Qatar University

Graduate Studies

College of Art and Sciences

“Vulnerability of mangroves to sea level rise in Qatar: Assessment and identification of vulnerable mangroves areas”

A Thesis in

The Department of Biological and Environmental Sciences

By

Mohammad Ahmad Shehadi

Submitted in Partial Fulfillment

Of the Requirements

For the Degree of

Master of Science

May 2015

COMMITTEE PAGE

The Thesis of Mohammad Ahmad Shehadi was reviewed and approved by the following:

We, the committee members listed below accept and approve the project of the student named above. To the best of this committee's knowledge, the thesis confirms the requirements of Qatar University, and we endorse this thesis for examination.

Name: Dr.Sumith Pathirana

Signature: ………………………………………… Date: …………………………

Name: Dr. Mohammad Ahmad Al-Ghouti

Signature: ………………………………………… Date: …………………………

Name: Dr. Radhouane Ben Hamaduo

Signature: ………………………………………… Date: …………………………

Name: Dr. Christian Strohmenger, ExxonMobil.

Signature: ………………………………………… Date: …………………………

ABSTRACT

Qatar is one of few countries in Arabian Gulf where mangrove ecosystem exist. They are essential number of ecosystem function; however, this valuable ecosystem is threatened by both anthropogenic and global climatic factors. This study is aimed at investigating the vulnerability of mangroves resulting from the rise in sea level. Remote sensing, GIS and soil analysis were used to achieve this assessment. Four main research questions including the change in mangrove area over time, the endangered area by sea level rise, the potentially expected migration area and the management strategies were answered. Thus the first objective of identifying potentially endangered mangrove areas by sea level rise in Qatar and second objective of enhancing the mangrove protection and resilience to sea level rise were achieved. The results of comparative analysis of satellite images show a 50 % increase of the growth of mangrove ecosystems. Comparison of soil within mangrove and outside mangrove area showed the same pH values with slightly different salinity, and similar soil Type. This will positively affect the migration process for existing mangroves. High exposure to sea level rise is estimated from overlaying recent mangrove layer over elevation layers of expected sea level rise scenarios. The result showed that endangered mangrove areas were 35% and 45% with 0.52 m and 0.74 m sea level rise respectively. Outward migration using spatial techniques was observed, while new conservation strategies are recommended to minimize the vulnerability of mangroves.

ملخص البحث

تعتبر قطر من الدول القليلة في الخليج العربي التي تنمو بها أشجار القرم. هذه الأشجار تشكل أهمية كبيرة للعديد من وظائف النظام الإيكولوجي, ولكنها مهددة بعوامل بشرية ومناخية مختلفة. تهدف هذه الدراسة إلى التعرف على مدى تأثر أشجار القرم بالارتفاع المتوقع لمستوى سطح البحر. ولتحديد مستوى التأثر تم استخدام نظام الاستشعار عن بعد ونظم المعلومات الجغرافية وكذلك تحليل التربة. يتضمن البحث هدفين رئيسين, الهدف الاول يتمثل بتحديد مساحة مناطق أشجار القرم المحتمل أن تكون عرضة للخطر بسبب ارتفاع مستوى سطح البحر في قطر, و الهدف الثاني يتمحور حول السبل المحتملة لتعزيز حماية أشجار القرم وزيادة قدرتها على التكيف مع ارتفاع مستوى سطح البحر. من اجل تحقيق الاهداف تم الإجابة عن أربع أسئلة بحثيه, التغير الزمني لأشجار القرم, والمنطقة المعرضة للخطر بسبب ارتفاع مستوى سطح البحر، ومنطقة الهجرة المتوقعة واستراتيجيات الإدارة. وأظهرت نتائج مقارنه صور الأقمار الصناعية زيادة بنسبة 50٪ من مساحة أشجار القرم, بالمقابل فان ثلاثة و خمسون و اربعة و خمسون بالمئة من مساحات اشجار القرم ستكون معرضه للخطر تزامنا مع ارتفاع مستوى سطح البحر الى 0.52 و 0.74 متر تباعا". كما و أظهرت نتائج مقارنة التربة داخل وخارج منطقة أشجار القرم تساوي في الرقم الهيدروجيني واختلاف بسيط في الملوحة كما أظهرت تشابه في نوع التربة. وهذه النتائج تبين احتماليه نجاح هجره أشجار القرم نحو البر. من ناحيه اخرى , فان الخطر المحدق بأشجار القرم يجب ان يواجه باستراتيجيات و حلول لتساعد على تخفيف تأثر أشجار القرم بارتفاع مستوى سطح البحر

ABBREVIATION

- CCSLR: Climate Change and Sea Level Rise.
- DEM: Digital Elevation Model.
- EA: Ecological Assessment.
- ESAR: Environmental Statistical Annual Report.
- ICZM: Integrated Coastal Zone Management Plan.
- MMUP: Ministry of Municipalities and Urban Planning.
- PMSL: Permanent Service for Mean Sea Level.
- RCP: Representative Concentration Pathway.
- RSL: Relative sea level.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

The first thank is to Allah that gave me the power to do this study. Second thank is to the people that the study had been made possible through their help. I would like to thank Dr. Sumith Pathirana for his help and support. Also I would like to thank the members of advisor committee Dr. Mohammad Ahmad Al-Ghouti, Dr. Radhouane Ben Hamaduo, and Dr Christian Strohmenger (ExxonMobil), for their follow up and important comments. I would like to thanks Dr. Jassem Al Khayat for supporting the field work. Enormous thanks goes to my friend in Qatar university Noora Al shamary and Rabab Ahmad for their help and positivity. At last a great thanks to my brother Ismail, my friends in Qatar and to my family and friends in Lebanon that were patient enough to listen to me and deal with me during stressful time.

Chapter 1

1 Introduction

Climate change is certainly one of the main contributors to the vast alterations of planet Earth. One main result of climate change is the fluctuations in sea levels. These fluctuations are enhanced by global warming (thermal expansion of water) and melting of land ice (Church *et al.*, 2001).The Intergovernmental panel estimated that the increased climate change would raise sea levels by 1.5 ± 0.5 mm/year. The most recent estimation for the rise in sea level in 100 years is 0.52 m and 0.74 m for both medium and high coastal impacts respectively (IPCC, 2013). Sea level rise may further exceed by 5-6 meters over the span of a century, if the West Antarctic Ice Sheet (WAIS) would collapses (Nicholls *et al.*, 2005).

Mangroves consist of a number of species including trees, shrubs, and palms that withstand salty water, and grow in intertidal zones of coastal areas within tropical and subtropical regions (Wan *et al.*, 2011; Zhou *et al.*, 2010). The total area of mangroves around the world is 137,760 Km^2 and Asia possesses 42% of this area (Giri *et al.*, 2011). The mangrove ecosystem can be seen as a nursery and shelter for a vast number of species such as shrimp, crabs, fish, mollusks…etc. Some animals depend on mangroves for a limited time, while others spend their entire lifetime within mangrove areas (Nyati *et al.*, 2012). Mangroves also provide services and materials to people living in close vicinity to them, such as fuel wood, timber and medicine (Spalding *et al.*, 2010; Ewel *et* *al.*, 1998). Moreover, mangroves form a buffer zone that protects coastlines from natural events such as coastal flooding and tsunamis (Alongi, 2008). Human activities such as urbanization, conversion to agriculture field, and aquaculture are responsible for the loss of one third of mangrove area during last two decades (Penha-lopes *et al.*, 2011). Another major threat to mangrove ecosystems is the accelerated sea level rise (Field, 1995). Although anthropogenic factors are causing destruction to mangroves more than inundation due to rise in sea level (Duke *et al.*, 2007), sea level rise is recognized to be a significant threat to mangrove health presently and in the future (Gilman *et al.*, 2006; Cahoon *et al.*, 2007). An unmistakable factor associated with sea level rise is flooding. Flooding would drastically lower the productivity and process of photosynthesis which in turn shortens the overall lifespan of mangroves (Ellison, 2000). Inundation also results in higher salinity that affects the health of mangrove species (Gilman *et al.*, 2006). Overall, mangroves certainly play an important ecological role, and the threats that can affect them should be investigated.

Mangrove is commonly found along Qatar coastal areas. It covers approximately 21.26 Km^2 of the total area of Qatar (ICZMP-EA, 2014). These mangroves help preserve the limited biodiversity due to extreme environmental conditions, and greater efforts to preserve this ecosystem are needed considering the provided ecosystem services (e.g. nursery for commercial fishes or shoreline protection against flooding and erosion). Since mangroves is an important ecosystem in Qatar, it is important to assess, understand and take appropriate actions to reduce the vulnerability of mangroves to sea level rise. The work done in this study will shed light on how managing, adapting, and protecting mangroves from the effects of a global climate change and will help preserving this vegetation communities.

Remote sensing and GIS are modern spatial information technologies that can be used to characterize mangrove areas and may be applied to estimate the threat from potential sea level rise (Wilkie and Finn, 1996). Satellite images can be used to extract mangrove areas, while GIS can be used to model the impact and produce maps. Mangrove layers are overlayed with digital elevation model to predict the areas that will be affected by sea level rise. Soil monitoring is one of the factors that help in identifying the best areas for potential mangrove expansion (Wan Rasidah *et al.*, 2010).

The area of focus in this study was Al Khor and Al Dhakhira, where the largest mangrove communities found in Qatar. A number of studies have been conducted on mangroves in Qatar (ICZMPL-EA, 2014; ICZM-CCSLR, 2014; Al-Ghazaly *et al.*, 1993). Many of those studies were just field assessments or mapping using remote sensing technique in general. We propose here a combined approach integrating field study (pH, salinity, soil type analysis, accuracy assessment) and modern spatial information technologies (Remote sensing and GIS) for mapping and modeling the potential vulnerability of mangroves. This study is the most recent in depth study conducted in Qatar, to evaluate the geographic extend of mangroves in Al Khor and Al Dhakhira and assess the vulnerability to sea level rise.

The first objective of this study is to identify potentially endangered mangrove areas under forecasted sea level rise in Qatar, while the second objective is to propose protection and resilience enhancement strategies considering sea level rise.

Figure 1 represents the adopted approach to address these objectives.

The objectives of the study were divided into four research questions:

The research questions for the first objective are:

1. Is the mangrove area increasing or decreasing through historical time series?
2. What locations and extension of mangrove area are potentially threatened by sea level rise?

The research questions for the second objective are:

1. Is the expected potential migration area suitable for the growth of mangroves?
2. What are the possible measures for the protection of mangroves against sea level rise?

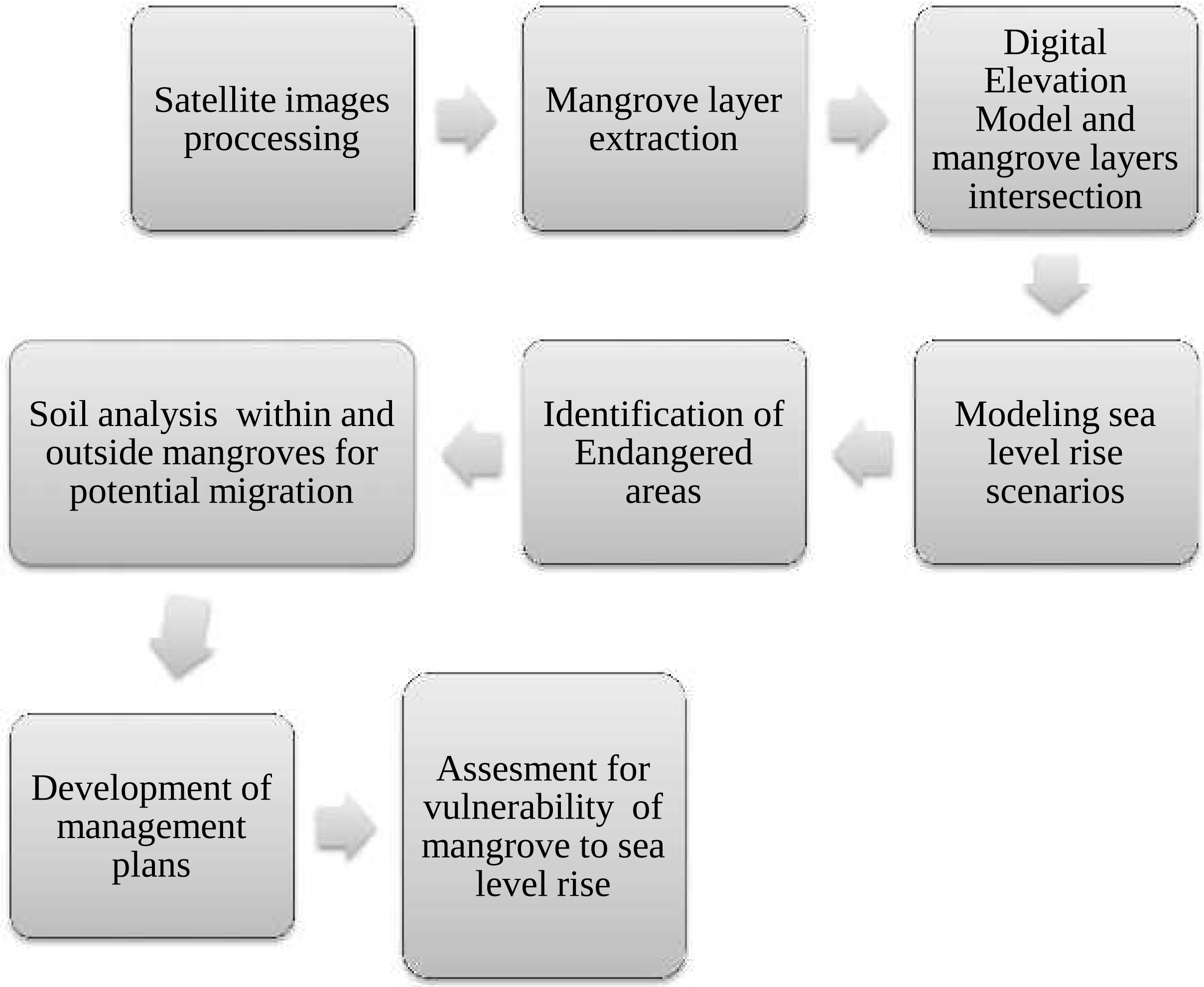


Figure 1: Methodology used in the study.

Chapter 2

2 Literature Review

2.1 Background on Mangrove Ecosystem

2.1.1 General description for mangrove ecosystem

Mangroves are defined as a transitional ecosystem located at the intersection of ocean, land, and fresh water (Suratman, 2008). Suitable hydrology is one of the important factors for mangrove recruitment. The tidal connections may be altered or cut off, but when re-established, can enhance the nature recruitment and improve the function and health of mangroves ecosystem (Kraynak and Tetrault, 2003).

2.1.2 The main functions of mangrove ecosystem

Mangroves are an important habitat for different communities of organisms, such as bacteria, fish, shrimp, bird, reptile and mammals, as their role in the primary production process (Bandaranayake, 1994). These areas are rich in nutrients that support the aquatic living species. They are nurseries and vital spawning grounds for aquatic fishes and crustaceans and play a protection role for their reproduction (O'Grady *et al.*, 1996). Various types of insect are present in mangrove areas and support their pollination and provide food for other living organisms (Hogarth, 1999). Mangrove areas contains different species of trees and shrubs, which send their snorkel roots or pneumatophores through anoxic mud to the surface, where they take oxygen and filter plant matters, breaking it down into detritus. The base of the mangrove food chain is detritus. The roots of trees and shrubs are home to different invertebrates, including mussels, sponges, tunicates, hydroids and oysters, along with other juvenile fish species. Mangroves are pool of biodiversity. They are extremely important to the coastal area for protection against sea erosion and buffering the intensity of cyclones (Kraynak and Tetrault, 2003). Through trapping sediments, forming soil and sediments from their decomposed organic matter, they stabilize the soil and reduce the risk of erosion. Moreover, they absorb the strong energy from tidal waves, strong winds, floods and severe storms, thus reducing the damage to coastal areas.

2.1.3 The commercial benefits of mangrove.

Commercial benefit of mangroves include, wood that is used for furniture and boat building, and indirectly, from derivatives of different parts of mangrove trees, contributing elements to cosmetics, medicine, dyes, fibers, perfumes, soap substituent and condiments. Also, ecotourism is a non-destructive coastal economic activity as mangrove forests are attractive to tourists (Spalding *et al.*, 2010; Ewel *et al.*, 1998). Qatar has the highest emission of carbon dioxide per capita and for that it should compensate by reducing the emission in different countries, but mangroves can absorb carbon from the atmosphere and thus reducing both the emission and the cost of compensation (Lunstrum and Chen, 2014). *Avicennia marina* stores around 11.65% of ecosystem carbon stock, this indicates an important role for mangrove in trapping carbons and providing cheap and environmental solution for carbon emission (Wang *et al.*, 2013).

2.1.4 Impact of pollution on mangrove ecosystem

Mangroves contaminants come from diverse sources. For example agriculture activities add more phosphorus and nitrogen to the mangrove area and resulting in algal blooms and other fouling organisms, barnacles and oysters. Inorganic pollutants from industrial activities and heavy metals represent the most affecting agents (Hogarth, 1999). Organic contaminants from oil spills, such as poly aromatic hydrocarbons, can affect mangroves, but the duration of exposure and the amount that will reach mangroves are key factor in determining the severity of effect (Syed Sanwer Ali *et al.*, 2013).

2.1.5 Impacts of salinity and flooding on mangroves

Flooding can affect the mangroves by decreasing soil oxygen, which in turn affects the root tissue that needs oxygen to metabolize (Ellison, 2000). Mangroves can adapt to this lack of oxygen in deep soil through shallow roots system, and above ground through root tissue such as pneumatophores (vertical extension of underground root to allow gas exchange) in *Avicenna*. Such adaptations transport oxygen from atmosphere to the root system. Oxygen is spread around the underground tissue and form an oxygenated microlayer around the root to increase nutrient uptake and avoid toxicity. Mangroves can also grow under different ranges of salinity level (Gilman *et al.*, 2006). *Avicenna* has a special salt- secreting gland, through which salt is collected as crystal on its leaves, and then blown away or washed away by rain. On the other hand, extreme salinity and permanent flooding can negatively affect the growth of mangroves and their productivity (Rebecca *et al.*, 2010).

2.2 Global climate variability and sea level rise

Intergovernmental Panel on Climate Change (IPCC) has repeatedly emphasized that Greenhouse gases (GHG) are main drivers that cause global climate change (IPCC, 2007, 2013). Sea level rise is one of the consequences. The average rate of global sea level rise was initially recorded 1.8 mm/year between 1961 and 2003, but it later revised the estimate to 3.1 mm/year between 1993 and 2003 (IPCC, 2013).

2.2.1 Processes behind sea level change

Different processes within the ocean, land ice, the hydrological cycle, and the atmosphere, are climate sensitive and effect sea level, causing change at regional and global scales (IPCC, 2013). Regional change in sea level is affected by both temperature and salinity (Church *et al.,* 2010). Moreover, addition of fresh water affects the temperature and salinity of the ocean’s water; that will induce a change in ocean current and result in local sea level change (Stammer *et al.,* 2008). The ocean-atmosphere interaction also has a role in the dynamics of sea level changes. Anthropogenic processes (ground water depletion, water impoundment such as dams) that affect the freshwater runoff, and evapotranspiration rates, will induce changes in the hydrological cycle, and cause shifts in sea level (Sahagian, 2000; Wada *et al.,* 2012). Figure 2 represents the different processes that are sensitive to climate change, and cause change in sea level (IPCC, 2013). Mainly melting glaciers and changes in the hydrological cycle will also affect the relative sea level rise.

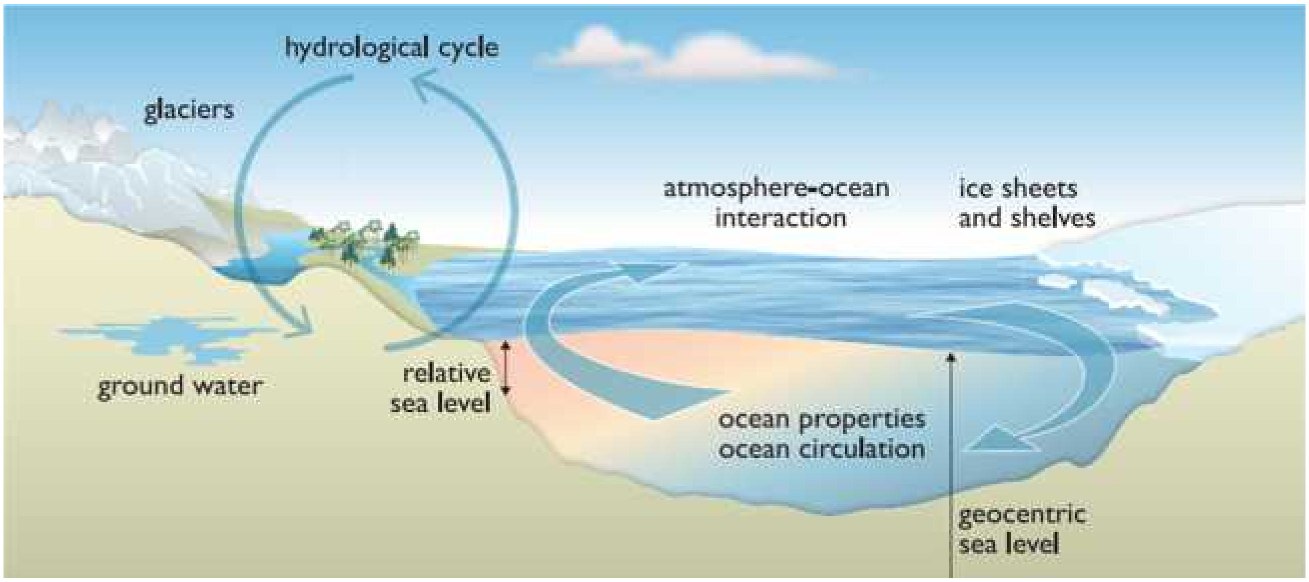


Figure 2: The processes and their components that are climate-sensitive and induce a change in sea level at global and regional scale (IPCC, 2013).

2.2.2 Impact of sea level rise on mangroves ecosystem

Mangroves can be affected by sea level rise in a number of ways. For example the mangrove area can be reduced due to inundation by sea level. Moreover, particularly due to the limited elevation changes that support *Avicennia*, they are less able to resist increase in sea level, pushing them to retreat landward or prograde seawards (Ellison and Zouh, 2012). The rate of accretion is affected by sea level rise, so more recession of mangroves takes place at rapid sea level rise, and with sea level rise (S.L.R) at rate of 1.2 mm/year, mangroves will be retreated (Ellison, 1998). Furthermore, inundation due to sea level rise may carry the propagules to unsuitable places, where conditions are not favorable for the growth of mangrove trees. Inundation affects the distribution of juvenile vegetation layer, and result in modifying the flora distribution from regional point of view (Nitto *et al.*, 2008). Rising sea levels will bring waves with high energy, destroying mangroves and enhancing erosion, resulting in sediment removal, and forcing the shoreline to retreat (Boatemaa *et al.*, 2013). The sea level rise can also result in relocation of coastline, so that a shoreline might be retreated by 2.2 m in the 0.18 m sea level rise, while in case of 6m sea level rise it can be located on average at 74.3 meters (Frykm and Seiron, 2009). Coastline relocation will affect the mangroves with an increase in salinity, and allows invasive species to be within mangrove area. When mangrove surfaces are covered with sea water due to sea level rise, they will retreat landward with low level mangrove islands being the most threatened. This will decrease their density, since many barriers will affect their migration, and increase soil erosion. (Parmanik, 2014).

2.3 Recent studies on sea level rise and mangrove ecosystem in Qatar

2.3.1 The integrated coastal zone management plan study on climate change and sea level rise 2014 (ICZM-CCSLR, 2014)

The state of Qatar is a peninsula with an area of 11,437 Km^2, located halfway along the west coast of the Arabian Gulf, and projecting approximately 160 Km into the central zone of the Gulf along its north-south axis. Qatar is surrounded by the Arabian Gulf from the north and east, and by the gulf of Bahrain from the west. Grey mangrove *Avicennia marina* is the single species that forms mangrove vegetation in Qatar (Hegazy, 1998). Qatar may lose around 3%, 8%, and 13% of its area if there is sea level increase by 1m, 3m, and 5m respectively (AFED, 2009). The Ministry of Municipality and Urban Planning in Qatar recently conducted a study on climate change and sea level rise titled "Integrated Coastal Zone Management Plan for the State of Qatar" (ICZM-CCSLR, 2014). The study provided information about the impact of climate change on the whole coastal zone of Qatar. Sea level rise was also examined at number of scenarios as projected by the IPCC in their fifth assessment (IPCC, 2013). The mean sea level rise by 2100 was estimated to be 0.52m for RCP 4.5 (Representative concentration pathway of medium coastal impact), and 0.74m for RCP8.5 (Representative concentration pathway of high coastal impact). It is estimated with both scenarios 0.52 m and 0.74 m mangroves will be highly impacted (ICZMP-CCSLR, 2014).

Mean Sea level rise is observed using different databases. Permanent Service for Mean Sea Level (PSMSL) is an instrumental data source; which is responsible for collection, interpretation and analysis of data. It has a global network of tide gauge.

Measurements are available from 1982 till 2010. One of its stations is located inside the Arabian Gulf (Bahrain), called the Mina Sulman station. Figure 3 represents the trend in mean sea level rise between 1980-2010. The unit used was in mm. A linear trend is used to fit the gap between 1998 and 2003. The trend estimated 3.28 mm/year (±1.1 mm/ year) and 2.97 mm/year (±2.55 mm/year) for the periods 1982-2003 and 1993-2008 respectively. The gap in data between 1998 and 2003 increased the uncertainty of the trend estimation (ICZMP-CCSLR, 2014).

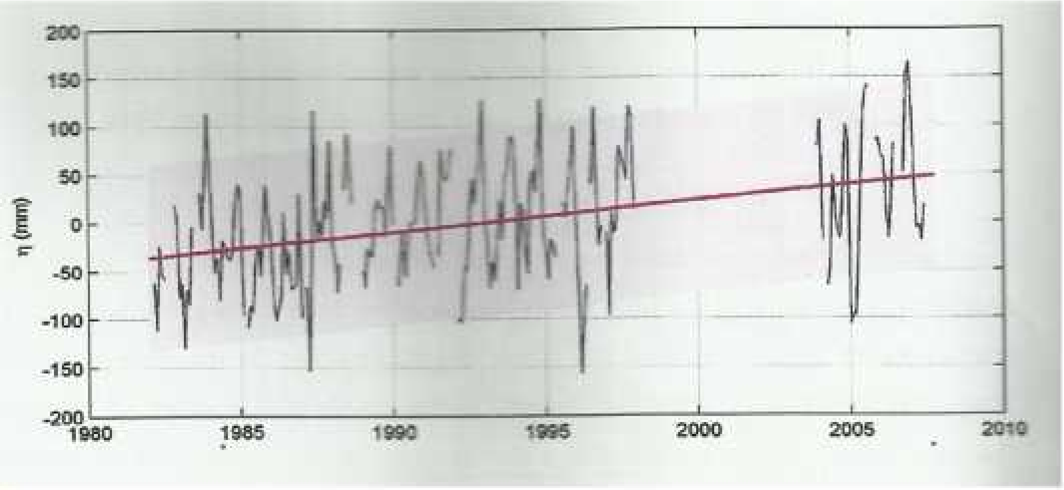


Figure 3: The trend in mean sea level rise during time series 1980-2010 of the Mina Sulman station from PSLMSL data set. The linear fitting and the confidence intervals (95%) (ICZM-CCSLR, 2014)

Doha station located at Doha port is another source to estimate seal level rise changes. This tidal station gives measurement from 1976 to 2013. Figure 4 represents the linear trend produce from Doha station.

The linear trend initially recorded 1.47 mm/year between period 1976-2013, but later revised the estimate to 2.8 mm/year for the periods 1993-2013 (ICZMP-CCSR, 2014).

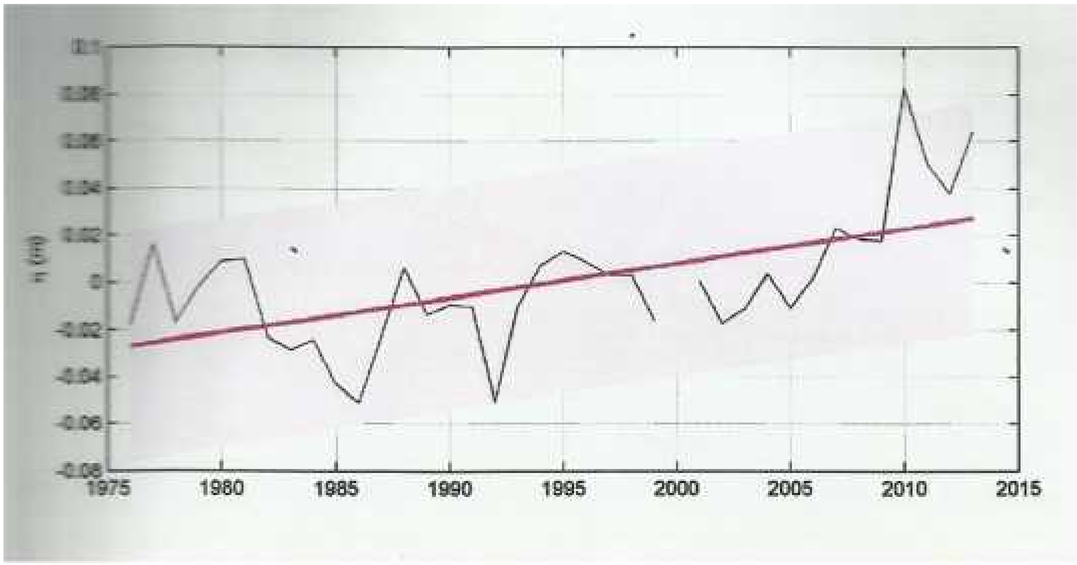


Figure 4: The linear trend in mean sea level produced from Doha station. The linear fitting and the confidence intervals (95%) (ICZM-CCSLR, 2014)

The trend in mean sea level rise on local (Qatar), regional, and global scales is summarized in Table 1, Table 2, and Table 3 respectively. Local trend analysis is established from the climate change and sea level rise study in Qatar (ICZM-CCSLR, 2014). Regional and global analysis is based on the intergovernmental fifth assessment report on climate change (IPCC, 2013), and other studies such as Ayhan and Alothman, 2009; Church and White, 2011; Nerem *et al.*, 2010. Those tables describe the data used, the period, and any technical comment involved in trend calculation.

Table 1: Summary of Local mean sea level Trends (ICZM-CCSLR, 2014)

Data set	Trend (mm/year)	Period	Technical comments
Mina Sulman station (PSMSL data set)	3.28±1.1 2.97± 2.55	1983-2007 1993-2007	Local estimation without GIA correction 66% completeness
Doha Station	1.47± 0.69 2.8 ± 1.58	1975 – 2013 1993 – 2013	Local estimation without GIA correction annual records

Table 2: Summary of regional mean sea level trends (ICZM-CCSLR, 2014)

Data set	Trend (mm/year)	Period	Technical comments
4 stations (PSMSL) (Ayhan and Alothman, 2009)	1.96 ± 0.21 2.27 ± 0.21	Longer than 19 years	Regional estimation 1. Without GIA correction. 2. With GIA correction without quality control
Node [62 ; 20] Church and White (2011) database	1.9 ± 0.44	1950 – 2009	Regional estimation with GIA correction
TOPEX and Jason Altimeter (Cazenave) at al., 2009	1.0 - 3.0	1993 – 2009	Regional estimation at Arabian Gulf with GIA correction

Table 3: Summary of global mean sea level trends (ICZM-CCSLR, 2014)

Data set	**Trend (mm/year)**	**Period**	**Technical comments**
Global data from Church and white (2011)	1.7 ± 0.2 1.9 ± 0.4	1900- 2009 Since 1961	Global estimation with GIA correction
TOPEX and Jason Altimeter (Cazenave) ***at al*****., 2010**	3.4 ± 0.4	1993 – 2009	Global estimation with GIA correction
IPCC AR5 (2013)	1.7 ± 0.20	1901 – 2010	Based on tide gauge records and additionally on satellite data since 1993
IPCC AR5 (2013)	3.2 ± 0.40	1993 – 2010	Based on tide gauge records and on satellite data

According to the report current level of flooding in Qatar will increase with the increase in sea level rise for the two climate change scenarios 2040 and 2100 (ICZMP-CCSLR, 2014). This increase is associated with the increase in the impact on both socio-economic and natural systems.

2.3.2 The Integrated Coastal Zone Management Plan for Ecological Assessment 2014 (ICZM-EA, 2014)

Integrated Coastal zone management plan for the state of Qatar, Ecological Assessment (ICZM-EA) is another integrated coastal zone management plan study conducted by Ministry of Municipalities and Urban Planning (MMUP). This study addressed the ecology of the coastal area. ICZMP-EA was developed to evaluate the state of different ecosystems at the shoreline of Qatar, mainly the Eastern side where dramatic changes are taking place due the huge and rapid urbanization. Mangrove ecosystems were included in the areas studied. The assessment of mangrove ecosystems by literature review, local expert views, and the use of satellite images to evaluate the shoreline, shows a dramatic change in mangroves, while the use of remote sensing to detect the changes quantitatively gave opposite results: the latter detected an increase by 80% in mangrove area from 2006 to 2013 (ICZMP-EA, 2014). This contradiction was explained by different factors: the lack of base line information about the coastal ecosystem; the use of only two satellite images, making change detection difficult; the use of remote sensing for marine ecosystem evaluation, which is still not accurate; seasonal changes, however, were not considered, since they require more time and effort. In summary, fast and dynamic change in coastal areas requires a broader temporal extent that should be analyzed to give more accurate detection of the changes in shoreline ecosystems (ICZMP-EA, 2014).

2.4 The model used to estimate impact of sea level rise on mangroves

This study used a high resolution Digital Elevation Model (DEM) derived from data Lidar (ExxonMobile). Mangrove area is extracted from satellite data and overlayed over the elevation layer derived from DEM. With this integration, different scenarios for sea level rise can be studied, and potentially threatened areas can be identified. The numerical modeling helps in understanding the impact of sea level rise on wetlands (Fagherazzi *et al.*, 2012)

Remote sensing is a technique that has been used for decades. This software has different uses, one of which is to make an accurate mapping for aerial photos, resulting in data that helps in digital analyzing and classification (Wilkie and Finn, 1996). Moreover, this application can analyze areas of land and sea that are inaccessible (Guidon and Edmonds, 2002). Mangroves occur at inaccessible areas, so remote sensing is needed for their assessment and monitoring programs (Luca *et al.*, 2002).

2.5 The model used in vulnerability assessment

The response of humans and the environment to climate change can be analyzed using vulnerability and adaptive capacity concepts (Adger *et al.*, 2007). Natural systems such as habitats and species were recently included in vulnerability assessment, and so for mangroves ecosystem (Glick and Stein, 2010). Vulnerability is assessed by three main factors: exposure (the amount and duration of changes applied to the system), sensitivity (the natural characteristics of species that will be affected: for example, in mangroves it is the reduction in productivity, biodiversity, and resilience), and adaptive capacity (the ability of the system to overcome the climate change with minimum impact) (Glick and Stein, 2010). Both exposure and sensitivity to stress will induce harm; however, the adaptive capacity tends to reduce the harm. The combination of these three factors, exposure, sensitivity, and adaptive capacity, represents the potential of climate change to affect the system: in our study, the mangrove the adaptation can be through resistance and resilience. Resistance represents the ability of our system to withstand the changes and continue doing its function, while resilience is the ability to absorb and overcome the disturbance. So the adaptation process is based on improving resilience and minimizing the vulnerability (Adger *et al.*, 2007).

This study is different from the recent studies in Qatar (ICZM-CCSLR, 2014; ICZM-EA, 2014) by addressing the impact sea level rise on mangrove in more depth. The study gave numerical values for the impacted areas by sea level rise at different scenarios. It addressed the changes in mangrove area through wide historical time span. At last it has suggested methods to enhance the growth of mangroves and reduce their vulnerability, which was absent in the recent studies done in Qatar.

Chapter 3

3 Methodology

3.1 The study area

Mangroves are located in many coastal areas of Qatar, but mainly on the north eastern coastal (ICZM-EA, 2014; ICZM-CCSLR, 2014; Gamal and Abdel-Razik., 1993; Abdel-Razik, 1991). The distribution map of the mangrove ecosystem is shown in Figure 5, while the estimated areas of mangroves are shown in Table 4. The data shown in table 4 was collected in the recent study of MMUP using remote sensing, field survey, and orthoimage interpolation. Moreover it is considered as the first record for the area of mangroves in Qatar (ICZMP-EA, 2014). The MMUP study clearly shows that over 65 % of mangroves are located at Al Khor and Al Dhakhira (ICZM-EA, 2014; ICZM- CCSLR, 2014). Therefore, the focus of this study will be mainly in this area.

Qatar peninsula is characterized by a rocky and conglomerate land-form, while soil is varying from calcareous sandy clay and loam to clay-loam including a grayish sub soil (El-Ghazaly *et al.*,a 1993). Current and waves are two factors that are responsible for sediment movement in the shallow western part of the Arabian Gulf. The shoreline orientation in Al Khor is parallel to northwesterly Shamal winds. This generates a strong shoreline drift from north to south, and result in beaches with hook-shaped spits at their southern end (Rankey and Berkeley, 2012). The beach spits consist of cross-bedded, coarse, bioclastic grainstone, and admixed quartz sand.

The characteristics of sediments at subtidal area are soft, grey, reduced, peloidal, and muddy (Shinn, 1973). Although muddy subtidal sediments result in long-term progradation, some beach deposits are underlying intertidal and supratidal deposits (Shinn, 1973). As a result of those geomorphic observations, the beaches are migrating landward (Shinn, 2010). This migration of beaches and spits (Shinn, 1973), result in protected lagoon and tidal flats due to the formation of local energy barrier (Rankey and Berkeley, 2012).

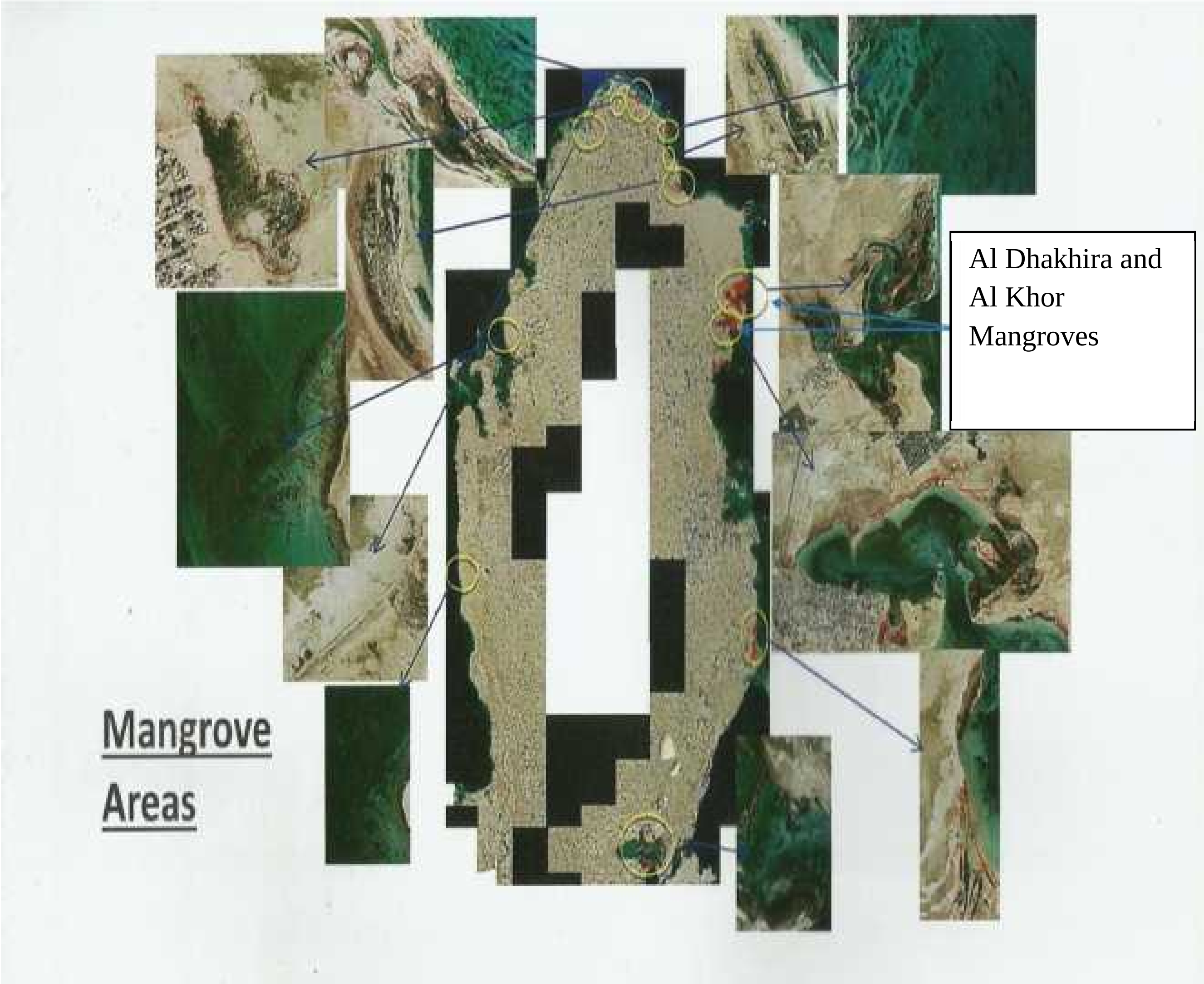


Figure 5: Location of mangroves on Qatar's coast (Satellite photos from MMUP; ICZMP-CCSLR, 2014)

Table 4: Qatar's mangrove area (ICZMP-EA, 2014)

Province	**Location**	**Area (ha)**
East coast	Alkhor and Al Dhakhira	1392
	Simaismah	39
	Al Alia Island	40
	Doha	10
	Al Wakra	112
	Al Messaied	262
West Coast	Main land, Ras Al Abroq*	12
North Coast	Al Jumail*	65
	Al Ruwais*	13
	Ras Al Shendwee	144
	Fuwairit	017
	Al Jasasiyah Beach	48
	RasLaffan	17
Total mangrove area		**2126**

*: Not reported in MOE Sensitivity mapping (2006)

3.1.1 Selection of study area

Al Khor and Al Dhakhira areas are located at the north eastern coast of Qatar at coordinates 25.69°N 51.51°E. Figure 6 represents a satellite image for Al Khor and Al Dhakhira areas with respect to the map of Qatar. *Avicennia marina* is the only mangroves species that exist in Qatar (Kogo, 1986). During the field visit we observed that the mangroves at Al Khor near Cornish area are few and are at serious risk from the discharge of treated waste water. More details about the climate, are shown in appendix 7.1.1.

Ras Matbakh is an area within Al Khor where mangroves exist at higher percentage than that of Al Khor Cornish area. An excess growth of algae was observed at this location. Other places in Al Dhakhira like Eraida and Um Saa contain mangroves that are not as easily accessible as Ras Matbakh. For that reason, the soil analysis within these mangroves and away from mangroves was limited to Ras Matbakh. However, the remote sensing and GIS analysis includes all the regions within Al Khor and Al Dhakhira.

Another area called Simaisma was included in this study. This area is an ideal example of landward migrations of mangroves, because the field observation shows a clear propagation of mangroves into the land. A soil analysis was conducted area to understand the factors behind the healthy status of mangroves and their rapid propagation.

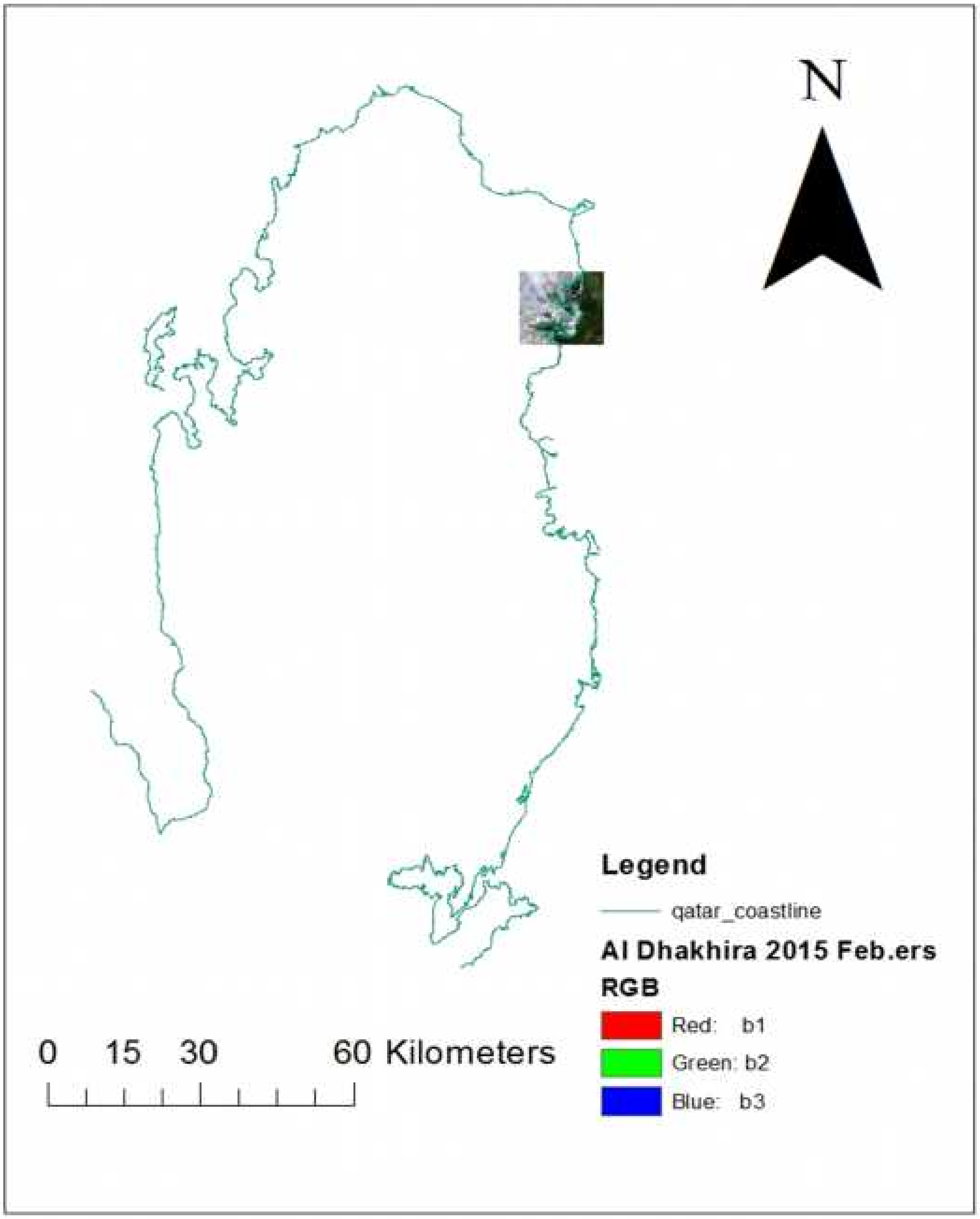


Figure 6: Map of the study area at Al Khor and Al Dhakhira with respect to the map of Qatar

3.2 The data used in this study.

3.2.1 The data used:

- Digital Elevation Model for the study area
- Land Sat Satellite images for Al Khor and Al Dhakhira for the years 1973 , 1996, 2000, 2007, 2014, and 2015

3.3 Details about the used Data and sampling procedure

3.3.1 Satellite images

Satellite images were used to understand the changes in mangrove area over a period of time spanning the years 1973, 1996, 2000, 2007, 2014, and 2015. The images were Landsat satellite images taken from the United State Geographic Survey (http://www.usgs.gov). An unsupervised classification of the study area was used form which we extracted the mangrove layer. Moreover the red band was used to extract the mangrove layer as it shows high reflectance from vegetation cover and in our study it was the mangrove layer.

3.3.2 Digital Elevation Model DEM

The digital elevation model was supplied by ExxonMobil, Doha, Qatar. A polygon shapefile for the study area was given to ExxonMobil so as to extract the DEM for this area from the DEM of Qatar as a whole. This DEM represents the different elevations at various points within the study area. The variation in elevation was from -8.4937 m to 27.88 m. Reclassification of elevations was carried out in this study.

3.3.3 Mangrove layer

Unsupervised satellite image were used to classify mangrove layer. The mangrove class was identified based on the points collected from the field, which were of the same color and pixel number in the satellite image. Thus, the mangrove layer was extracted. This used image was taken in February 2015. The extracted mangrove layer was then intersected with the DEM of the study area.

3.3.4 Soil sampling

Soil samples were collected from different places within the study area. Small glass jars were used for collecting the samples. A mattock was used to acquire the samples. Approximately equal depth was used for all samples. The depth was equivalent to 5 cm which is the length of the digging end of mattock. Random sampling was applied and a zigzagged pathway was followed in collecting soil samples (Myers and Stokes, 2008; Crozier *et al.,* 2010).

The study area was classified into three sections:

Section 1: Al Khor area close to the Cornish.

Section 2: RasMatbakh area.

Section 3: Simaisma.

In Section 1, the collected samples were numbered from 1 to 12. Soil samples were collected from mangrove areas and surrounding land areas. The potential for mangroves to migrate is negated in this area by the presence of the Cornish barrier; therefore the soil analysis was mainly conducted to test the soil quality in the presence of treated waste water. Figure 7 represents satellite image for section 1.

Figure 7: Section 1, Al Khor area near the Cornish (www.Googleearth.com).

In Section 2 the samples were classified as within mangroves and at a distance from mangrove. This section was divided into six different zones. Zones A, B, and C are distant from the mangroves, while zones A’, B’, and C’ are within mangrove areas. In each zone, twelve samples were collected. Zones A and A’ are parallel to each other as are zones B to B’, and C to C’.

Distinct zones were allocated to allow for a better evaluation of the possibility of migration inland, and to check the difference in soil properties at different locations. Zones A’, B’ and C’ are the mangrove areas parallel to zones A,B, and C respectively.

The area in section 3 is an ideal example of landward migration of mangroves. The migrating mangroves were in a healthy state. That samples from this section were collected as control samples, representing the best habitat for mangroves growth.

All the soil samples were analyzed for the following properties:

- Particle size and soil type
- Soil salinity
- Soil pH

The coordinates for the source of each sample were determined using GARMIN GPS (MONTANA 650). The icon “Mark Waypoint” was used to save the coordinates of the location (North “N” and East “E”). Each Waypoint has an associated number, which was written on the plastic gar of the collected sample.

3.4 Data preparation

3.4.1 Developing time-series of satellite images for the change in the mangroves ecosystem between 1973 and 2015

The remote sensing images were classified using unsupervised classification methodology. Pixels were grouped based on their reflectance properties, and this grouping is called a cluster. The cluster was merged into ten various classes that are vary in color. To extract mangrove layer, we selected a specific pixel at which mangroves exit; this pixel was determined using the coordinates associated with samples taken from the mangrove area. At this pixel the color is homogenous and represents the mangrove class. The satellite image was then classified according to this pixel value

.

3.4.2 Accuracy assessment of satellite images.

The method used for the accuracy assessment was quantitative and comparable method. The total number of points was sixty-eight. The points within the mangrove area were thirty-six, and the points outside were thirty-two. After locating those points on the digitized map, we ascertain whether or not they match the mangrove map. The percentage of points matching represents the level of accuracy.

3.4.3 Elevation Classification of DEM

The Digital Elevation Model was classified into six different elevations. This was done to estimate the area of mangroves at different elevations, and to make the analysis process straightforward. Those classes were extracted as separated layers.

After converting the classes into layers, each class has a new designation.

Another classification was done based on the IPCC 2013 prediction for sea level for the year 2100. The estimated sea level rise was divided into two scenarios:

- 0.52 m for the RCP4.5 (Representative concentration pathways, medium prediction)
- 0.74 m for the RCP 8.5 (Representative concentration pathways, high prediction)

The elevation classes and the name of the associated elevation layers are summarized in Table 5.

Table 5: Elevation classes for scenarios of sea level rise after 100 years (IPCC, 2013)

Elevation class for Sea level rise	**Elevation layer**
0 m to 0.52 m	0.52 m
0 m to 0.74 m	0.74 m

3.4.4 Overlaying mangrove layer to different elevation

The Mangrove layer was overlayed with the DEM. For a more specific analysis, each class was intersected with the mangrove layer. This method exhibits details about the area of mangrove at each elevation level.

3.4.5 Analysis of soil samples

3.4.5.1 Soil type

Each soil sample was analyzed for particle size using the “Master size 2000” device. The reference used in soil analysis is the Environmental Study Center at Qatar University. The result appears in three forms, table, graph and histogram. The outcome from this device is the percentage of clay, silt and sand in each soil sample. Soil type was concluded from the combination of the percentages, using the soil type triangle.

3.4.5.2 The pH analysis of soil samples

Soil pH was determined for all soil samples. The procedure used in the Environmental Study Center at Qatar University was used to determine pH. A pH meter from the ESC was used, and was calibrated using two standard solutions: pH 9 and pH 6.5. Ten grams were taken from each sample grams. Ten milliliters of distilled water were added to the ten gram samples. This mixture was shaken for three minutes at a speed of 300 rpm. The mixture was left for two minutes and the PH was measured for water above the soil.

3.4.5.3 Salinity

Salinity was measured for each soil sample. The measurement was based on ESC methodology for measuring salinity. The device used was a “650 MDS”. The method used for pH measurement was applied again; however, in salinity measurement we did not immerse the electrode into water above soil. Instead the 10 milliliters of water above soil was placed in a separate tube, into which the salinity electrode was immersed. Between measurements, the tube and salinity electrode were washed using distilled water. The unit of measure for salinity was g/l.

3.4.6 Converting results from soil analysis to points at the study area.

The data obtained pH, salinity, and soil type from soil analysis was inputted to an Excel sheet. The coordinates of each sample were added and converted to WGS_1984_UTM_zone_39N coordinate system units, so as to match the DEM coordinates and coordinates on digitized satellite images.

The obtained table was saved in the form “CVS (Comma delimited)” form, and then added as data file to Arc GIS. The X and Y coordinates were displayed on the map. The file was exported from event to shape file. In the final form, the attribute table will be accessible and each point will have coordinates (X, Y), salinity, pH, and soil type.

Different symbols were used to differentiate between samples within and samples outside of mangroves.

The type of soil was determined using the soil texture triangle. The intersection between percentages of different soil size is the soil type of the sample. Figure 8 shows the triangle used in determining the soil type.

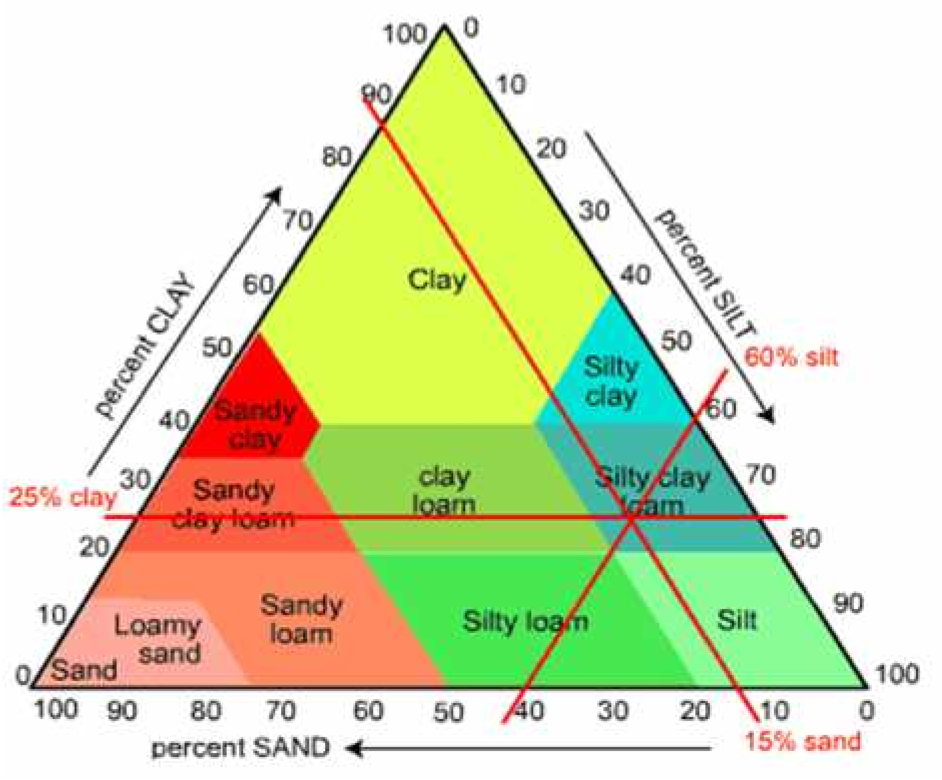


Figure 8: Soil texture triangle (nationalvetcontent.edu.au)

The duration between collecting samples and doing the analysis was around one week. The samples were kept in a fridge. According to Doctor Jassem Al Khayat and the lab instructor at the Environmental Study Center in Qatar University, the delay in doing the analysis will not affect the results of the analysis.

Chapter 4

4 Results and discussion

4.1 Time-series analysis of satellite data

The analysis includes both unsupervised and supervised classification of Landsat data. The unsupervised images were produced using spectral cluster. Time series analysis of unsupervised classification for years 1973 and 2015 are shown in Figure 9 and Figure 10. Comparison of mangrove layer using unsupervised images is a challenging task. Therefore a technique based on supervised classification using field samples was applied. This class was validated by points taken during field visit. More details about mangrove layer extraction from unsupervised images were described in section 3.4.1. The mangrove layers during the years 1973 and 2015 are shown in Figure 11 and Figure 12.

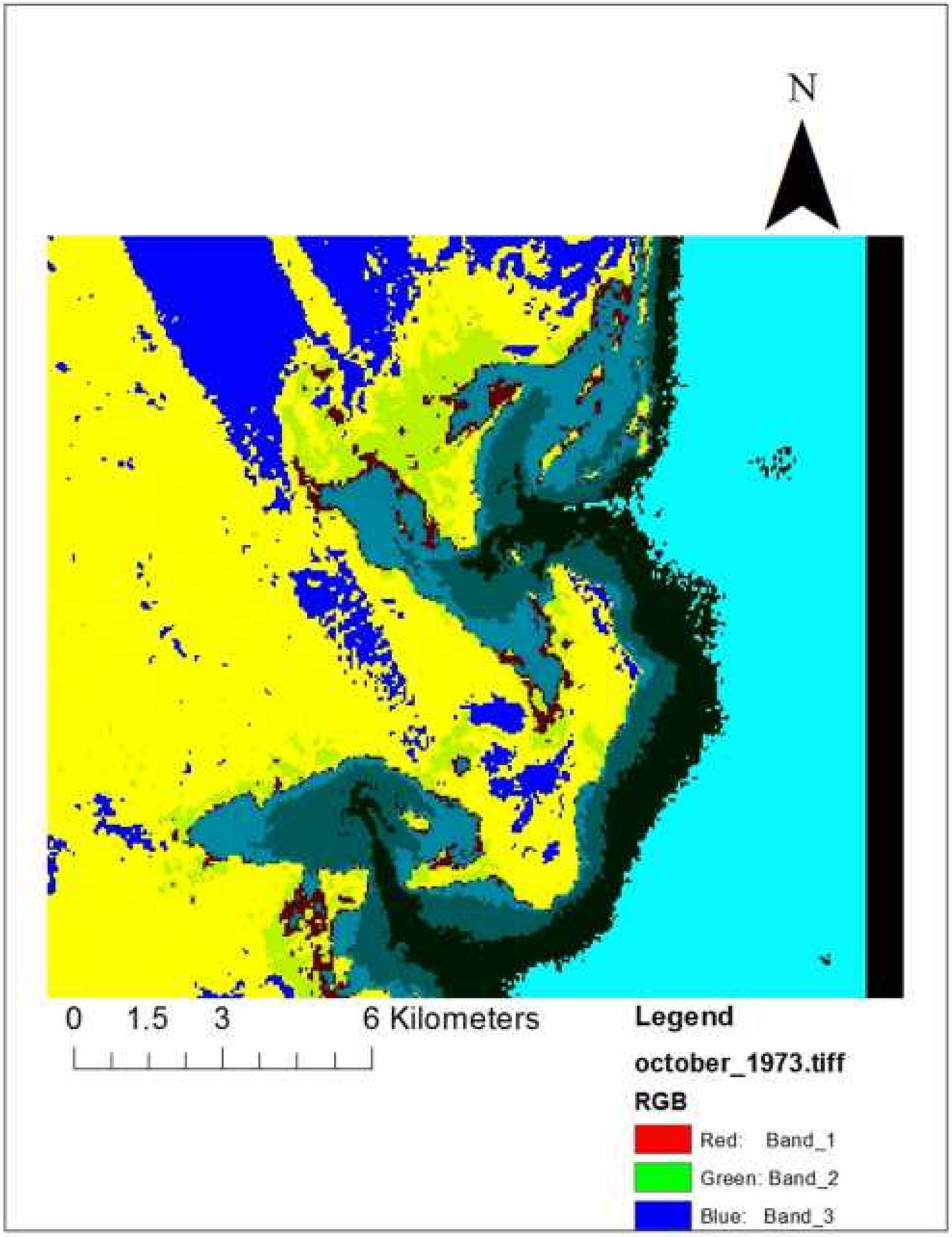


Figure 9: Unsupervised image for the study area (October 1973)

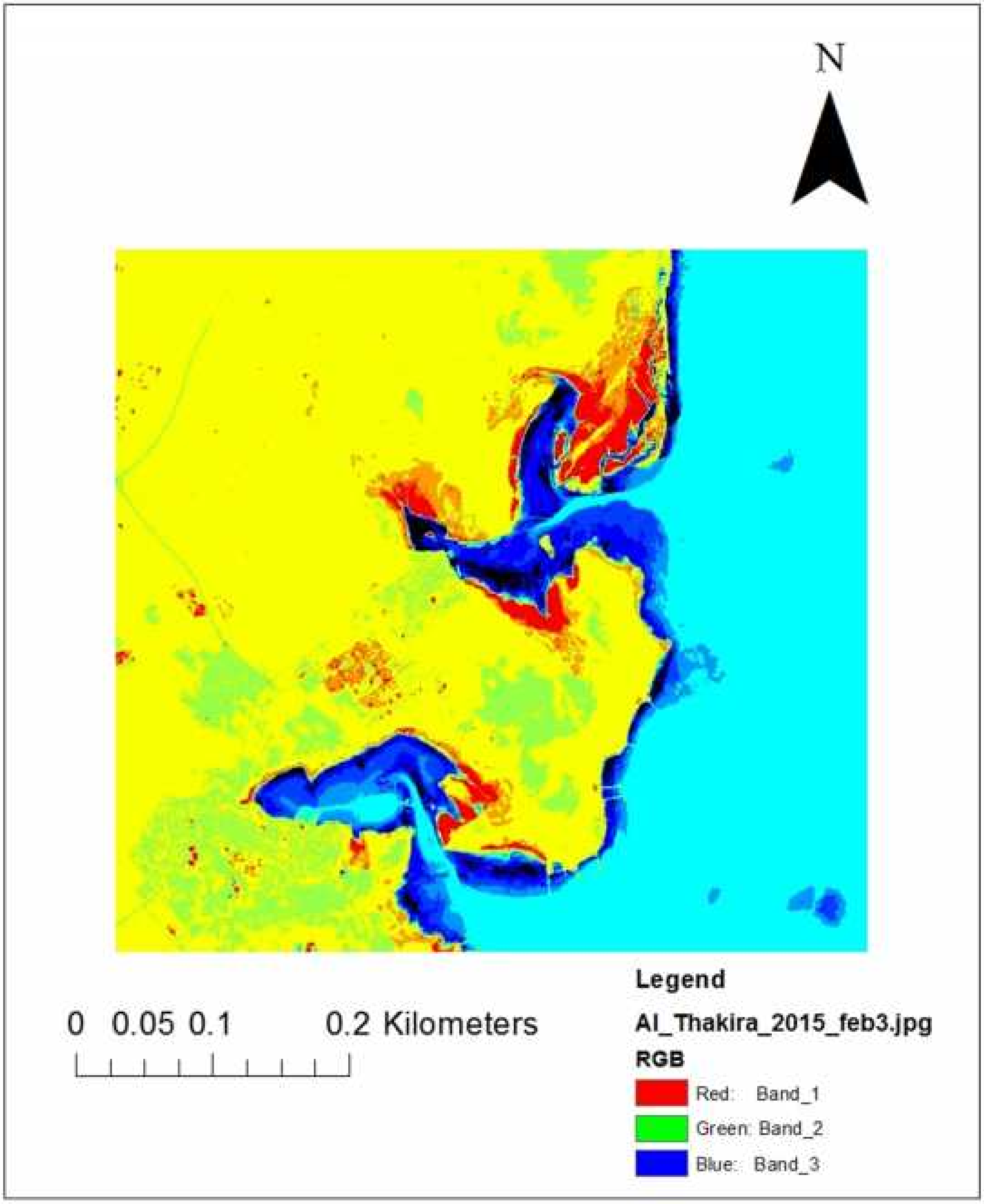


Figure 10: Unsupervised image for the study area (February 2015)

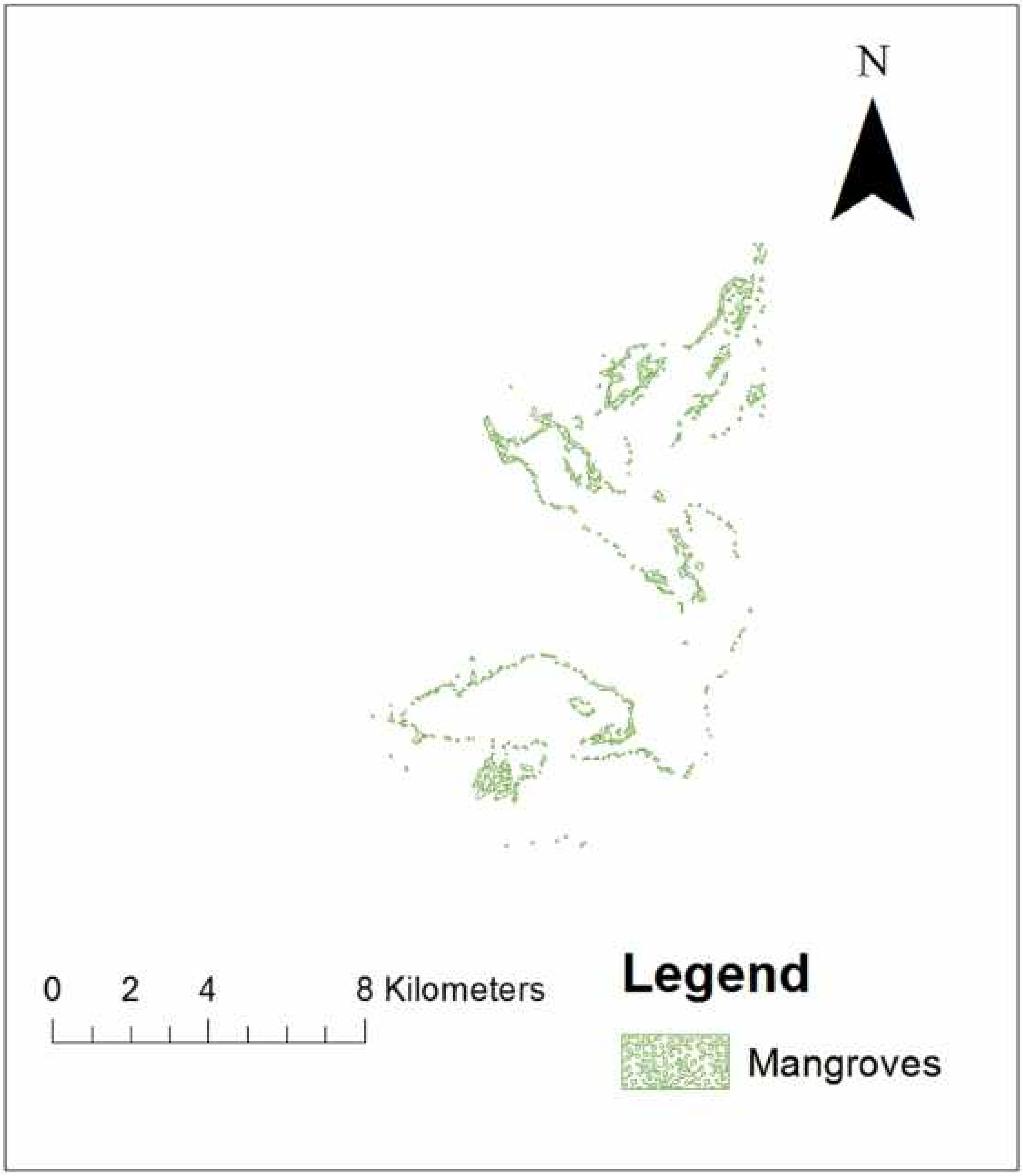


Figure 11: Spatial distribution of mangroves (October 1973)

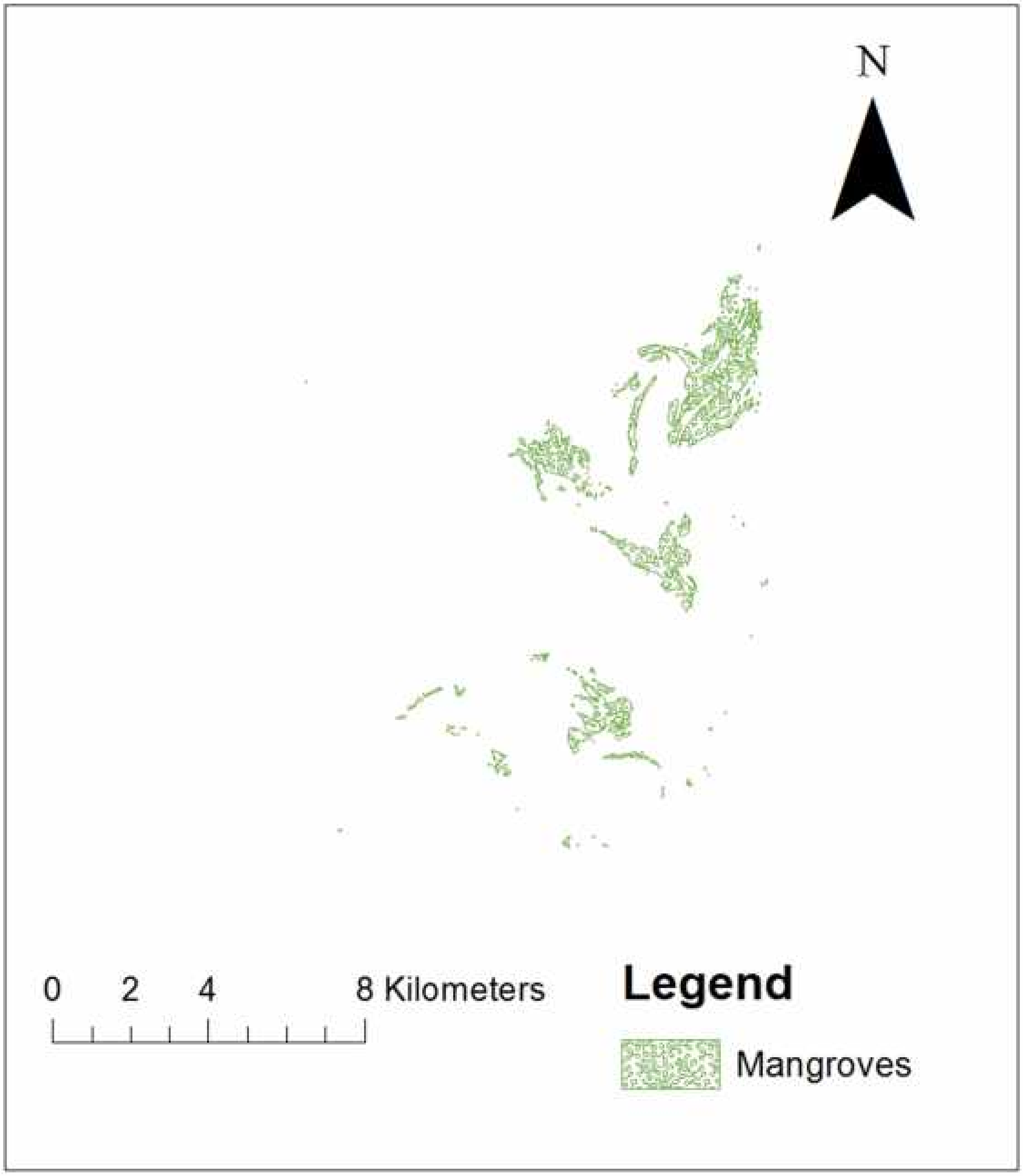


Figure 12: Spatial distribution of mangroves (February 2015)

Comparative assessment of mangroves distribution clearly indicates that the mangrove layer is increasing. Changes of the geographic extend was analysed based on 2015 image. Table 6 and Figure 13 shows the variation in mangrove areas between the years, 1973, 1996, 2000, 2007 and 2015. It is clear that mangrove is increasing where that total area increased by two fold between the years 1973 and 2015. There is a decrease in mangrove area during 2007. However it was recovered in later years. This observation was also reported by the recent study of Ministry of Municipalities and Urban Planning (MMUP) (ICZM-EA, 2014). Further, Al Khayat reported that the mangroves area is at 797.6 ha (Al-Khayat and Balakrishnan, 2014). This result approximates the finding of this study. The increase in mangroves between the years 1973 and 2000, followed by a decrease between the year 2000 and 2008 was also observed in another study for Al Dhakhira area (Balakrishnan, 2012). Therefore the first research question is answered and it is clear that mangrove area is increasing with years. The increase of mangrove may be due to its designation as protected state. The year of declaration was in 2006 under decree number 6 (Protected Area Action Plan 2008-2013).

Table 6: percentage of mangroves with respect to the year 2015

Year of Landsat satellite data	Area of mangroves (ha)	% with respect to 2015
2015	783.373	100
2014	716.540	91
2007	386.843	49
2000	704.791	89
1996	396.710	51
1973	430.104	55

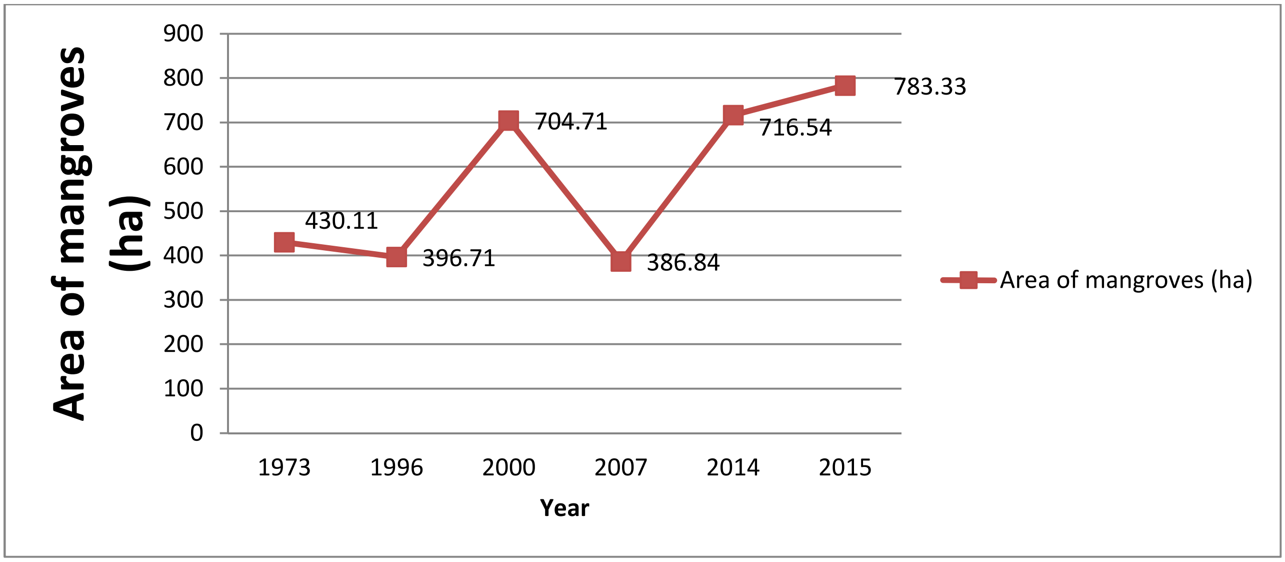


Figure 13: Graphic representation for variation of mangroves area with respect to different time series

4.2 Accuracy assessment of classification.

Validation of the classification using field investigating. The validation of satellite images using mangrove area shows a high level of precision. Table 7 represents percentage of points taken from field visit and intersecting mangrove area on satellite images.

Table 7: Number and percentage of points matching both field study and digital mapping of study area

Location of points	Total Number of points from field study	Total number of points on map	Percentage of points accuracy
Within mangrove area	36	24	67%
Away from mangrove area	32	28	88%
Total	68	52	76%

Table 7 shows the high precision of satellite images for areas away from mangrove. 88% of the points taken outside mangrove area were mapped as points outside the mangrove area.

Figure 14 and Figure 15 represents the percentage of accurate points, and overall accuracy assessment respectively. Three to four of the points were accurate. This method in assessment of accuracy shows a good accuracy with 3 out of 4 points matching both field and satellite mapping.

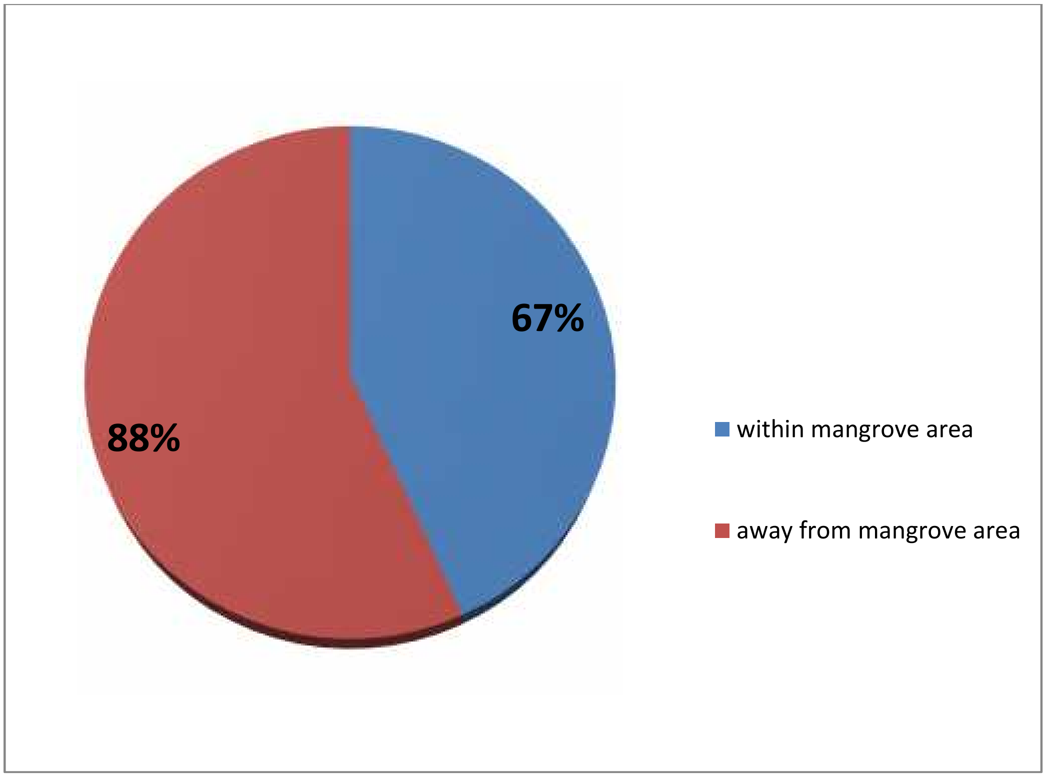


Figure 14: Percentage of accurate points within mangroves and outside mangrove areas

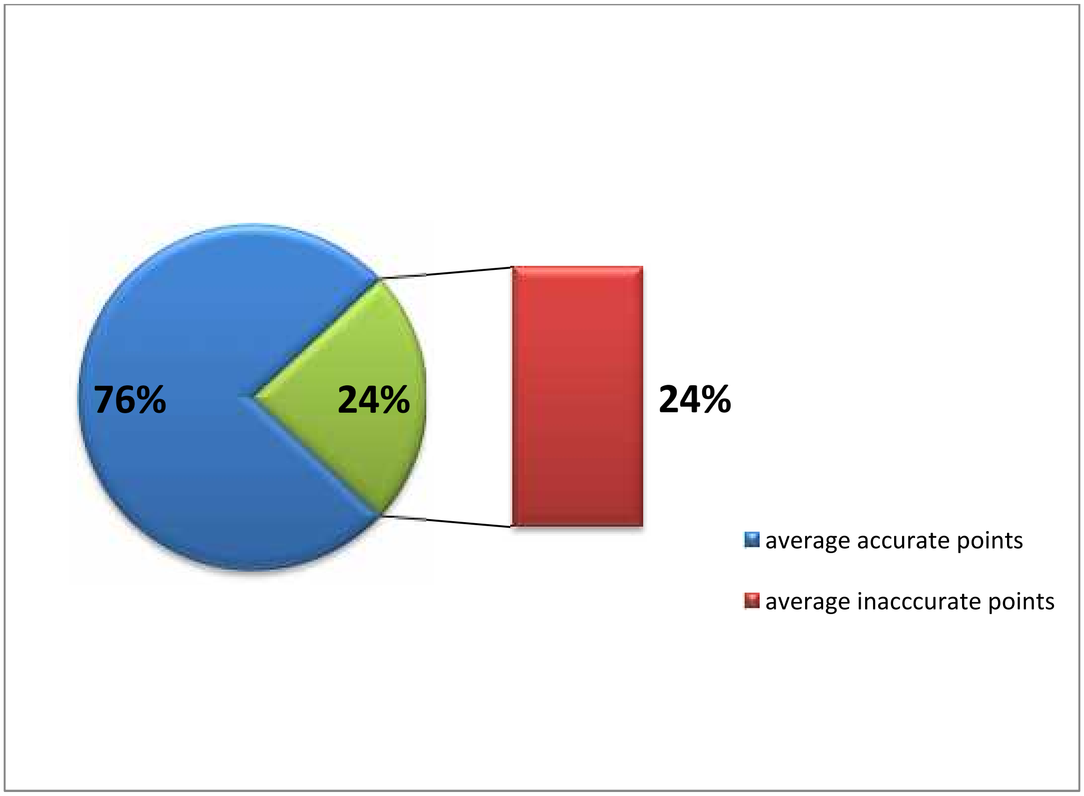


Figure 15: Percentage of accuracy for all points in the study area

4.3 DEM classification

The digital elevation model was reclassified into 6 layers to extract coastal areas. Figure 16 represent the map of the 6 layers. Reclassification of elevation model was important to do the sea level rise model. Each elevation was intersected with mangrove layer to identify the area that may be affected by potential sea level rise. Most of the areas are between 0 and 3 meter elevation. The dominance of low lying area shows that there is high risk of inundation with even 1 meter sea level rise. The rest of layers with the impacted area by sea level rise are shown in Table 8 and Table 9.

Table 8: : Area for each elevation layer intersecting mangrove layer, and their percentage with respect to total area of mangrove layer intersecting all elevation layers.

Mangrove intersecting different elevations	**Area (ha)**	**% with respect to total mangrove area**
0 m elevation	59.37	7
1 m elevation	557.05	64
2 m elevation	153.43	18
3 m elevation	97.16	11
4 m elevation	2.29	0
5 m elevation	0.70	7
Total mangrove area intersecting the 6 elevation layers	869.32	100

Table 9: Shape Area for RCP 4.5 and RCP 8.5 elevation layers intersecting mangrove layer individually, and their percentage with respect to total area of mangrove layer intersecting all elevation layers.

Mangrove intersecting different elevations	**Shape Area (ha)**	**% with respect to total mangrove area at 5 classes**
0.52 m elevation layer	291.23	34
0.74 m elevation layer	393.24	45

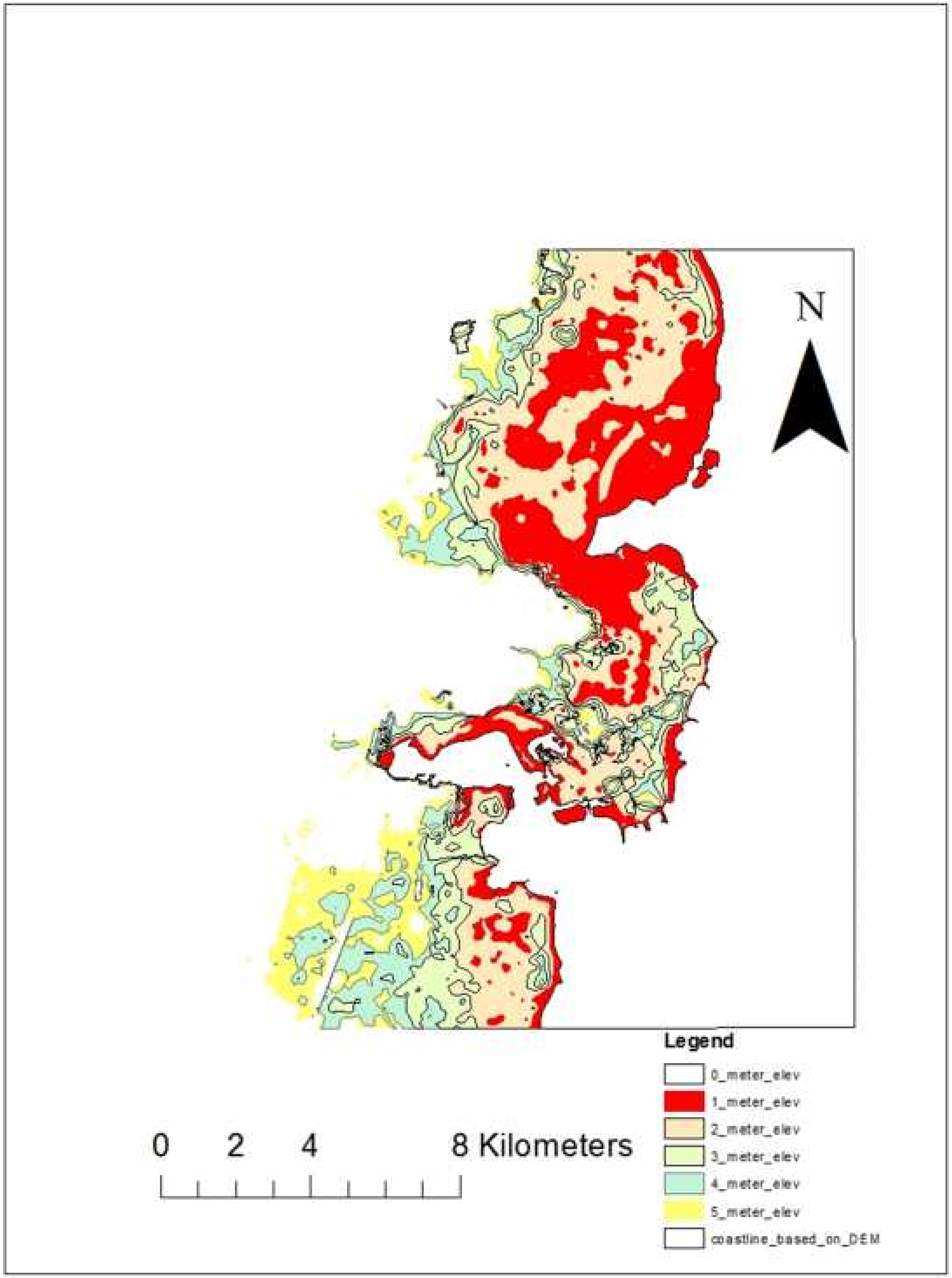


Figure 16: Map of the classified elevation layers of Al Khor and Al Dhakhira area.

4.4 Assessment of potential sea level rise risk to mangroves

The intersection of mangroves and each elevation layer was produced using Arc GIS 10.3. Figure 17 shows areas of 1 meter elevation layer intersecting mangrove layer. The map of (0-1) m elevation layer is the most important one, as it depicts the area of highest probability of inundation with 1 meter sea level rise.

The results indicate that most mangrove layers exist between 0 and 1m elevation. The 1 meter layer which is between 0 meter and 1 meter elevation present 64 % of the total mangrove area. Figure 17 shows that most mangroves at 1 meter elevation will be highly affected by sea level rise. The area of mangroves intersecting different elevation layers are shown in Figure 18, while maps for mangrove area intersecting 0 m and 2 m elevation are shown in Appendix Figure 1 and Appendix Figure 2 respectively. Mangroves at elevations more than 1 meter will be less affected.

A more detailed subsequent analysis was conducted at sub meter elevation range. The first layer was from 0 to 0.52m, while the second layer was from 0 - 0.74 m. The intersection between mangroves and those layers is shown in Figure 19 and Figure 20 respectively. Moreover the percentage of those layers with respect to total mangrove layer intersecting different elevations is shown in Figure 21.

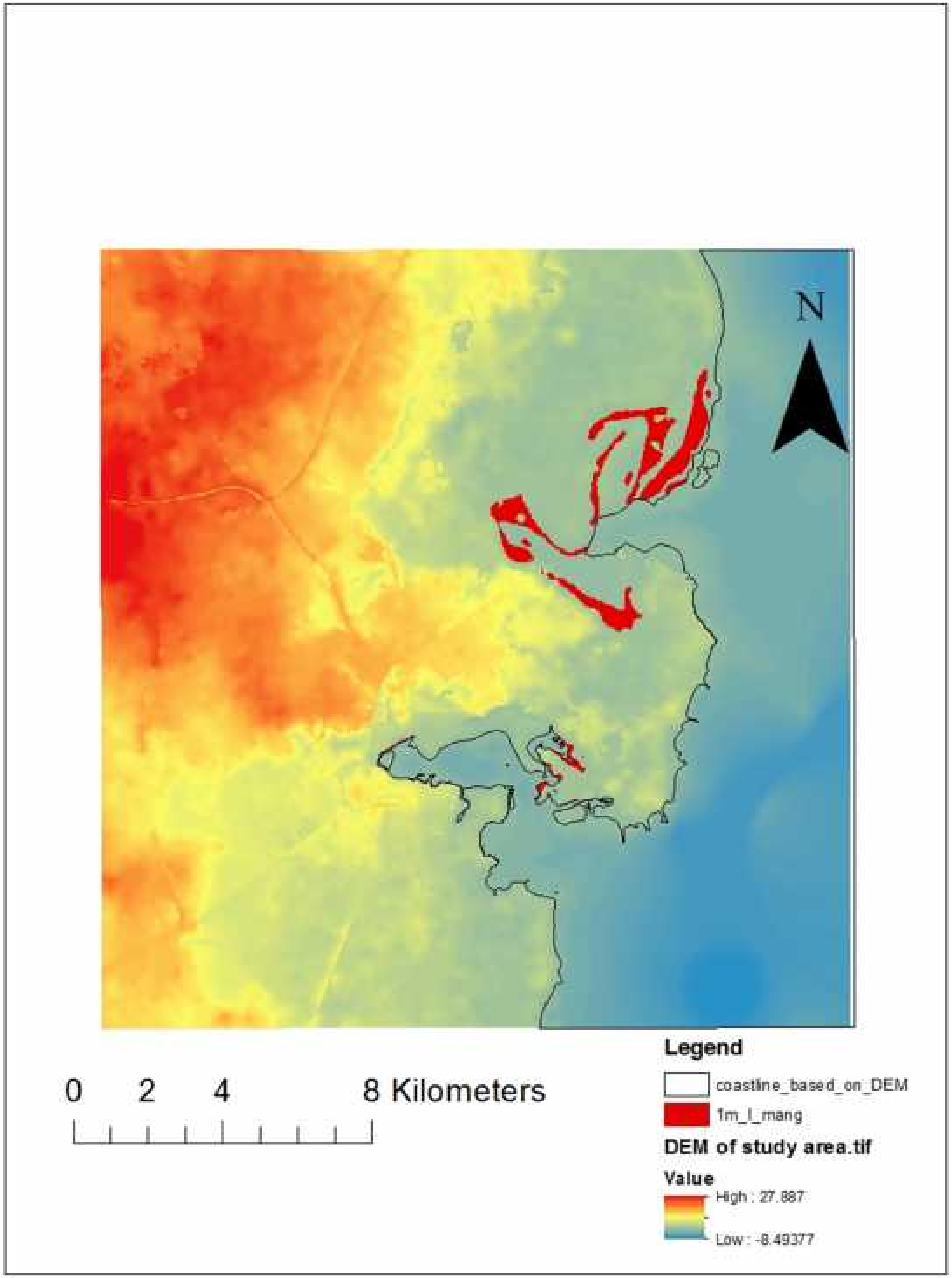


Figure 17: Map mangrove layer intersecting 1 meter Elevation

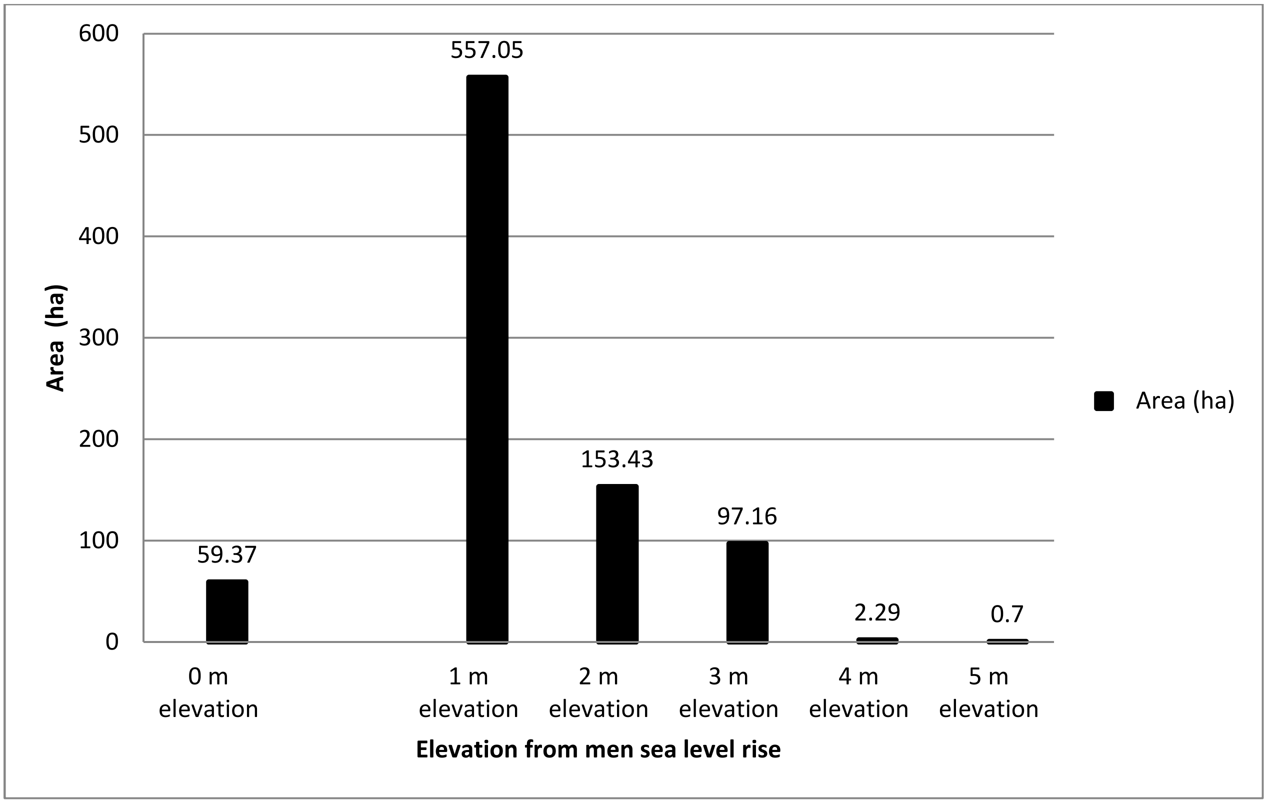
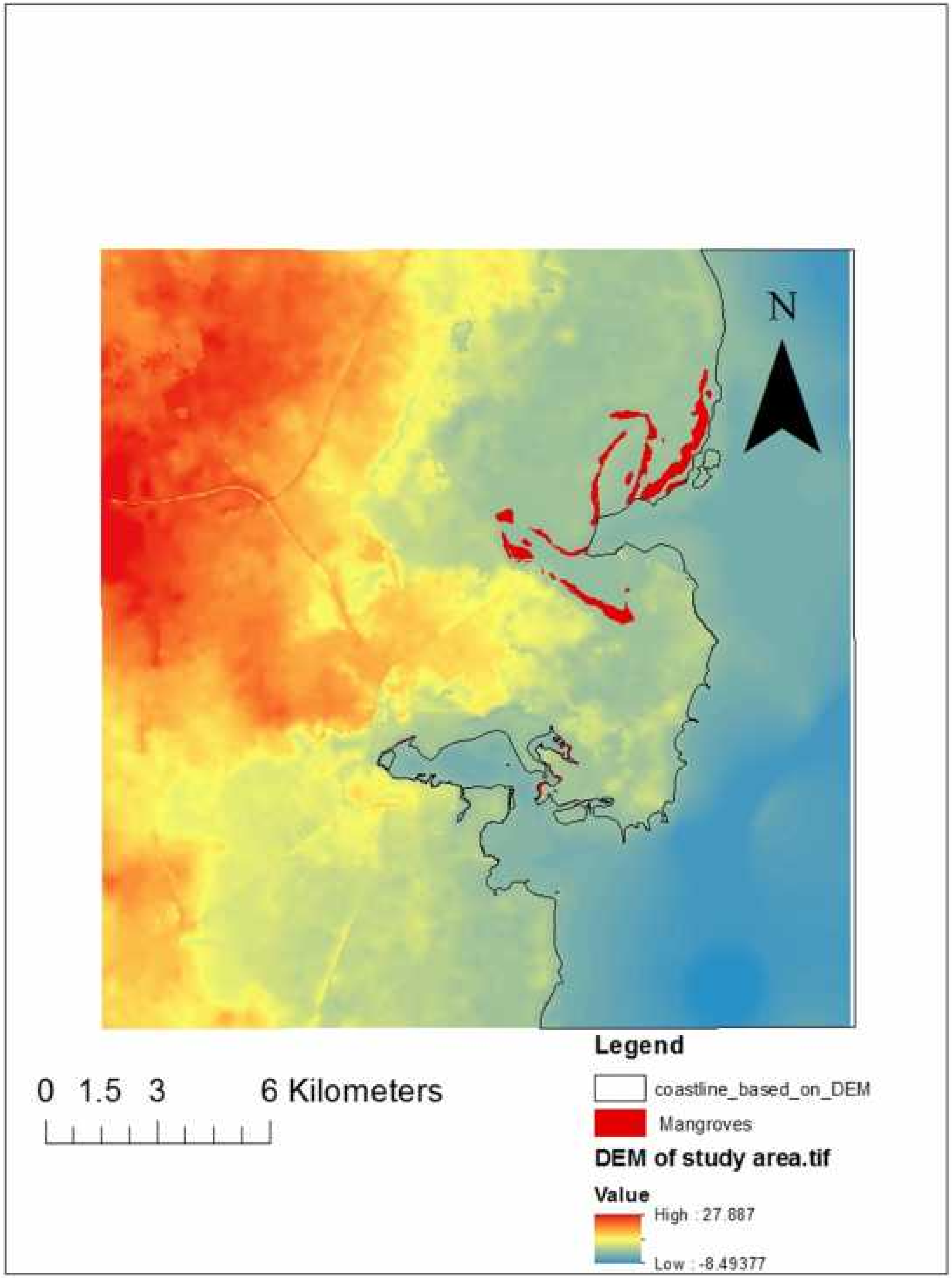


Figure 18: Area of mangrove layers intersecting different elevation levels with thier percentage total area of mangroves.


N
0 1.5 3 6 Kilometers
Legend
coastline_based_on_DEM
Mangroves
DEM of study area.tif
Value
High : 27.887
Low : -8.49377

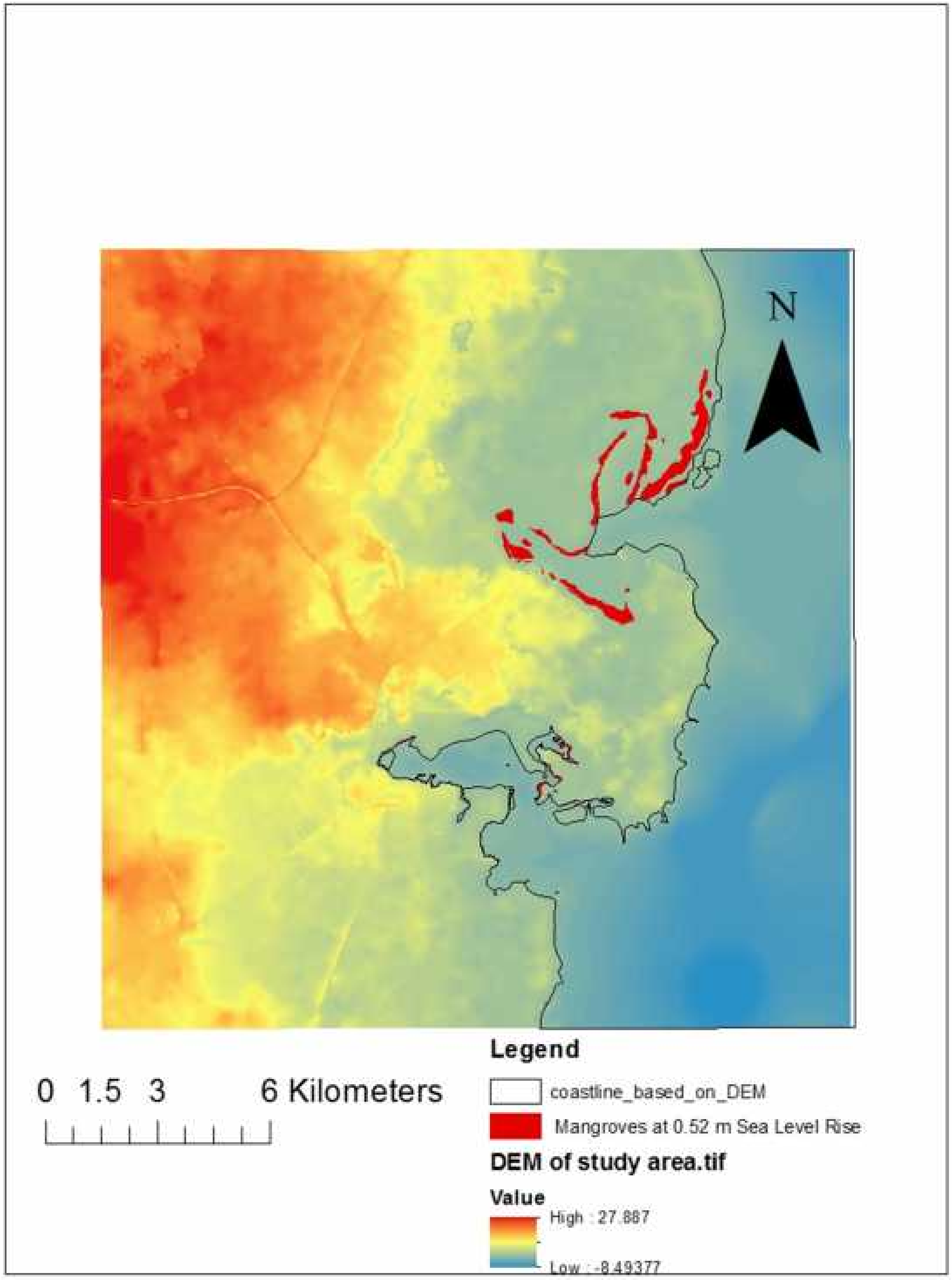


Figure 19: Map of mangroves intersecting 0.52 m Sea Level Rise

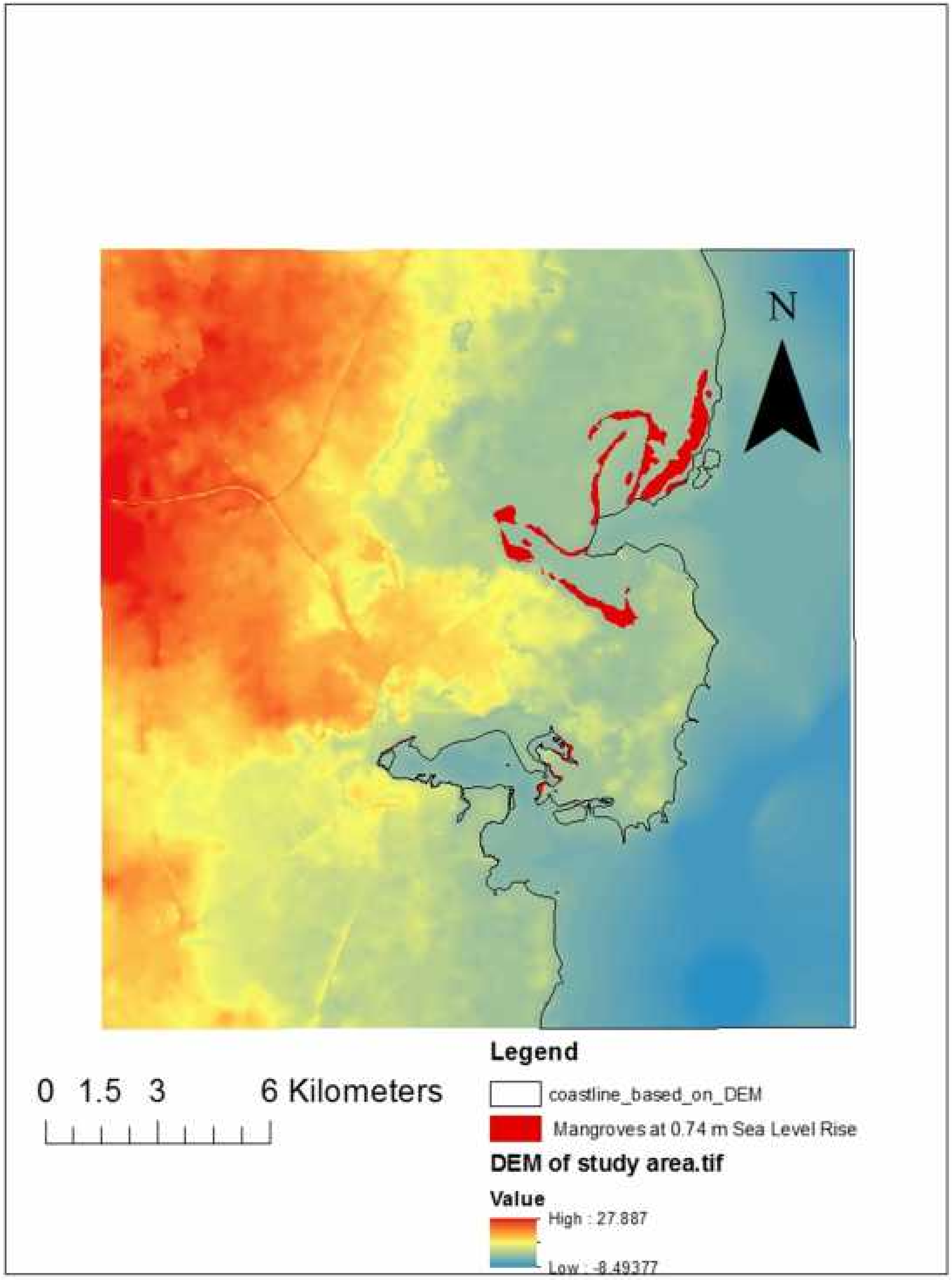


Figure 20: Map of mangroves intersecting 0.74 m elevation layer

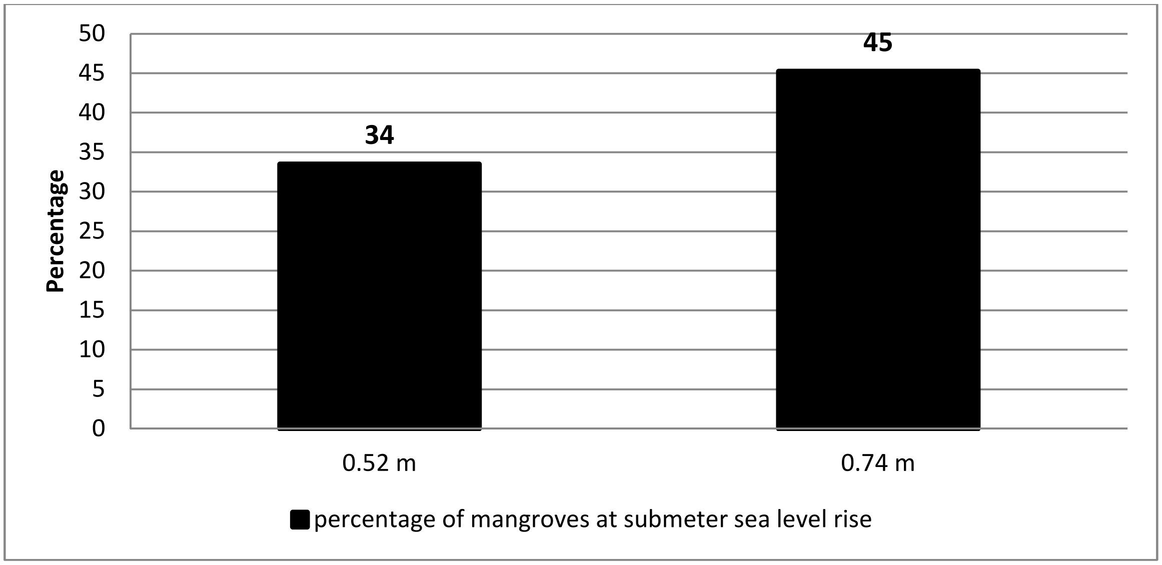


Figure 21: The percentage of mangroves endangered by sea level rise scenarios 0.52 m and 0.74 m Sea Level rise.

The result of the analysis as per IPCC scenarios shows that 45% of mangrove area will be affected by a rise of 0.74 meter, while 34 % will be affected by rise of 0.52 meter. This result is also consistent with the MMUP (Ministry of Municipalities and Urban Planning) recent study (ICZM-CCSLR, 2014).

Analysis answers the second research question which is the area of mangrove that may be subjected to potential sea level rise. Endangered areas will be 45% and 34% for sea level rise by 0.52 m and 0.74 m respectively. The result obtained in this study is important and give public, decision makers and manager more information to develop better strategies for and mitigate the impact of sea level rise (Ellison, 2012). The inundation that results from sea level rise will negatively impact mangroves; death of seedlings is one of the negative impacts (Sanders *et al.*, 2008; Rivera-Monroy *et al.*, 2011).

The impact of tidal inundation will reduce the photosynthesis and growth of mangroves (Lu *et al.*, 2013). Therefore the endangered areas by sea level rise are highly vulnerable and will be under the risk of death.

4.5 Soil analysis

As indicated in methodology soil samples were taken from three different sites in the study area.

4.5.1.1 Soil samples from section 1 (Al Khor area near the Cornish)

Salinity, pH and particle size were analyzed for the three sites. Results from first site analysis are shown in Figure 22. Appendix Figures 3 and Appendix Figure 4 represent mapping of salinity and soil particle size in section1.

Table 10: Measurements of pH, salinity and soil type with the coordinates of samples collected from section 1(Al Khor)

Samples from section 1	X. coordinate(E)	Y coordinate(N)	pH	Salinity(g/l)	Clay %	Silt %	sand %	soil type
1	550632	2841482	8.26	5.32	11.58	67.24	21.18	Silt Loam
2	550570	2841443	8.29	6.11	31.36	57.76	10.88	Silty Clay Loam
3	550629	2841456	8.20	7.39	10.73	60.68	28.59	Silt Loam
4	550637	2841491	8.28	3.63	8.94	46.21	44.85	Loam
5	550651	2841444	8.34	20.95	4.84	23.01	72.15	Sandy Loam
6	550699	2841434	8.38	6.64	0.49	2.25	97.26	Sand
7	550612	2841472	8.49	4.04	1.32	3.78	94.9	Sand
8	550630	2841490	8.38	6.15	1.07	2.41	96.52	Sand
9	550636	2841492	8.24	5.83	10.66	65.67	23.67	Silt Loam
10	550641	2841484	7.95	15.04	11.95	65.59	22.46	Silt Loam
11	550628	2841484	8.45	14.72	7.61	66.35	26.04	Silt Loam
12	550603	2842468	8.20	11.65	1.65	12.69	85.66	Loamy Sand
13	550612	2841472	8.17	3.77	0.63	7.72	91.65	Sand
14	550630	2841490	8.17	8.76	8.28	67.35	24.37	Silt Loam

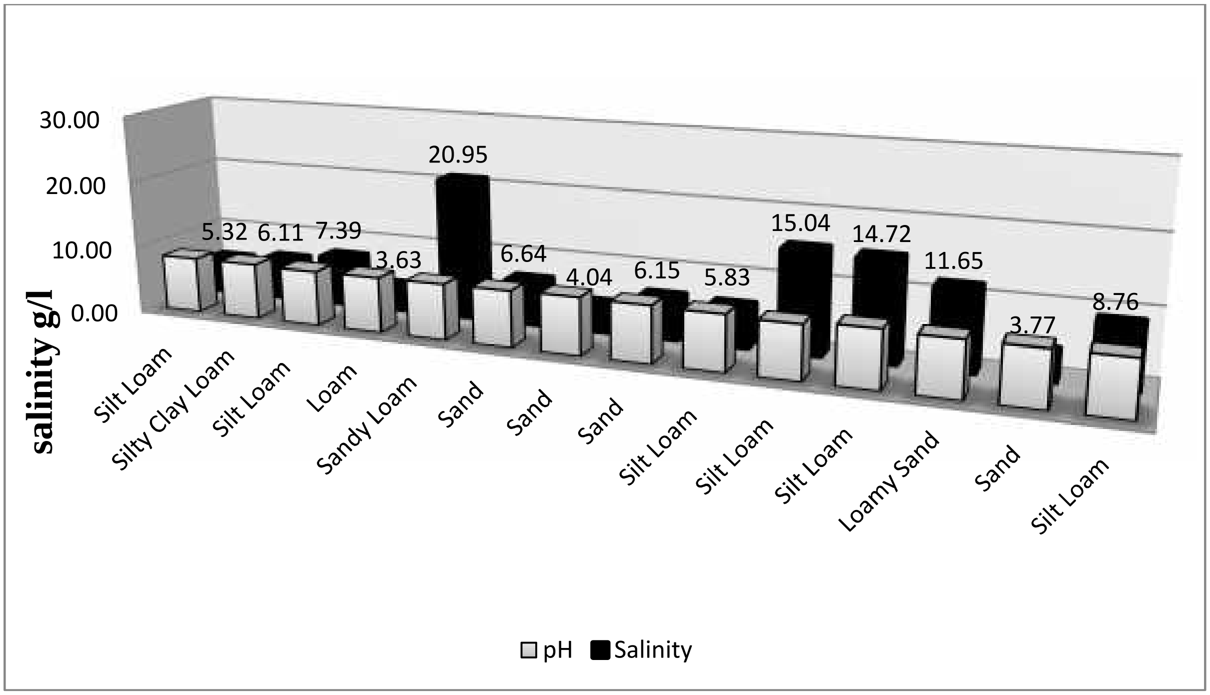


Figure 22: 3D column for pH, Salinity, and soil type at section 1

The pH value varies between 7.95 and 8.40. This variation is small and can be neglected; pH is considered constant. On the other side the salinity was variable. It has a minimum 3.6 g/l and maximum 20.95 g/ l. This variation in salinity was expected due to the continuous discharge of treated waste water. This discharged water reduces the salinity of sea water. This causes increase in water level covering mangroves are. This may cause the death of mangrove plants in the area.

The dominant soil type in the area was silt loam. The finding is a clear indication that permanent inundation increases the vulnerability of mangroves to sea level rise.

4.5.1.2 Soil analysis of Ras Matbakh area

This section as selected to assess the landward migration of mangroves. More details about soil analysis were described in section 3.3.4. The average salinity, pH and dominant soil type for samples outside mangrove and within mangrove respectively is shown in Figure 23 and Figure 24. More details about the Soil type, pH, and salinity for samples in zones A, B, C, A', B', C' are shown in Appendix Table 1 to Appendix Table 7 respectively.

The locations of collected samples for soil type, Salinity, and pH are shown in Appendix figure 5, Appendix figure 6, and Appendix figure 8 respectively.

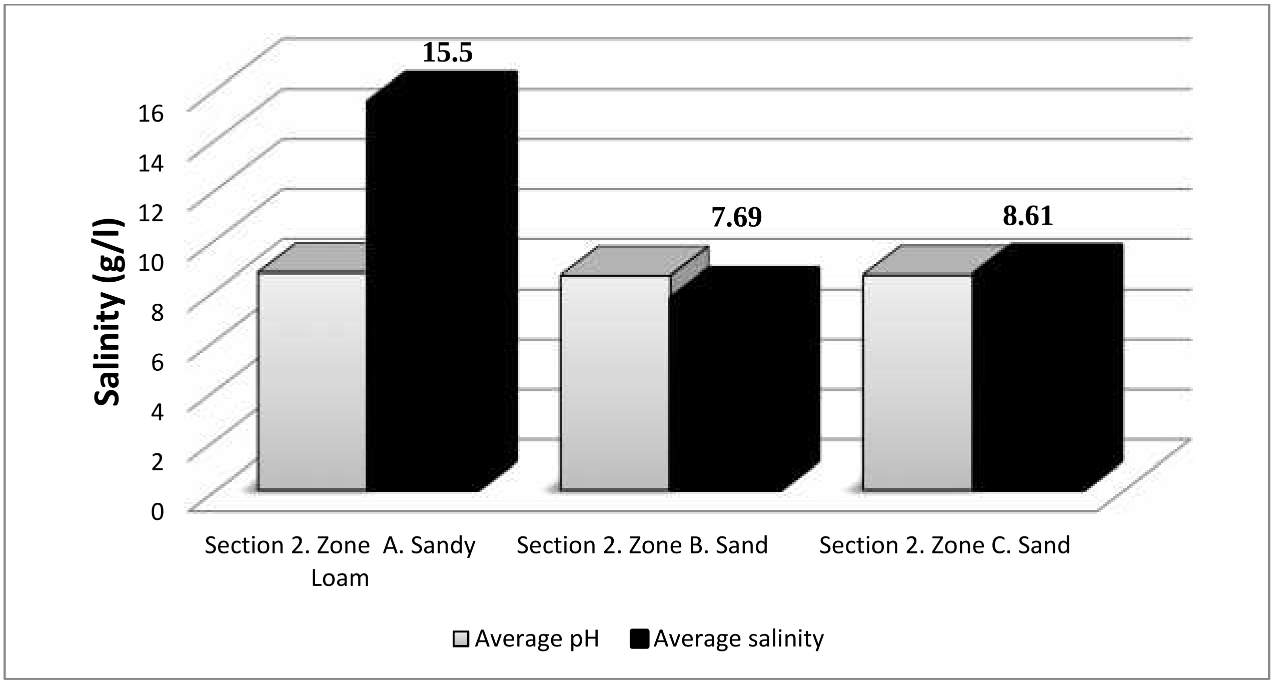


Figure 23: Salinity, pH and soil type in section 2. Zones A, B and C.

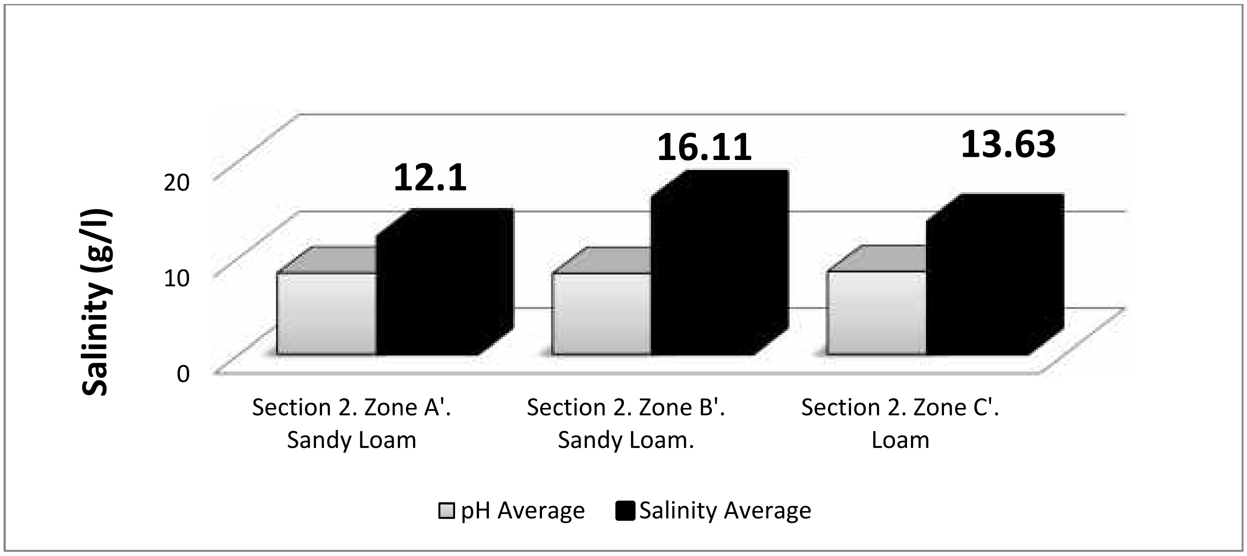


Figure 24: Salinity, pH and soil type in section 2. Zones A', B' and C'.

The pH values of the sample sides in section 2 were uniform at each sample location between 7.82 and 8.88. Recent study at Al Khor and Al Dhakhira shows similar range of pH, averaging 8.3 (Al Khayat and Balakrishnan, 2014). However the salinity value observed in the study were different from other studies. The mean annual salinity for Al Khor, Al Dhakhira, and Semisama was 43.6, 45.6 and 44 respectively (Al Khayat and Balakrishnan, 2014). Average salinity for the study area was reported around 45 g/l (El Ghazaly *et al.*,a 1993; El Ghazaly *et al.*,b 1993). This difference in salinity between this study and the other studies needs more investigation. However, the salinity is still within the accepted range for the growth of mangroves which is below 50 g/l (Ball, 1988). The similarity in salinity may support the possible migration of mangroves to non mangrove area. On the other side the soil type in zones A and A’ is identical which indicates a favorable migration as response to sea level rise. Sand is the dominant soil types in zones B and C, while sandy loam and Loam are the dominant soil types in zones

B’ and C’. The mangroves can grow in sandy substrate, where mud content is greater than 16.5%. (Al Khayat and Balakrishnan, 2014). Accordingly the migration to zones B and C may be favorable since the mud content is above the required level.

4.5.1.3 Soil analysis of Simaisma area

The soil sample analysis shows that all the sample point contains same type of soil, silt loam. The field observation shows a healthy and well propagating mangrove species. The result of soil analysis are shown in Figure 25

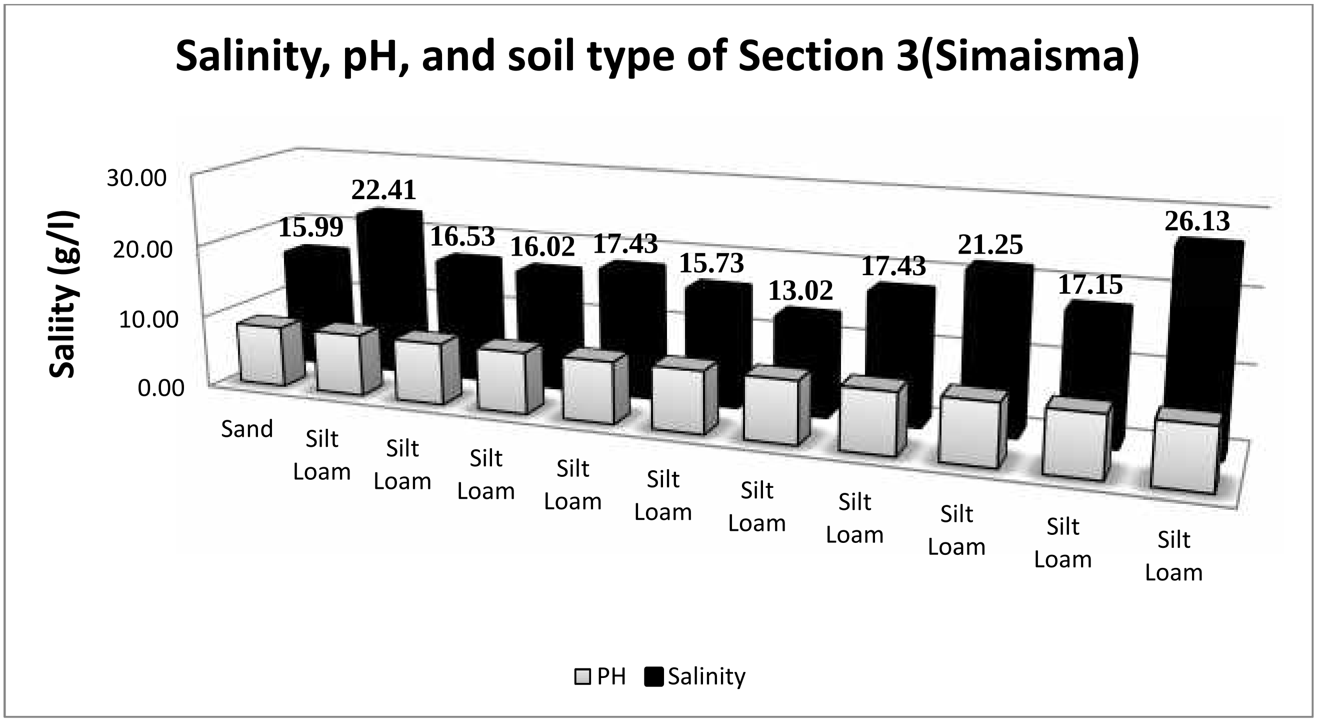


Figure 25: Salinity, pH, and soil type in section 3

The result indicates an average pH of 8.4. Average salinity was between 13.02g/l and 26.13 g/l. The dominant soil type was Silt Loam and it was dominating all other types by high percentage (92%). This section was an ideal example for the growth of mangroves. Moreover, landward migration of mangroves was successful. This perfect zone was similar to the compared zone in term of pH and range of salinity. However the soil type was different. The area is subjected to construction activities.

4.5.2 Summary analysis for all sections

The total study area is shown versus salinity soil type and pH in Figure 26. The pH was approximately the same in all the sections. The salinity was variable, but still within the range of salinity that mangroves can tolerate. The type of soil was variable too. Three locations had the sandy loam as dominant soil type, two of them had sand soil type, another two had silty loam soil type and the last one was Loam type. Mangrove can grow in those types of soil (El Ghazaly, a 1993).

Soil analysis was done in addition to GIS and remote sensing in order to have a combination of both field study and digital modeling of sea level rise. This combination will help in monitoring the changes in soil type with the increase in sea level rise. This monitoring will help in the assessment of mangrove ecosystem. Moreover the produced map using coordinates of collected samples will help in modeling and predicting the possible migrating areas. Those maps can be given to decision makers to make the potential migration area a close area. This will reduce the vulnerability of mangroves and enhance their growth.

The overall output of soil analysis gives a partial answer to the third research question. It shows the three studied zones will be suitable for mangrove migration. This suitability is limited to the considered parameters (pH, salinity, and soil type). More analysis for other parameters such as nutrients and organic elements should be done. Also, new constructions method may result in barriers that should be avoided as they will interrupt the migration process. This output indicates a low vulnerability of mangroves to sea level rise, according to successful migration based on the three studied parameters.

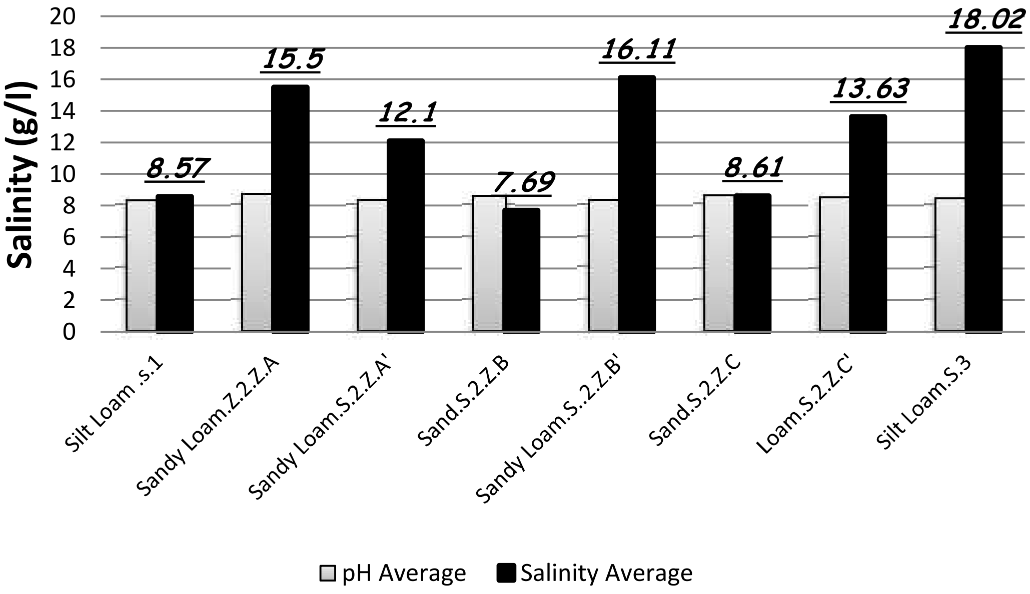


Figure 26: Salinity, pH and soil type for all sections

4.6 Management plans and awareness enhancement

The previous section highlights the areas of vulnerability and the physical characteristic of existing mangroves. Strategies should be in place to preserve and increase the current distribution of mangroves, minimizing the potential threat from anthropogenic and global climatic change. The current area is protected; however management plan is required to reduce threat against sea level rise.

In Qatar the dredging is a repeated process because of the constructions within the sea (Pearl Island, Banana Island, new port, new airport). Those sediments can be used to recreate mudflat and support mangrove vegetation (Kumara *et al.,* 2010). Sediment deposition will help mangroves to do self-regulation in response to sea level rise (Stralberg *et al.,* 2011; Ellison, 2012). This method requires analysis for sediment to check their suitability for mangroves.

Applying my knowledge, i suggested a new method to speed up their growth in the nearby area. By searching through internet and checking new articles i didn't find this new method. My suggested strategy is to produce artificial migration for mangroves by artificial growth in expected migrating areas. This type of migration will be independent of soil presented at areas outside mangrove. Pipelines from sea can be taken into the land nearby mangroves. Those pipelines will pass into big vessels and form the artificial sea. Within the big vessels a small vessel is made from two components. A mangrove plant and a proper soil collected from growing mangrove area. Different vessels will be connected and the sea water will passes through them till it come back to the sea. This system will provide a nursery for mangroves and fishes that can grow in water part and provide support to food security issues. When mangrove are large and can’t fit into the vessels, it will be taken to a mangrove land and thus increase population. Moreover the connected vessel can be moved to different sites in case of any new project being planned in the interested area. Even the used pipeline can be made from materials that enhance evaporation. The vapor within pipeline can be use to rotate the introduced turbine and generate electricity. As a result more mangroves will exist at different areas within the state of Qatar. This suggested method needs a detailed analysis and more comprehensive study to check it is applicability. Even though it can be a promising methodology for accelerating mangrove growth and switching from traditional slow migration to enhanced dynamic migration.

Restoration of mangroves is one of the strategies used in Qatar to increase the area of mangroves. Establishing a national Restoration and Re-habitation Strategy was recommended in the recent ecological assessment done by the ministry of municipality and urban planning (ICZM-EA, 2014). Plantation programs are important in enhancing the growth of mangrove and the most recent plantation program was established in 23rd November 2013 by both Ministry of Environment and Qatar University at Al Khor area (Ministry of Environment).

The conservation strategies beside the suggested migration process gave the answer for the last research question. They support the second objective by enhancing and improving the growth of mangrove locally in Qatar, and globally around the world.

5 Conclusion and Recommendations

Mangroves at Al Khor and Al Dhakhira area were analyzed for vulnerability potential sea level rise. The assessment was based on three basic vulnerability factors exposure, sensitivity, and adaptation. The results show that around 35% of mangrove areas will be affected by 0.52 m sea level rise while 45% will be affected by 0.74 m sea level rise. Time series analysis of satellite images shows an increase in mangrove areas. The analysis indicated that pH, salinity, and soil type in all sites are comparable, suggesting that these areas are suitable for potential migration. The suggested management strategies include moving dredged soil into mangrove area to increase accumulation rate and enhance migration and replantation. Existing protection strategies has positively contributed to the increase in mangrove areas over years. This need to be further supported and explained. The study shows that the vulnerability of mangroves in Qatar to sea level rise is at moderate level. However, anthropogenic factor from urbanization may increase this vulnerability of mangroves. Therefore, management plans should address these factors and develop new guidelines for new development plan. More in depth analysis including chemical and biological analysis is recommended for potential suitable migration areas. Although this study answered some questions about the vulnerability of mangroves, more investigations should be undertaken, to acquire in depth knowledge about potential threat and status of mangroves in Qatar.

6 References

Abdel-Razik M.S. (1991). Population structure and ecological performance of the mangrove Avicennia marina growing on the Arabian Gulf coastal of Qatar. *Arid Environment*, 20:331-338.

Adger W. N. Agrawala, S., Mirza, M. M. Q., Conde, C., O'Brien, K, Pulhin, J., Pulwarty, R., Smit, B., & Takahashi, K. (2007). *Impacts, adaptation, and vulnerability.Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. 717–743.

Al-Khayat A. Jassim and Balakrishnan Perumal. (2014). Avicennia marina around Qatar: Tree, Seedling and Pneumatophore Densities in Natural and Planted Mangroves using Remote Sensing. *International journal of Sciences.* Volume 3

Alongi D.M. (2008) Mangrove forests: resilience, protection from tsunamis, and responses to global climate change. *Estuar Coast Shelf* Sci 76:1–1

Arab Forum for Environment and Development (AFED), (2009). Arab environment: climate change, impact of climate change on Arab countries. http://www.afedonline.org/afedreport09/

Ayhan M. E. and Alothman, A. (2009). Sea level rise within the west of Arabian Gulf using tide gauge and continuous GPS measurements. *Geophysical Research Abstracts*. volume 11, EGU 2009-6006-1.

Balakrishnan Perumal (2012). Application of Remote Sensing for Mangroves Mapping: A Case Study of Al Dhakira, the State of Qatar. *Journal of Earth Science and Engineering* volume 2 602-612.

Ball M.C. (1988). Salinity tolerance in the mangroves, *Aegiceras corniculatum* and *Avicennia marina.* I. Water use in relation to growth, carbon portioning and salt balance, Australian journal Plant Physiology. Volume 15, 447-464

Bandaranayake W.M. (1994). Phyto-chemical constituents and pigments in mangrove species and mangal associates of Northern Australia. Australian Institute of Marine Science (AIMS) Report 19, 1–21, AIMS, Townsville, Australia.

Cahoon D.R., Hensel PF, Spencer T, Reed DJ, McKee KL, Saintilan N (2007) Coastal wetland vulnerability to relative sea-level rise: wetland elevation trends and process controls. In: Verhoeven JTA, Beltman B, Bobbink R, Whigham DF (eds) *Wetlands and natural resource management*. Springer, Berlin, pp 271–272

Church J., Gregory J, Huybrechts P, Kuhn M, Lambeck K, Nhuan M, Qin D, Woodworth P (2001) Chapter 11. Changes in sea level. In: Houghton J, Ding Y, Griggs D, Noguer M, van der Linden P, Dai X, Maskell K, Johnson C (eds) Climate change 2001: the scientific basis. Published for the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge/New York, pp 639–693, 881pp

Church J. A. and N.J. White (2011), Sea-level rise from the late 19th to the early 21st century. *Survey in Geophysics*, doi: 10.1007/s10712-011-9119-1

Church J. A., Woodworth, P.L., Aarup, T., Wilson, W.S. (Eds.), (2010). Understanding Sea Level Rise and Variability. Wiley-Blackwell Publishing, Chichester, UK. ISBN: 978-14443-3451-7

Crozier C. R., D. H. Hardy, D. E. Kissel, C. C. Mitchell, J. L. Oldham, S. Phillips, and L. Sonon. (2010). "Research-Based Soil Testing and Recommendations for Cotton on Coastal Plains Soils." Southern Cooperative Series Bulletin. http://www.clemson. edu/sera6/sera6-cotton%20pub.pdf

Duke N.C., Meynecke JO, Dittmann S, Ellison AM, Ange K, Berger U, Cannicci S, Diele K, Ewel KC, Field CD, Koedam N, Lee SY, Marchand C, Nordhaus I, Dahdouh-Guebas F (2007) A world without mangroves? *Science* 317:41–42

El-Gazaly Gamal and Abdel-Razik Mohamed (1993) Propagation and Transplantation of the Mangrove Avicennia Marina within the State of Qatar. Qatar University, Scientific and Applied Research center.ISBN 999 – 39 – 4

El-Ghazaly Gamal, HanafyHolail, OssamaH.Sayed, OssamaAboul Dahab (1993). Effect of sea level rise on mangrove ecosystem at Al-Dhakhira state of Qatar. Qatar University. Scientific and Applied Research Center

Ellison J. C. (2000) Chapter 15: How South Pacific mangroves may respond to predicted climate change and sea level rise. In: Gillespie A, Burns W (eds) Climate change in the South Pacific: impacts and responses in Australia, New Zealand, and Small Islands States. Kluwer Academic Publishers, *Dordrecht*, pp 289–301

Ellison J.C. (2012) Climate change vulnerability assessment and adaptation planning for mangrove systems. WWF US, Washington DC

Ellison Jonna C., and Zouh Isabella. (2012). Vulnerability to Climate Change of Mangroves: Assessment from Cameroon, Central Africa. *Biology*. 1030617. 617-638.

Ellison J.C. (1998). Impacts of sediment burial on mangroves. *Marine Pollution Bulletin* 37: 420-426

Environmental Statistics Annual Report (EASR) (2013), Ministry of Development and planning and statistics, (www.mdps.gov.qa)

Ewel K.C., Twilley RR, Ong J.E. (1998) Different kinds of mangrove forests provide different goods and services. *Glob EcolBiogeogrLett* 7:83–94

Fagherazzi, S., Kirwan, M.L., Mudd, S.M., Guntenspergen, G.R., Temmerman, S., D'Alpaos, A. et al. (2012) Numerical models of salt marsh evolution: ecological, geomorphic, and climatic factors. *Reviews of Geophysics*, 50, RG1002.

Field C.D. (1995) Impacts of expected climate change on mangroves. *Hydrobiologia* 295(1–3):75–81

Frykman Hanna and Seiron Per-Olof. (2009). The Effects of Climate Induced Sea Level Rise on the Coastal Areas in the Hambantota District, Sri Lanka. A geographical study of Hambantota and an identification of vulnerable ecosystems and land use along the coast.

Gilman E., Ellison J, Coleman R (2006) Assessment of mangrove response to projected relative sea-level rise and recent historical reconstruction of shoreline position. *Environ Monit Assess* 124:112–134.

Giri C., Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, Masek J, Duke N (2011) Status and distrion of mangrove forests of the world using earth observation satellite data. *Glob EcolBiogeo* 20:154–159

Glick P., & Stein, B. A. (Eds.) (2010). Scanning the ConservationHorizon.National Wildlife Federation.

Guidon B., Edmonds CM (2002) Large-area land-cover mapping through scene-based classification compositing. *Photogram Eng Remote Sens* 68(6):589–596

Hegazy A.K. (1998). Perspectives on survival, phenology, litter fall and decomposition, and caloric content of Avicennia marina in the Arabian Gulf region. Journal of Arid Environments 40: 417– 429.

Hogarth.P. J., (1999). The Biology of Mangroves.Oxford: *Oxford University Press*. Hogarth. 228.

Integrated Coastal Zone Management Plan for the State of Qatar, CLIMATE CHANGE AND SEA LEVL RISE STUDY (ICZM-CCSLR, 2014). Ministry of Municipality and Urban Planning (MMUP).

