic tanks as they are will improve the groundwater condition within 3-5 years. Backfilling it with sand is not a viable option

3- As the island is not formed on a large reef, with the newly constructed harbor, the island will be directly connected to the ocean. What would be the effect of this on the island's groundwater level

The island's water lens is formed on the corals. Therefore, the effects of different projects on the groundwater table will be based on the hydrological connection. If the connection is stronger, the impact on the groundwater lens will be higher. After the construction of the harbor, the water lense is not found to be effected significantly. Therefore, it could be a good sign at the design stages of the project to restore the groundwater of the island

Annex X: Photographs of the Soil Profiles

	Soil Profile 1	Soil Profile 2	Soil Profile 3	Soil Profile 4	Soil Profile 5
Th. Kandoodhoo					
Th. Vandhoo					
Th. Omadhoo					
Th. Gaadhiffushi					
Sh. Foakaidhoo					

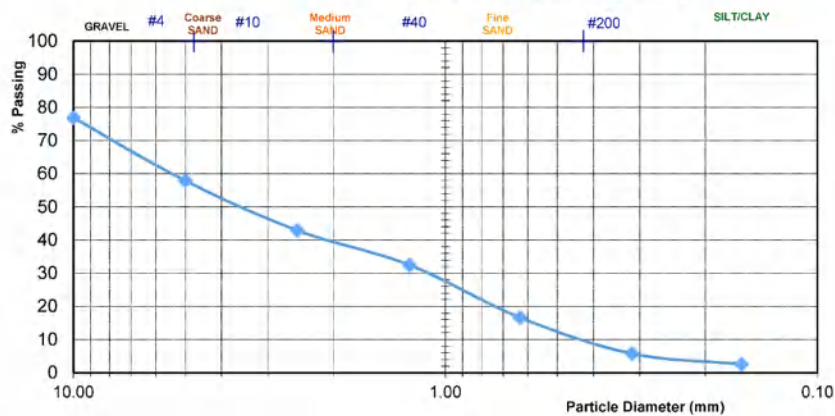
Annex XI: Sieve Analysis Test Results



Sieve Analysis Data

Project Name: N/A	Tested By: Shunaif
Source: MHEC (SL)	Checked By: Naushad
Sample No: 1	Test #: 1
Sample Depth: Varies 0-2m	Tested on: 14.11.2021

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
#	10.00	690	945	255.0	23.1	76.9
#	5.00	705	915	210.0	19.0	57.8
#	2.50	685	850	165.0	15.0	42.9
#	1.25	585	700	115.0	10.4	32.5
#	0.63	545	720	175.0	15.9	16.6
#	0.32	570	690	120.0	10.9	5.7
#	0.160	540	575	35.0	3.2	2.5
Pan		470	498	28.0	2.5	0.0
TOTAL:				1103.0	100.0	



Weight of Sample **1090 g**
 Percentage Loss **-1.19%**
 Fineness modulus **5.7**

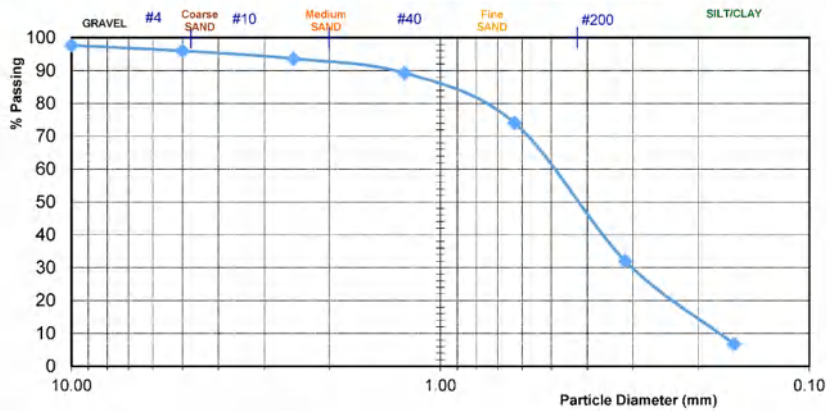
Notes:
 Sample with roots and organic matter



Sieve Analysis Data

Project Name: N/A	Tested By: Shunaif
Source: MHEC (SL)	Checked By: Naushad
Sample No: 2	Test #: 1
Sample Depth: Varies 0-2m	Tested on: 14.11.2021