Integrated Coastal Zone Management Plan for the State of Qatar, ECOLOGICAL ASSESSMENT FINAL REPORT (ICZ-EA, 2014). MMUP

Intergovernmental panel on climate change in the fifth assessment report (IPCC), (2007). https://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm.

Intergovernmental panel on climate change in the fifth assessment report (IPCC), (2013). http://www.ipcc.ch/report/ar5/wg1/

Kogo Motohiko, (1986). A report of Mangrove research in Saltanate of Oman. The fourth research on mangroves in the Middle East. Japan cooperation center for the middle east.

Kraynak.J and Tetrault.K, (2003). The Complete Idiot's Guide to The Oceans. Penguin Group (USA).

Kumara M.P., Jayatissa LP, Krauss KW, Phillips DH, Huxham M (2010). High mangrove density enhances surface accretion, surface elevation change, and tree survival in coastal areas susceptible to sea-level rise. Oecologia. Volum:164, 545–553.

Lu Weizhi, Luzhen Chen, Wenqing Wang, Nora Fung-Yee Tam, Guanghui Lin, (2013). Effects of sea level rise on mangrove Avicennia population growth, colonization and establishment: Evidence from a field survey and greenhouse manipulation experiment. *Acta Oecologica* V. 49. P. 83-91

Lucas R.M, J.C. Ellison, A. Mitchell, B. Donnelly, M. Finlayson & A.K. Milne (2002).Use of stereo aerial photography for quantifying changes in the extent and height of mangroves in tropical Australia. *Wetlands Ecology and Management* 10:161–175.

Lunstrum Abby, Chen Luzhen (2014). Soil carbon stocks and accumulation in young mangrove forest. *Soil biology and biochemistry*. Volume 75, pages 223-232

Malay Kumar Pramanik. (2014). Assessment the Impact of Sea Level Rise on Mangrove Dynamics of Ganges Delta in India using Remote Sensing and GIS. *Environmental and Earth Science*. 4. 2224-3216.

Ministry of Environment (http://www.moe.gov.qa/English/News/Local/pages/MoE-organizes-Mangrove-planting-drive-at-Al-Thakhira-area.aspx)

Myers, D., J. Hardy, and Stokes. C. (2008). "Soil Sampling Large Areas: Agricultural Crops, Pastures, Parks, or Athletic Turf." North Carolina Department of Agriculture and Consumer Services. http://www.ncagr.gov/agronomi/pdffiles/samcrop.pdf

Nerem RS, Chambers D, Choe C, Mitchum GT. (2010). Estimating Mean Sea Level change from the TOPEX and Jason Altimeter Mission. Marine Geodesy. 33(1 supp1): 435.

Nicholls, R.J., R.S.J. Tol and A.T. Vafeidis, (2005), Global estimates of the impact of a collapse of the West Antarctic Ice Sheet: An application of FUND, *FNU*-78 (submitted).

Nitto D. Di, F. Dahdouh-Guebas, J.G.Kairo, H.Decleir, N. Koedam. (2008). Digital terrain modeling to investigate the effects of sea level rise on mangrove propagule establishment. *MARINE ECOLOGY PROGRESS SERIES Mar EcolProg Ser*. 356. 175-188

O’Grady A.P., McGuinness, K.A. and Eamus, D. (1996). The abundance and growth of *Avicennia marina* and *Rhozophorastylosa*in the low shore zone of Darwin Harbour, Northern Territory.Aust.J. *Ecol.* 21: 272–279

Penha-Lopes G, Torres P, Cannicci S, Narciso L, Paula J (2011) Monitoring anthropogenic sewage pollution on mangrove creeks in southern mozambique: a test of palaemonconcinnusdana, 1852 (Palaemonidae) as a biological indicator. *EnvirPollu* 159:636–64

Pramanik Kumar Malay (2014) Assessment the Impact of Sea Level Rise on Mangrove Dynamics of Ganges Delta in India using Remote Sensing and GIS. *Journal of Environment and Earth Science.* ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online) Vol.4, No.21.

Protected Area Action Plan 2008-2013 (2007) Supreme Council for Environmental and Natural Reserves (SCENR) State of Qatar.

Qatar statistical Authorities (2011) and Ministry of Municipalities and Urban Planning MMUP, National Development Frame work.

Rankey Eugene C. and Andrews Berkeley (2012).Holocene Carbonate Tidal Flats.Principles of Tidal Sedimentology, DOI 10.1007/978-94-007-0123-6_19, © *Springer Science+Business Media B.V.*

Rebecca Hoff, Philippe Hensel Edward C. Proffitt and Particia Delgado, Gary Shigenaka, Ruth Yender, Alan J. Mearns, (2010). Planing and Response Considerations. Oil Spills in Mangroves.

Rivera-Monroy, V.H., Twilley, R.R., Davis, S.E., Childers, D.L., Simard, M., Chambers, R., Jaffe, R., Boyer, J.N., Rudnick, D.T., Zhang, K., CastañedaMoya, E., Ewe, S.M.L., Price, R.M., Coronado-Molina, C., Ross, M., Smith, T.J., Michot, B., Meselhe, E., Nuttle, W., Troxler, T.G., Noe, G.B.,(2011). The role of the everglades mangrove ecotone region (EMER) in regulating nutrient cycling and wetland productivity in South Florida. Crit. *Rev. Environ. Sci. Technol*. 41, 633e669.

Sahagian, D. (2000): Global physical effects of anthropogenic hydrological alterations: Sea level and water redistribution. *Global Planet*. 25. 39–48.

Sanders C. J., Smoak, J.M., Naidu, A.S., Patchineelamt, S.R., (2008). Recent sediment accumulation in a mangrove forest and its relevance to local sea-level rise (Ilha Grande, Brazil). *J. Coast. Res*. 24, 533e536.

Shinn EA (1973) Sedimentary accretion along the leeward SE coast of Qatar Peninsula, Persian Gulf. In: Purser BH (ed) The Persian Gulf – Holocene carbonate sedimentation and diagenesis in a shallow epicontinental sea. *Springer, Berlin*, pp 199–209

Shinn E.A. (2010) The interplay between quaternary sedimentation and diagenesis and implications for hydrocarbon exploitation: return to sabkha of Ras Umm Said, Qatar

Spalding M., Kainuma M, Collins L (2010) *World Atlas of Mangroves*. Earthscan, London

Stammer, D., N. Agarwal, P. Herrmann, A. Kohl, and C. R. Mechoso, (2008): Response of a coupled ocean-atmosphere model to Greenland ice melting. Surv. *Geophys*. 32. 621–642

Stralberg Diana, Matthew Brennan, John C. Callaway, Julian K. Wood, Lisa M. Schile, Dennis Jongsomjit, Maggi Kelly, V. Thomas Parker, Stephen Crooks Talaat WAW, Tahir NM, Husain ML (2011). Mangrove biodiversity management and conservation in Malaysia: The present legislative, administrative and policy framework. Proceeding of Universiti Malaysia Terengganu (International annual symposium on life science, Kuala Terengganu Malaysia; empowering science, technology and innovation towards a better tomorrow. LSP 36:399–404.

Subhajit Das, Minati De, DipnarayanGanguly, TusharKantiMaiti, Abhishek Mukherjee, Tapan Kumar Jana, TarunKuma De (2012). ”Depth Integrated Microbial Community and Physico-Chemical Properties in Mangrove Soil of Sundarban, India”*Advances in Microbiolog*, V.2, pages 234-240.

Suratman M.N. (2008) Carbon sequestration potential of mangroves in Southeast Asia. In: Bravo F, Jandl R, LeMay V, Gadow von K (eds) Managing forest ecosystems: the challenge of climate change. *Springer, Netherlands*, pp 297–315

Syed Sanwer, AliNasimKarim, Alia BanoMunshi and HinaAhsan. (2013). Persistent Toxic Impact of Crude Oil on Mangroves as Forge after Tasman Spirit Oil at Karachi Coast of Pakistan Canadian Journal on Computing in Mathematics, Natural Sciences, *Engineering and Medicine*. 4. 4.

Wada Y., L. P. H. van Beek, F. C. S. Weiland, B. F. Chao, Y. H. Wu, and M. F. P. Bierkens. (2012). Past and future contribution of global groundwater depletion to sea-level rise. *Geophys*. 39. 9402.

Wan Juliana W.A., Maimon A, Norhayati A, Razali SM, MohdFauzi E, Izwahanie I, Nurhanim MN (2011) Mangrove flora and fauna of Manjung riparian reserves, Perak, Malaysia. Proceeding of Universiti Malaysia Terengganu (UMTAS 2011). International annual symposium on life science, 11–13th July, 2011 Kuala Terengganu Malaysia; empowering science, technology and innovation towards a better tomorrow. LSP 39:412–417

Wan Rasidah K, MohdFakhri I, Suhaimi WC, Rozita A, Jeyanny V, AdiFadzly AK (2010) Soil profiles of mangrove forest: case studies in Peninsular Malaysia. Forest Research Institute Malaysia (FRIM), Malaysia, p 38

Wang Gang, Dongsheng Guan, M.R peart, Yujuan Chen, Yisheng Peng (2013). Ecosystem carbon stocks of mangrove forest in Yingluo Bay Guangdong Province of South China. *Forest Ecology and Management.* Volume 310, pages 539-546.

Wilkie D.S., Finn JT (1996) Remote sensing imagery for natural resources monitoring. *Columbia Univ. Press*, NY, p 29

Zhou Y., Zhao B, Peng Y, Chen G (2010) Influence of mangrove reforestation on heavy metal accumulation and speciation in intertidal sediments. *Mari Pollu Bull* 6:1319–1324

7 APPENDIX

List of appendix figures:

List of appendix tables

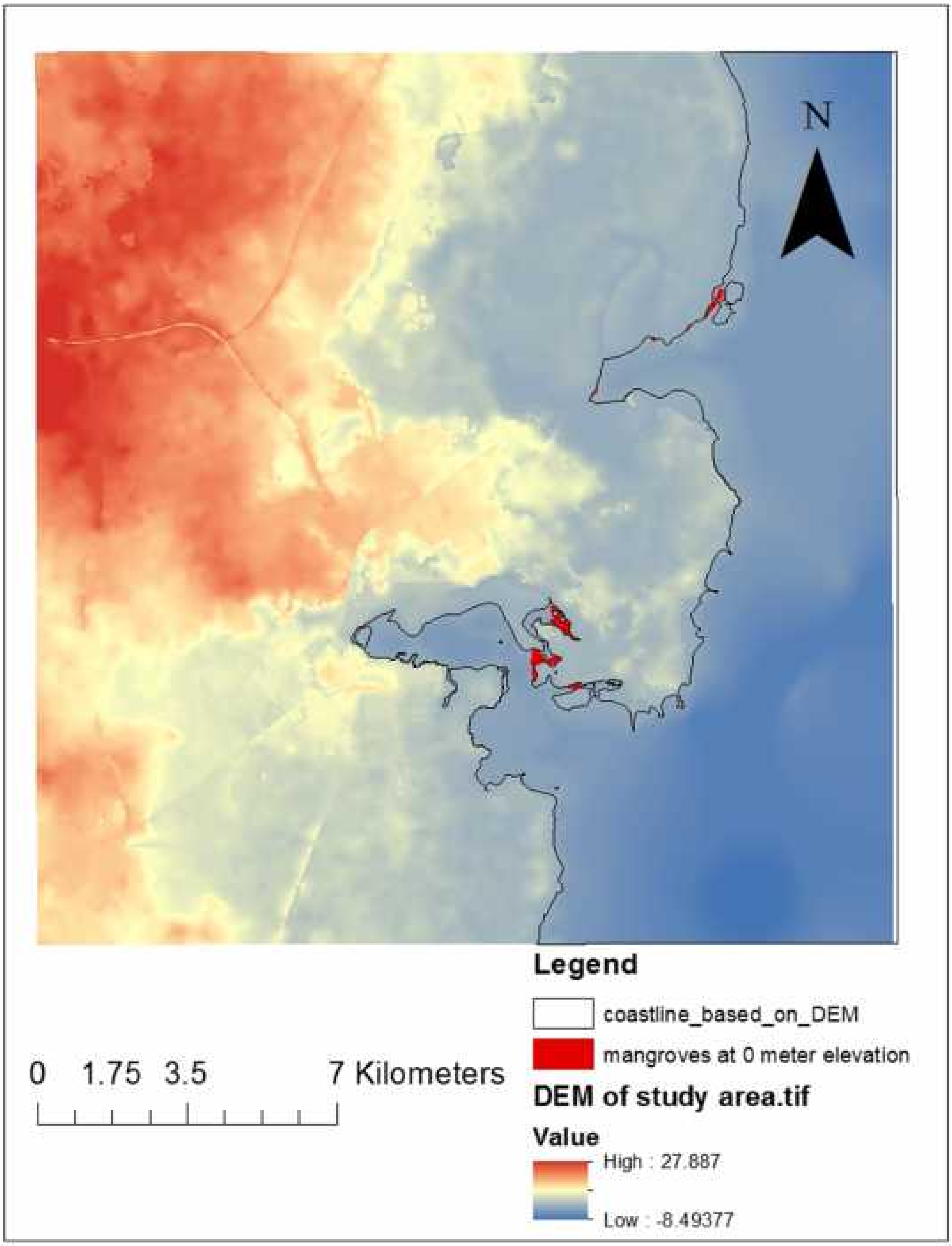
7.1 More details about the study area

7.1.1 The climate of the study area

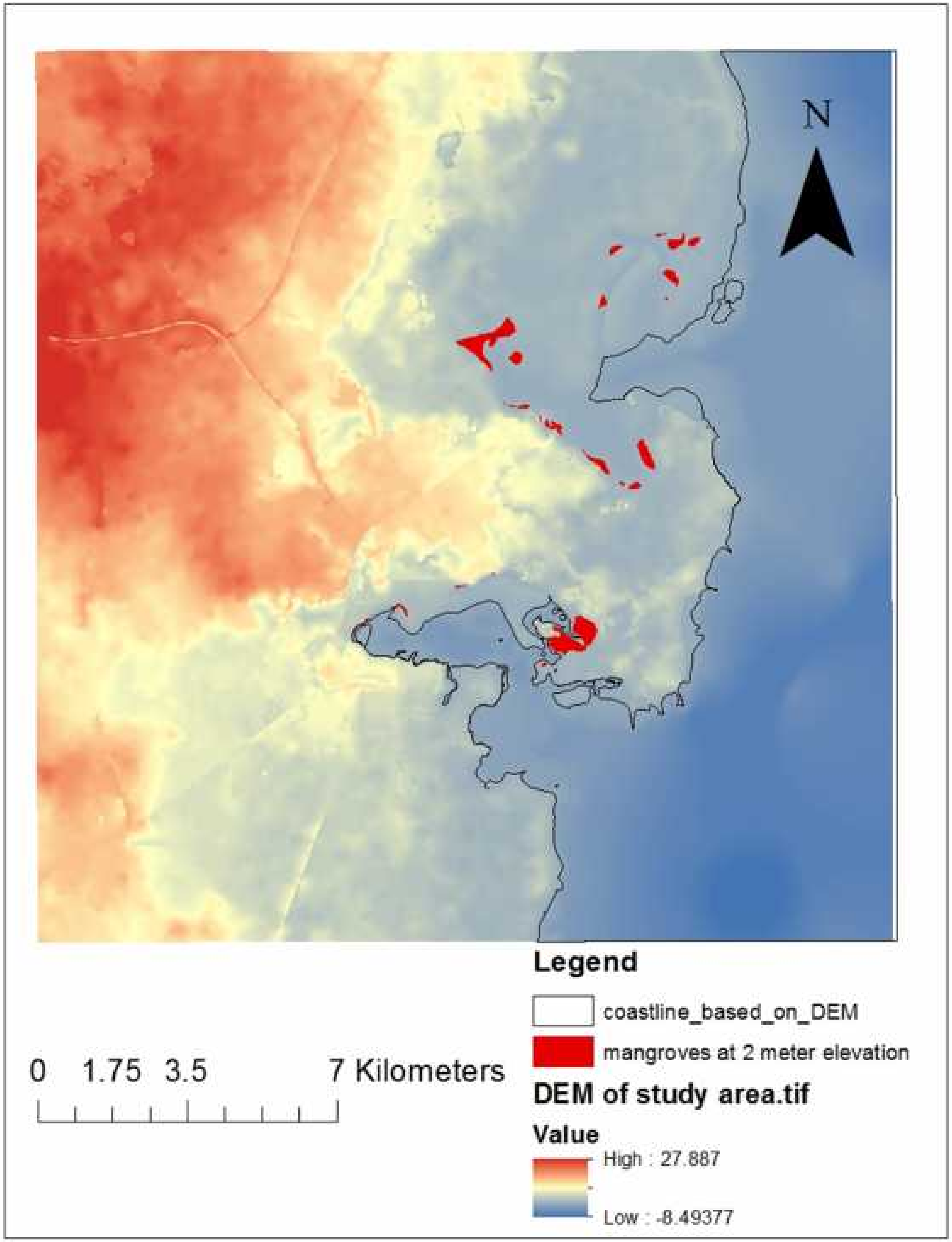
Qatar is classified by geographers as desert country. The climate is characterized by intense heat, with high humidity and dry winds in summer (May to September), and warm winter (October to April) (El-Ghazaly *et al.*, 1993). The average precipitation is 75.2mm^2/year making Qatar part of the bracket of countries with the lowest average rainfall worldwide (EASR, 2013).

Data provided in the five figures indicate high temperature with low precipitation. The result is a high rate of evaporation and increased salinity.. Salinity within Al Dhakhira fluccates between 40 and 41 g/l (El- Ghazaly *et al.*, 1993).

7.2 Maps of mangroves at different sea level rise



Appendix Figure: 1 Map of mangroves intersecting 0 meter elevation



Appendix Figure: 2 Map of mangroves intersecting 2 m elevation

7.3 Results of soil analysis (pH, salinity, and soil types)

7.3.1 Tables of soil analysis (pH, salinity, and soil types) at the three sections 1,2, and 3

Appendix Table 1: Measurements of pH, salinity and soil type as well as the coordinates of samples collected from section 2 Zone A

Samples from section 2, zone A	X coordinate(E)	Y coordinate(N)	pH	Salinity	clay %	silt %	sand %	soil type
1	**555289**	**2842410**	**8.55**	**20.98**	**9.24**	**33.22**	**57.54**	**Sandy Loam**
2	**555288**	**2842410**	**8.88**	**11.48**	**8.6**	**17.83**	**73.57**	**Sandy Loam**
3	**555281**	**2842360**	**8.77**	**11.66**	**0.85**	**9.75**	**89.4**	**Loamy Sand**
4	**555308**	**2842353**	**8.75**	**11.62**	**5.51**	**21.79**	**72.7**	**Sandy Loam**
5	**555325**	**2842336**	**8.75**	**11.29**	**9.04**	**28.38**	**62.58**	**Sandy Loam**
6	**555340**	**2842348**	**8.46**	**21.64**	**4.07**	**23.41**	**72.52**	**Loamy Sand**
7	**555380**	**2842379**	**8.82**	**12.81**	**8.57**	**30.24**	**61.19**	**Sandy Loam**
8	**555407**	**2842364**	**8.7**	**18.79**	**6.84**	**26.12**	**67.04**	**Sandy Loam**
9	**555436**	**2842352**	**8.57**	**18.30**	**6.31**	**29.51**	**64.18**	**Sandy Loam**
10	**555459**	**2842323**	**8.73**	**13.24**	**8.57**	**26.44**	**64.99**	**Sandy Loam**
11	**555483**	**2842318**	**8.56**	**16.62**	**0.28**	**2.49**	**97.23**	**Sand**
12	**555510**	**2842312**	**8.56**	**12.20**	**3.08**	**13.39**	**83.53**	**Loamy Sand**

Appendix Table 2: Measurements of pH, salinity and soil type as well as the coordinates of samples collected from section2 Zone B

Samples from Section 2, Zone B	X. coordinate(E)	Y coordinate (N)	pH	Salinity	clay %	silt %	sand %	soil type
1	**555625**	**2841117**	**8.70**	**6.18**	**0.00**	**0**	**100**	**Sand**
2	**555585**	**2841065**	**8.68**	**10.78**	**0.00**	**0**	**100**	**Sand**
3	**555563**	**2841025**	**8.50**	**7.05**	**0.00**	**0**	**100**	**Sand**
4	**555594**	**2841029**	**8.35**	**7.08**	**6.41**	**13.37**	**80.22**	**Loamy Sand**
5	**555639**	**2841043**	**8.40**	**10.87**	**9.02**	**15.65**	**75.33**	**Sandy Loam**
6	**555679**	**2841050**	**8.61**	**10.64**	**4.85**	**13.93**	**81.22**	**Loamy Sand**
7	**555701**	**2841065**	**8.38**	**10.52**	**7.66**	**15.5**	**76.84**	**Sandy Loam**
8	**555710**	**2841090**	**8.48**	**7.53**	**5.04**	**17.03**	**77.93**	**Loamy Sand**
9	**555712**	**2841121**	**8.59**	**6.46**	**8.35**	**20.88**	**70.77**	**Sandy Loam**
10	**555715**	**2841144**	**8.45**	**7.06**	**8.70**	**20**	**71.3**	**Sandy Loam**
11	**555708**	**2841169**	**8.71**	**2.71**	**0.20**	**1.02**	**98.78**	**Sand**
12	**555679**	**2841156**	**8.74**	**5.46**	**2.06**	**4.06**	**93.88**	**Sand**

Appendix Table 3: Measurements of pH, salinity and soil type as well as the coordinates of samples collected from section2 Zone C

Samples from section 2, zone C	X. coordinate(E)	Y. coordinate(N)	pH	Salinity	clay %	silt %	sand %	soil type
1	555320	2841860	NA	NA	11.62	47.90	40.48	Loam
2	555514	2841393	8.45	12.45	8.25	43.23	48.52	Loam
3	555469	2841406	8.77	5.37	1.85	8.08	90.07	Sand
4	555359	2841561	8.74	5.89	0.86	5.47	93.67	Sand
5	555358	2841582	8.53	12.60	5.70	12.59	81.71	Loamy Sand
6	555360	2841614	8.67	5.16	12.11	22.70	65.19	Sandy Loam
7	555371	2841653	8.45	28.80	NA	NA	NA	NA
8	555356	2841733	skip	Skip	6.54	9.15	84.31	Loamy Clay
9	555352	2841808	8.56	5.42	2.52	3.55	93.93	Sand
10	555361	2841774	8.41	3.30	0.00	0.00	100.00	Sand
11	555329	2841834	8.73	1.88	0.13	1.76	98.11	Sand
12	555319	2841862	8.42	5.25	NA	NA	NA	NA

Appendix Table 4: Measurements of pH, salinity and soil type as well as the coordinates of samples collected from section2 Zone A'

Samples from section 2, zone A'	X. coordinate (E)	Y coordinate (N)	pH	Salinity	clay %	silt %	sand %	soil type
1'	**555146**	**2842295**	**8.65**	**9.02**	**4.26**	**23.45**	**72.29**	**Sandy Loam**
2'	**555360**	**2842023**	**8.44**	**10.95**	**0.16**	**5.12**	**94.72**	**Sand**
3'	**555422**	**2841983**	**8.54**	**10.78**	**0.58**	**12.51**	**86.91**	**Loamy Sand**
4'	**555485**	**2841938**	**8.03**	**14.79**	**5.99**	**37.98**	**56.03**	**Sandy Loam**
5'	**555542**	**2841905**	**8.16**	**13.24**	**1.09**	**22.23**	**76.68**	**Loamy Sand**
6'	**555573**	**2841872**	**8.11**	**12.48**	**4.86**	**35.63**	**59.51**	**Sandy Loam**
7'	**555569**	**2841839**	**8.57**	**11.45**	**5.35**	**34.07**	**60.58**	**Sandy Loam**
8'	**555572**	**2841822**	**8.46**	**11.52**	**2.45**	**23.61**	**73.94**	**Loamy Sand**
9'	**555614**	**2841813**	**8.4**	**10.48**	**4.67**	**33.9**	**61.43**	**Sandy Loam**
10'	**555652**	**2841767**	**8.33**	**11.37**	**0.49**	**6.93**	**92.58**	**Sand**
11'	**555681**	**2841751**	**8.12**	**13.64**	**4.51**	**43.67**	**51.82**	**Sandy Loam**
12'	**555690**	**2841748**	**8.12**	**15.56**	**4.15**	**41.06**	**54.79**	**Sandy Loam**

Appendix Table 5: Measurements of pH, salinity and soil type as well as the coordinates of samples collected from section2 Zone B'

Samples frm section 2 Zone B'	X. coordinate (E)	Y coordinate (E)	pH	Salinity	clay %	silt %	sand %	soil type
1'	555630	2841181	8.16	19.66	5.53	52.18	42.29	Silt Loam
2'	555644	2841161	7.82	21.23	8.5	59.53	31.97	Sandy Loam
3'	555602	2841121	8.41	11.89	7.5	35.49	57.01	Sandy Loam
4'	555591	2841109	8.35	15.37	3.95	20.16	75.89	Loamy Sand
5'	555577	2841093	8.03	18.89	2.07	14.44	83.49	Loamy Sand
6'	555553	2841086	8.42	17.72	13.79	58.45	27.76	Silt Loam
7'	555534	2841088	8.24	18.00	11.57	42.05	46.38	Loam
8'	555521	2841094	8.48	13.30	16.36	40.51	43.13	Loam
9'	555503	2841091	8.55	18.21	7.12	37.39	55.49	Sandy Loam
10'	555498	2841103	8.47	12.17	9.34	45.14	45.52	Loam
11'	555506	2841103	8.17	14.08	11.08	35.67	53.25	Sandy Loam
12'	555487	2841090	8.38	12.84	8.32	31.75	59.93	Sandy Loam

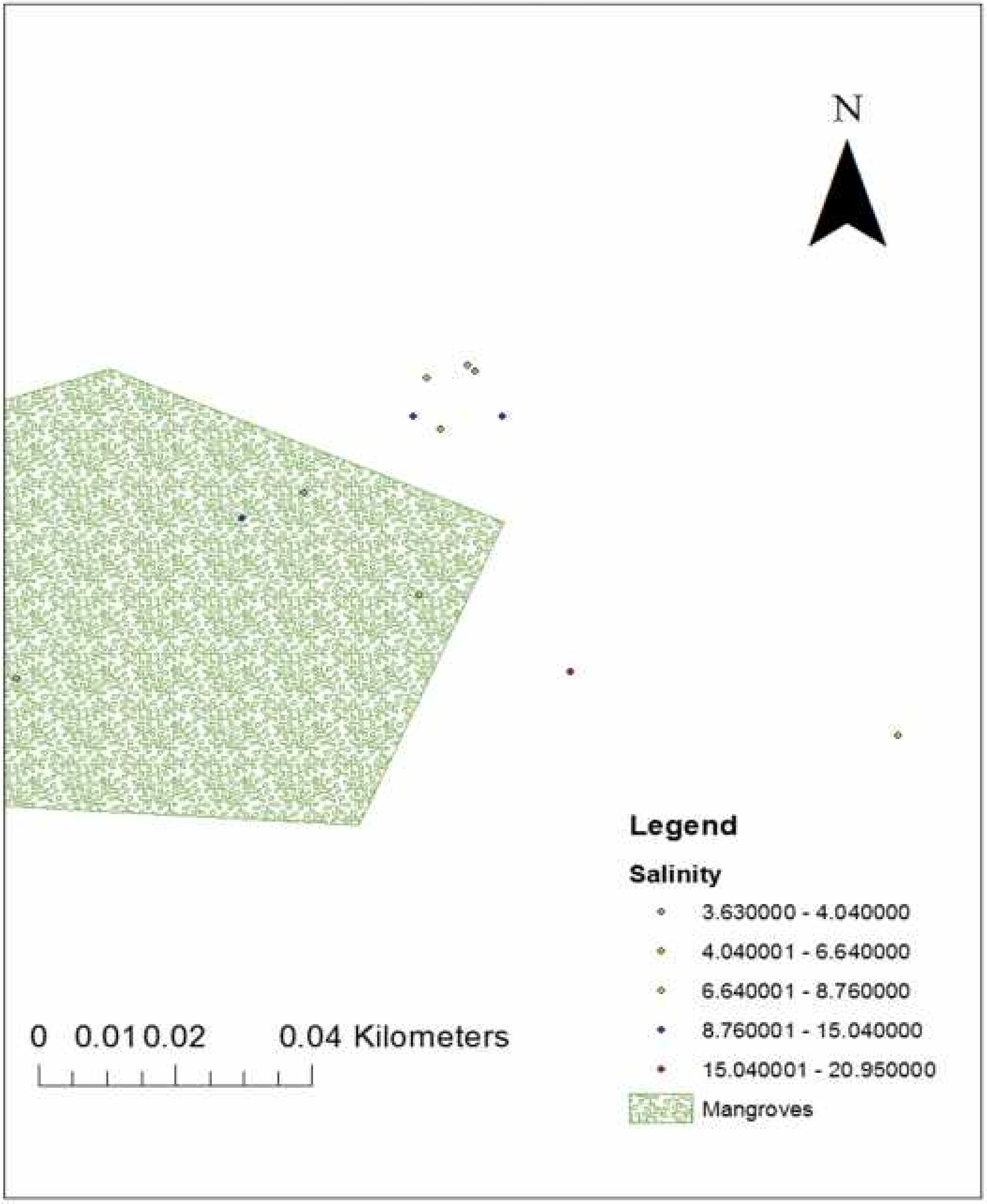
Appendix Table 6: Measurements of pH, salinity and soil type as well as the coordinates of samples collected from section2 Zone C'

Samples from section 2, zone C’	X. coordinate (E)	Y coordinate(N)	pH	Salinity	clay %	silt %	sand %	soil type
1'	555487	2841090	8.46	13.34	10.92	42.56	46.52	Loam
2'	555487	2841372	8.59	14.68	32.22	3.69	64.09	Sandy Clay Loam
3'	555474	2841380	8.60	13.63	29.21	52.61	18.18	Silty Clay Loam
4'	555462	2841397	8.58	14.58	24.43	47.26	28.31	Loam
5'	555449	2841416	8.63	14.37	20.20	45.54	34.26	Loam
6'	555375	2841524	8.36	14.83	20.61	49.31	30.08	Loam
7'	555440	2841677	8.63	11.62	17.25	38.84	43.91	Loam
8'	555449	2841698	8.50	12.24	12.36	41.86	45.78	Loam
9'	555448	2841715	8.10	15.15	9.05	44.95	46	Loam
10'	555428	2841728	8.31	13.25	14.60	43.81	41.59	Loam
11'	555419	2841733	8.48	13.07	13.15	46.23	40.62	Loam
12'	555414	2841738	8.57	12.81	8.78	44.60	46.62	Loam

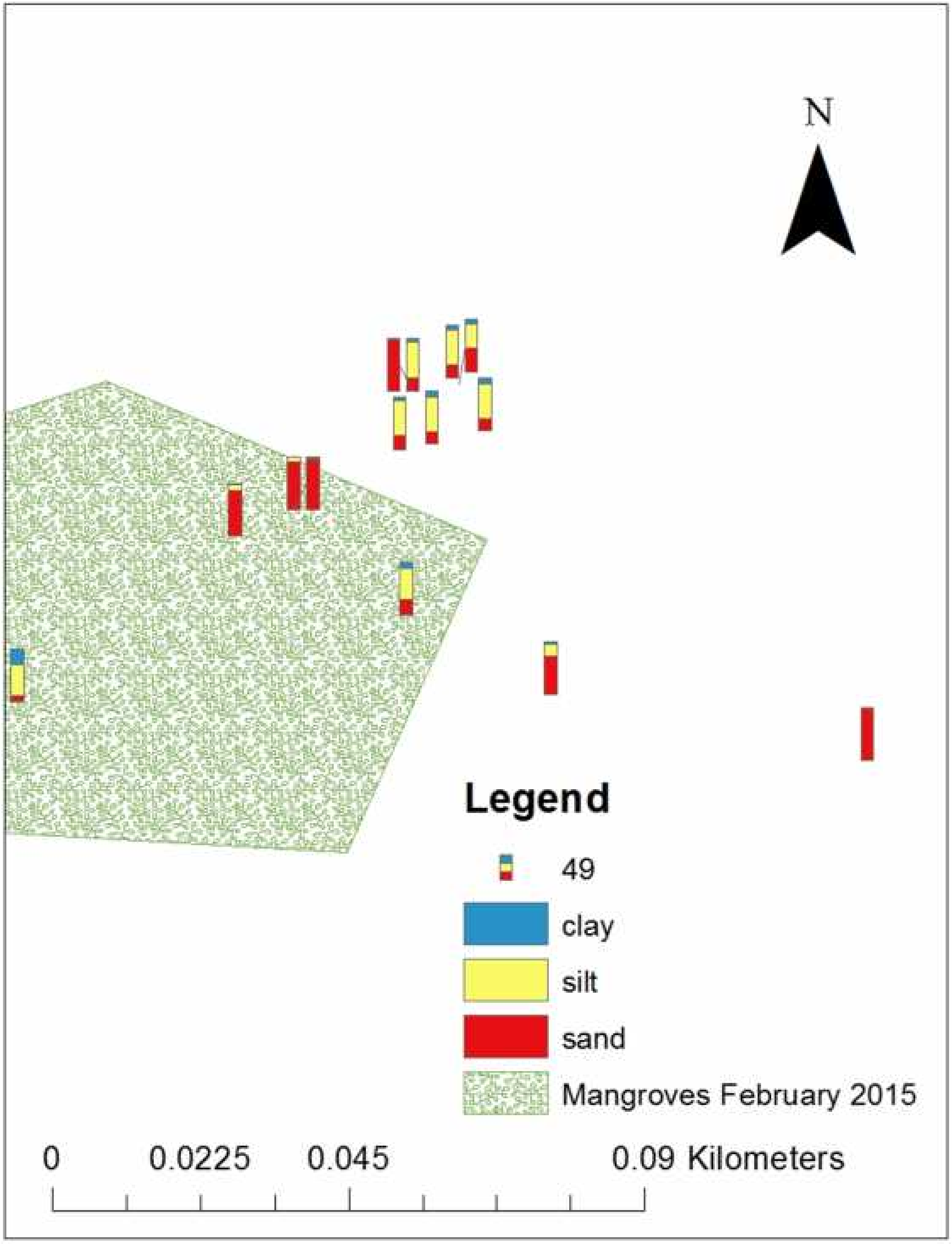
Appendix Table 7: **Measurements of pH, salinity and soil type of samples collected from section 3 (Semaisma)**

Samples from section 3	pH	Salinity	clay %	silt %	sand %	soil type
1	8.39	15.99	3.07	5.45	91.48	Sand
2	8.44	22.41	15.64	58.98	25.38	Silt Loam
3	8.42	16.53	17.48	53.62	28.9	Silt Loam
4	8.40	16.02	26.81	51.81	21.38	Silt Loam
5	8.38	17.43	23.47	50.02	26.51	Silt Loam
5	8.45	15.73	14.61	59.53	25.86	Silt Loam
7	8.46	13.02	19.50	55.76	24.74	Silt Loam
8	8.38	17.43	12.91	57.50	29.59	Silt Loam
9	8.40	21.25	20.99	56.10	22.91	Silt Loam
10	8.34	17.15	24.54	50.84	24.62	Silt Loam
11	8.30	26.13	13.13	56.77	30.1	Silt Loam

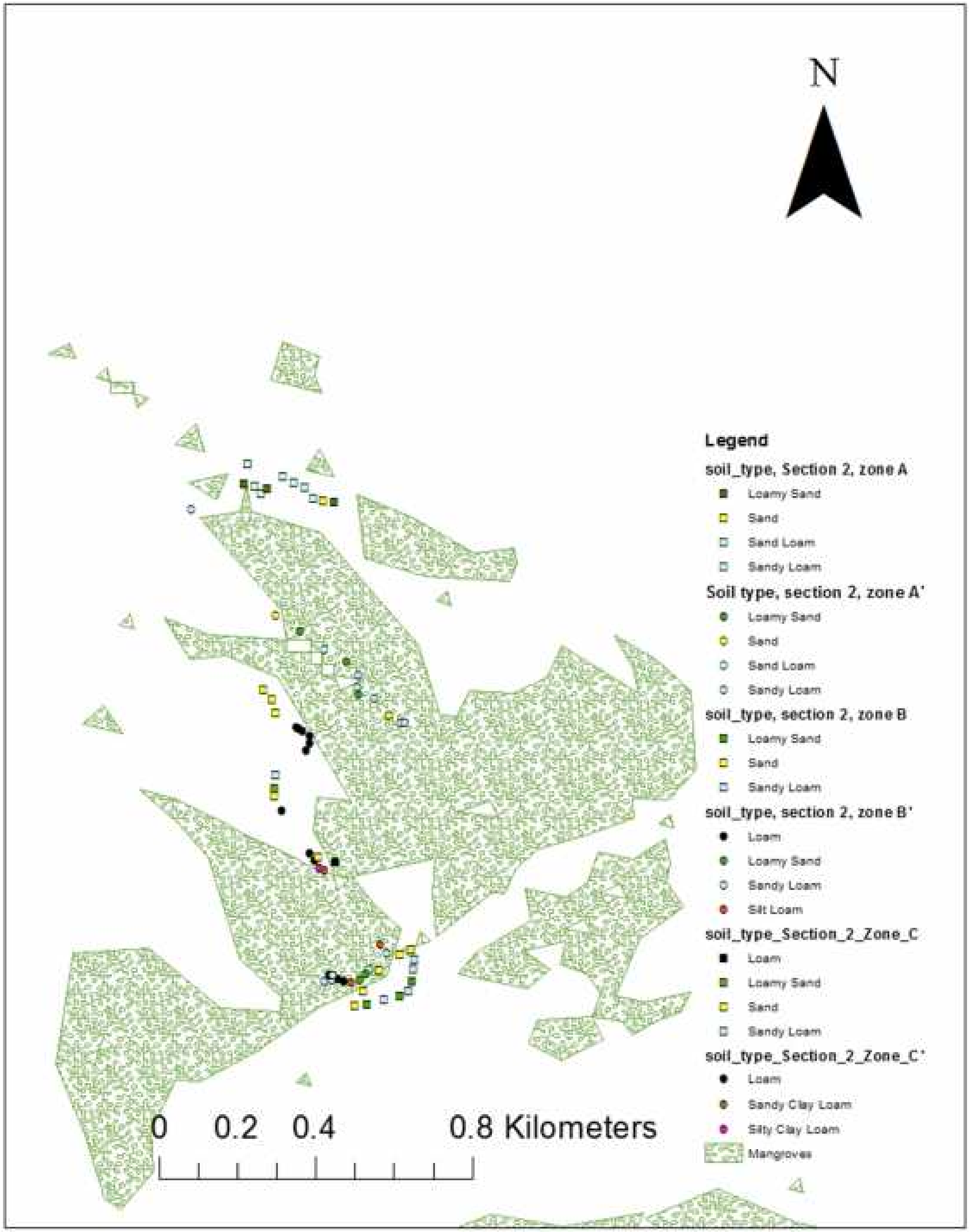
7.3.2 Maps of soil analysis (pH, salinity, and soil types)



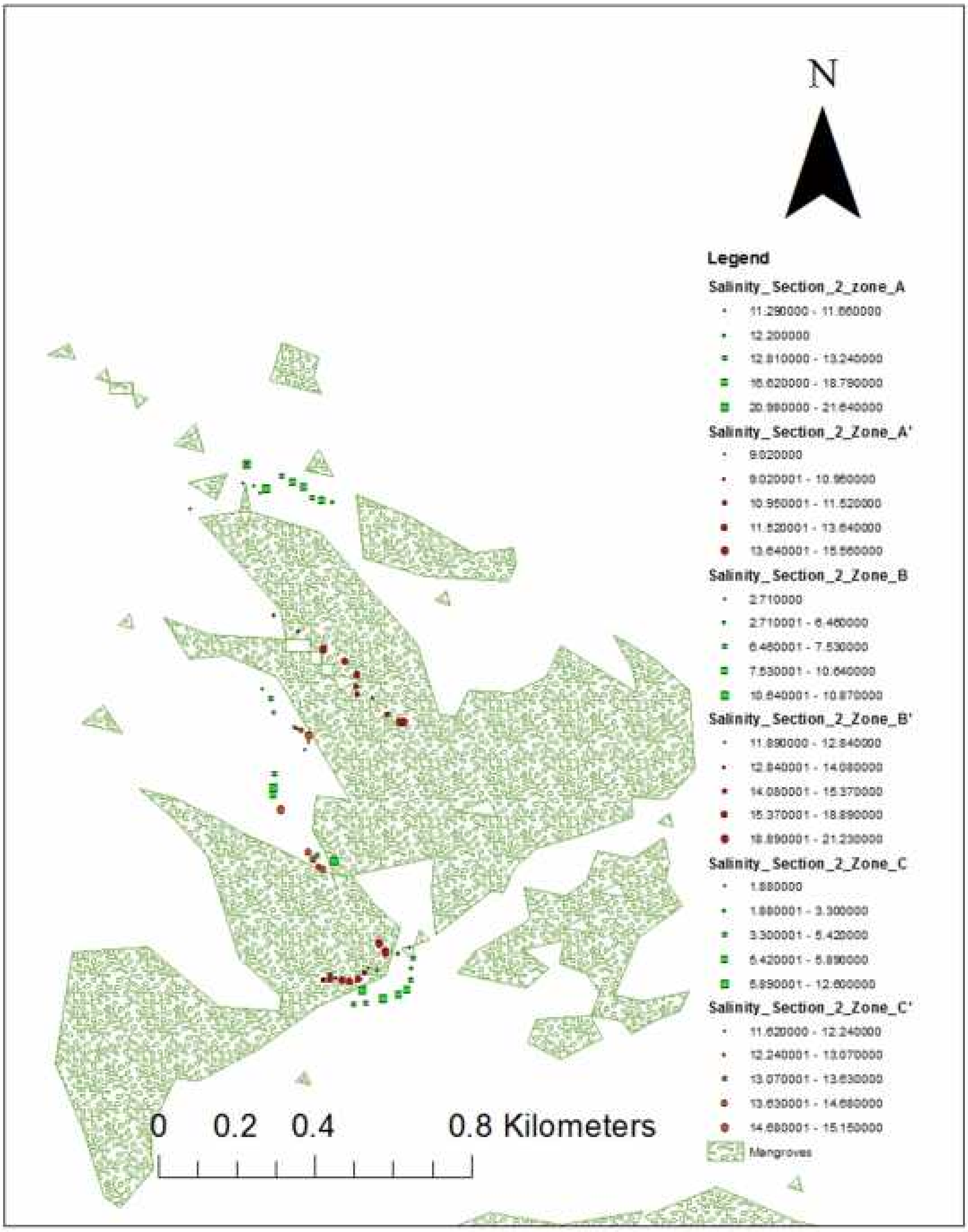
Appendix Figure: 3: distribution of salinity in section 1 based on different colors



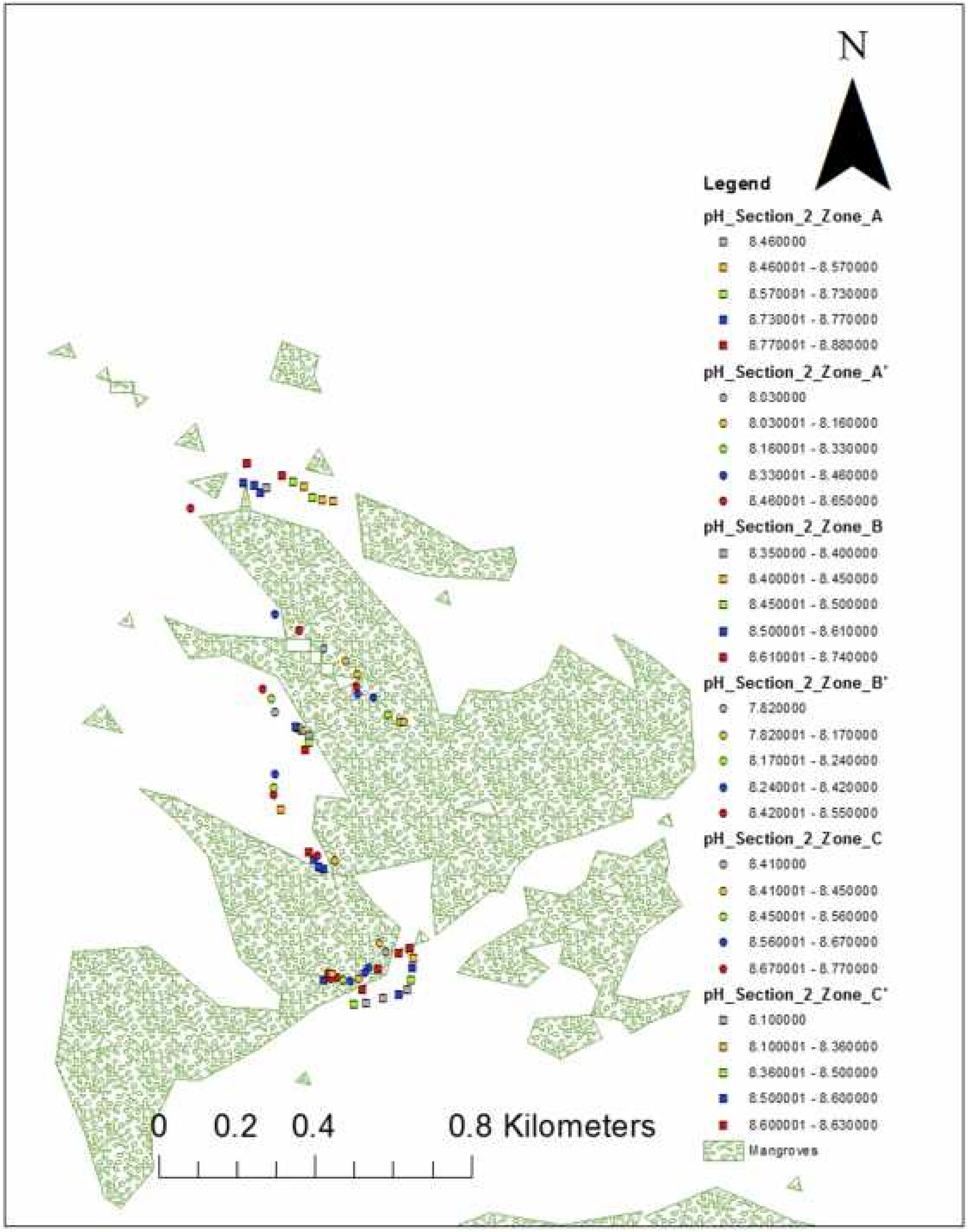
Appendix Figure 4: distribution of particle size in section 1 based on different quantities of clay, silt, and sand.



Appendix Figure 5: Comparison of soil type in section 2, zones A, A', B, B', C and C'



Appendix Figure 6: Comparison of salinity in section 2, zones A, A', B, B', C and C'



Appendix Figure 7: Comparison of pH is in section 2, zones A, A', B, B', C and C'