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
#	10.00	690	725	35.0	2.4	97.6
#	5.00	705	730	25.0	1.7	96.0
#	2.50	685	720	35.0	2.4	93.6
#	1.25	585	650	65.0	4.4	89.2
#	0.63	545	770	225.0	15.2	74.1
#	0.32	570	1195	625.0	42.1	32.0
#	0.160	540	915	375.0	25.3	6.7
Pan		470	570	100.0	6.7	0.0
TOTAL:				1485.0	100.0	



Weight of Sample **1485 g**
 Percentage Loss **0.00%**
 Fineness modulus **3.1**

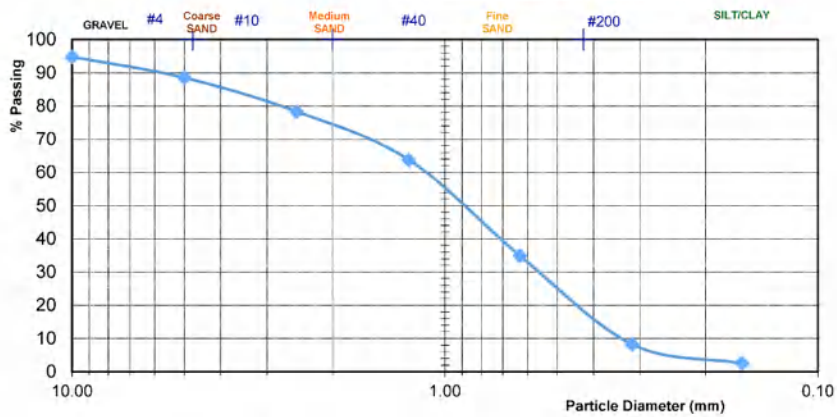
Notes:



Sieve Analysis Data

Project Name: N/A	Tested By: Shunaif
Source: MHEC (SL)	Checked By: Naushad
Sample No: 3	Test #: 1
Sample Depth: Varies 0-2m	Tested on: 14.11.2021

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
#	10.00	690	785	95.0	5.2	94.8
#	5.00	705	820	115.0	6.3	88.5
#	2.50	685	870	185.0	10.2	78.3
#	1.25	585	850	265.0	14.6	63.7
#	0.63	545	1070	525.0	28.8	34.9
#	0.32	570	1055	485.0	26.6	8.2
#	0.160	540	645	105.0	5.8	2.5
Pan		470	515	45.0	2.5	0.0
TOTAL:				1820.0	100.0	



Weight of Sample **1820 g**
 Percentage Loss **0.00%**
 Fineness modulus **4.3**

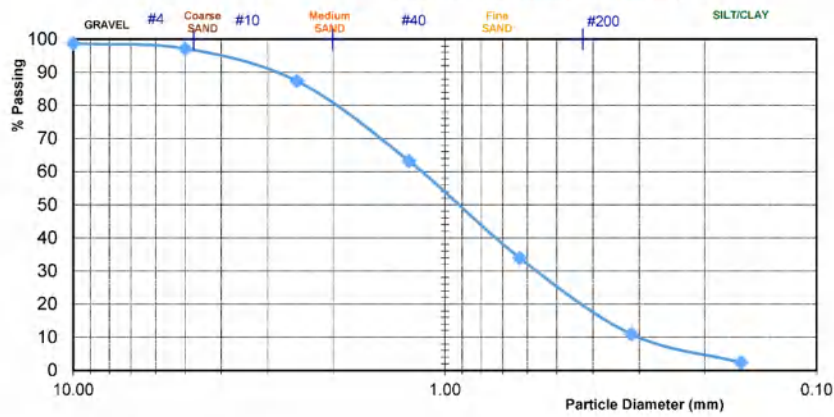
Notes:



Sieve Analysis Data

Project Name: N/A	Tested By: Shunaif
Source: MHEC (SL)	Checked By: Naushad
Sample No: 4	Test #: 1
Sample Depth: Varies 0-2m	Tested on: 14.11.2021

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
#	10.00	690	715	25.0	1.3	98.7
#	5.00	705	735	30.0	1.6	97.2
#	2.50	685	875	190.0	9.8	87.3
#	1.25	585	1050	465.0	24.1	63.2
#	0.63	545	1110	565.0	29.3	33.9
#	0.32	570	1015	445.0	23.1	10.9
#	0.160	540	705	165.0	8.5	2.3
Pan		470	515	45.0	2.3	0.0
TOTAL:				1930.0	100.0	



Weight of Sample **1930 g**
 Percentage Loss **0.00%**
 Fineness modulus **4.1**

Notes: