Mangrove forest extent and status along the Eritrean Red Sea coast

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Abstract

A mangrove forest species and spatial extent study has been conducted in Eritrea to see if there has been mangrove forest area change over the last two decades, and to describe mangrove cover status. GIS, field work data and remote sensing were used in the study. Supervised classification (Maximum Likelihood Classification technique) was used for remote sensing Landsat image classification. Pre-calculated NDVI value has been shown to represent and extract the amount of mangrove greenness cover along the study areas of Massawa and Assab. NDVI values are also used to see relationship with mangrove stem density per quadrant. There are three mangrove species identified in the study areas: *Avicennia marina, Rhizophora mucronata and Ceriops tagal.* They are generally limited to sheltered environments like bays, channels and semi closed inland side. *Avicennia marina* is the most dominant species. The results indicate that mangrove forest spatial extent covered an area of approximately 8900 ha in 1994, which had already declined by 7.7% in 2014. Anthropogenic impact and natural mortality could reasons for the mangrove forest loss.

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Contents

Abbreviations

cm	centimeter
ECMIB	Eritrea coast Marine and Islands Biodiversity
ETM	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization
FCC	False Color Combination
GBIF	Global Biodiversity Information Facilities
GIS	Geographical Information System
GLAS	Geoscience laser Altimeter System
GPS	Geographical Position System
ha	hectare
ICESat	Ice, Cloud and land Elevation Satellite
IFAD	International Fund for Agricultural Development
IUCN	International Union for Conservation of Nature
LGBH	Largest Girth at Breast Height
LH	Longest Height (maximum height)
MLC	Maximum Likelihood Classification
NDVI	Normalized Difference Vegetation Index
PSU	Practical Salinity Unit
OLI	Operational Land Imagery
SRTM	Shuttle Radar Topography Mission
SWIR	Short Wave-Length Infrared
TM	Thematic Mapper
TRI	Thermal Infrared imagery
UTM	Universal Transfers Mercator
USGS	United States Geological Survey
VNIR	Visible Near-Infrared
WGS	World Geodetic System

CHAPTER 1 INTRODUCTION

1.1 Importance of mangrove

Mangrove forests are typical ecosystems in tropical and subtropical coastal regions of the world (Hotel, 1995). Mangrove forests have huge value, an estimated of $1.6 trillion per year value service delivered from mangrove ecosystem mainly in terms of coastal protection, food, nursery area, nesting and firewood production (Costanza *et al.*, 1997, Cavanaugh *et al.*, 2014). Mangrove forests are distributed in intertidal zones where ocean, fresh water and brackish water meet in approximately between 30^0 N and 30^0S latitude (Giri *et al.*, 2011, Donato *et al.*, 2011).

Mangrove forests are important nursery areas. Mangrove forests are among the most ecologically and economically essential coastal ecosystem, providing crucial service such as food and habitats to different migratory birds and wide variety of marine creatures (Igulu *et al.*, 2014, Cavanaugh *et al.*, 2014). Mangrove forests are believed to be home of a high diversity of fauna including crustaceans, amphibians, teleost, mollusks, mammals, reptiles, birds, insects and micro-organisms (Han, 2011, Sremongkontip *et a*l., 2000). High numbers of fish and marine invertebrates use mangrove roots as special under water habitats during breeding period and early life stages (Laegdsgaard & Johnson, 1995, Feller, 1996, Abu El-Regal & Ibrahim, 2014). Coral reefs adjacent to mangrove harbor higher numbers of adult fish densities compared to coral reefs located further from these ecosystems (Mumby, 2006). Mangrove forests are relevant for different purposes throughout the tropics; as fishing areas, wildlife reserves, recreation, human habitation and aquaculture (Salam *et al.,* 1997). Without proper management and monitoring of mangrove forest, impacts on the spatial extents are expected.

1.2 Mangrove threats

Mangrove wetlands are a dominant feature of undisturbed tropical and subtropical shorelines around the globe. Throughout their range, however, these habitats are in a state of decline. Nearly 16% of mangrove species are at an elevated chance of extinction globally (Polidoro *et al.*, 2010). Approximately one-third of the world's mangrove forests have been lost to coastal development over the past 50 years (Craig & Faunce, 2006). Kathiresan (2008, p.476) said that "Approximately 90% of the global mangroves are growing in developing countries and they are under the condition of critically endangered and nearing extinction in 26 countries" The mangrove experts suggestion are that services offered by the mangrove forest may possibly be lost in the coming 100 years (Duke, 2007). As mangrove forests are the only coastal vegetation of the tropical and subtropical regions, they have been exploited often over the last two decades, at different scales in different regions (FAO, 2007). Global average annual mangrove loss was greater in the 1980s; estimated as 1.04% and 0.72% in 1990s (Spalding, 2010).

To determine the possible natural threats on mangrove forests, these must be considered against background natural disturbance, like cyclones which are common along tropical latitudes (Alongi, 2002). Other natural impacts, related to health problems at different parts of mangrove stands can lead to dieback, which is disease which attacks leaves first and moves from leaves, branches and twinges to the main stem (Alongi, 2002). Mangroves can be susceptible to disease and pests when stressed by physical input and pollutants in soil substratum such as salinity change, oil spills, herbicides, metals, sewage and acids, as well as damage from storms and cyclones (Alongi, 2002).

Natural mass mortal of mangrove, which is tree mortality that occur in response of rapid change in environment, camel grazing, cutting or logging are threats along Red Sea coast and the main reason for mangrove degradation and loss (Khalil, 2004).

1.3 Mangrove area cover and species distribution globally and in Eritrea coast

The total coverage of mangroves remains uncertain. The first attempt at estimating mangrove area cover in the world was conducted in 1980 and was estimated at 15 million ha (FAO, 2005). Later on, world mangrove area cover estimates range between 11 to 24 million ha, (Wilkie & Fortune, 2003; FAO, 2007). These variations could be due to different data sources, lack of uniformly accepted definition of mangrove communities or mangrove habitat, methodology or enhancement of technology for studying mangrove distribution through spatial and temporal dataset. According to Saenger (1995), African mangrove cover approximately 4.6 million ha of which 3.1million ha is found along western African coastlines, 0.33 million ha in Madagascar and 1.14 million ha in eastern Africa. Of this, approximately 10200 ha (102 km^2) area is found in Eritrea Red Sea Coast and Islands (Spalding & Kainuma, 2010). However according to the FAO (2005) and Fatoyinbo *et al.,* (2013) mangrove cover in Eritrea is estimated to be around 6400 and 4900 ha, respectively.

Despite there having been several studies on the number of mangrove species, there is currently no consensus. According to Spalding *et al.*, (1997) there are 9 orders, 20 families, 27 genera and 70 species of mangroves. However these were later reviewed, with true mangroves (not mangrove associate species) comprising of 54 species in 20 genera, belonging to 16 families (Hogarth, 1999).

In the Red Sea region, mangrove forests occur mainly in sheltered areas behind reef flats of fringing reefs, bays or creeks, in the lee of offshore islands and on some offshore islands distributed as forest, patches and stands (Saenger, 2002). Similarly to other Red Sea countries, Eritrea has mangrove ecosystems in semi-desert areas. They are comprised of two families; *Rhizhophoracea* and *Avicenniaceae* of which three species are represented. In Eritrean coastal communities, mangrove trees are of economic significance as a major source of firewood, timber for construction and for repairing fishing vessels as well as temporary housing. Furthermore, mangrove forests are grazed upon by domestic animals.

1.4 The role of field work and remote sensing data

At present, there are few studies which have information (Table 1) related to Eritrea mangrove forest species diversity, distribution and mangrove area change over time. Extensive fieldwork was conducted along the Eritrean coast during 2006/7 in order to collect mangrove data. These are quantitative and qualitative data on the mangrove forests of the Eritrea Red Sea coast and islands. The main purpose of the survey was assessing the mangrove vegetation status, as well as the intensity of anthropogenic and natural impacts. Furthermore, identification and characterization of mangrove species and their location were observed and measured.

In addition to the collected mangrove field work data, remotely sensed data are the best source of information which can show the location of mangrove and their status (Sremongkontip *et al.,* 2000). Remote sensing has been used widely to determine and detect changes in the coverage of vegetation type. Multi-date satellite image data can be used effectively to ascertain changes in areal extent of mangrove (Kishor and Singh, 2014). Remote sensing of objects plays a great role in collecting valuable land cover information, which is particularly useful when considering areas which are difficult to reach and penetrate such as mangroves along the coast and on islands (Sulaiman *et al.,* 2013, Wang *et al.,* 2003). It enables the gathering of information related to spatio-temporal, community assemblages, estimation of vegetation cover, and change in shorelines, coast and intertidal (Kuenzer *et al.*, 2011). Spectral response of vegetation is attributed to the physical properties of leaves and stems of trees which give a strong spectral response by absorbing visible near-infrared (VNIR) and short wave-length infrared (SWIR) regions (Howari *et al.*, 2009). Remote sensing can be an inexpensive method for data collection and combined with the analytical capability of GIS, can be used for analyzing the type, location, and rate of mangrove area changes. Importing recorded ground truth data (GPS reading) to GIS facilitates and integrating the data with Landsat images is possible (Wang *et al.*, 2003)

For this study Landsat images such as Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 have been acquired from United States Geological Survey (USGS).

In this thesis, Geographical Information System (GIS) and remote sensing analysis were used to conduct temporal analysis. Studying remote sensing image-analysis in conjunction with ground truth mangrove locations and mangrove structure measured data will give information related to: mangrove area change over the last 20 years, potential of Landsat classification accuracy and mangrove structure characteristics (mangrove diameter at girth height, density and height) and latitude in the study areas.

1.5 Objectives

The main objectives of this study are as follows;

Investigate whether there has been a change in mangrove area cover in Eritrea coast over the last two decades.

Describe mangrove forest status and threats along the Eritrea Red Sea coast and islands.

CHAPTER 2: BACKGROUND INFORMATION

2.1. General information on the Eritrea Red Sea Coast and Islands

The Red sea is a long and narrow body of water separating north east Africa from the Arabian Peninsula in Asia. It is connected with the Suez Canal to the north and the Indian Ocean through the Bab el Mandeb, in the southern part near the Gulf of Aden. Surface water temperature ranges between 12-25^{o}C. Salinity is higher than the world average with approximately 40 Practical Salinity Unit (PSU); this is due to high rate of evaporation and the small rainfall input as well as the lack of significant rivers or fresh water flow in to the sea. It is also characterized by semi locked water body properties, not mixing with other less saline water bodies (Kumar *et al*., 2010).

Eritrea is located on the horn of east Africa. It is located between 12 and 18^{o} N and 36 and 42^{o} E, including islands. It has about 1350 km mainland coastline and over 350 islands which add another 1950 km of shoreline. About 5% of national population resides in the Eritrea Red Sea coast. Most of them live in the urban port cities of Massawa and Assab as well as in many small towns and villages along the coast and islands (Figure 1).

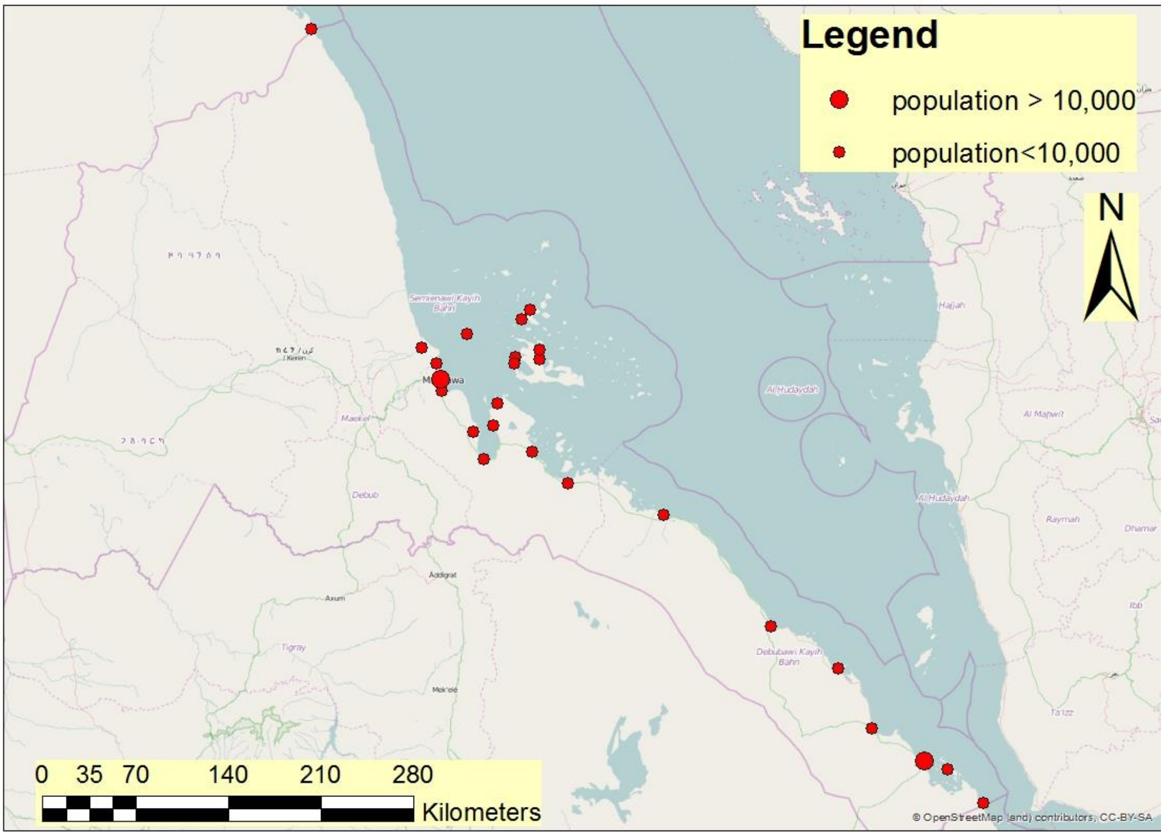

Figure 1: Villages and towns along the Eritrea Red Sea Coast and islands

2.2 Temperature and rainfall

The Red sea region is characterized by warm weather. It is very hot in the summer from May to September with maxima Jun-August (Figure 2). Average temperature and annual rainfall are recorded as 30°C and 205 mm respectively along the central Red Sea coast (Figure 2). Precipitation around the coast is generally characterized by short, fast showers accompanied by thunder and dust storms. Most of the seasonal river and streams that flow into the sea through mangroves sites are sourced in highland areas which are typically characterized by higher annual rainfalls.

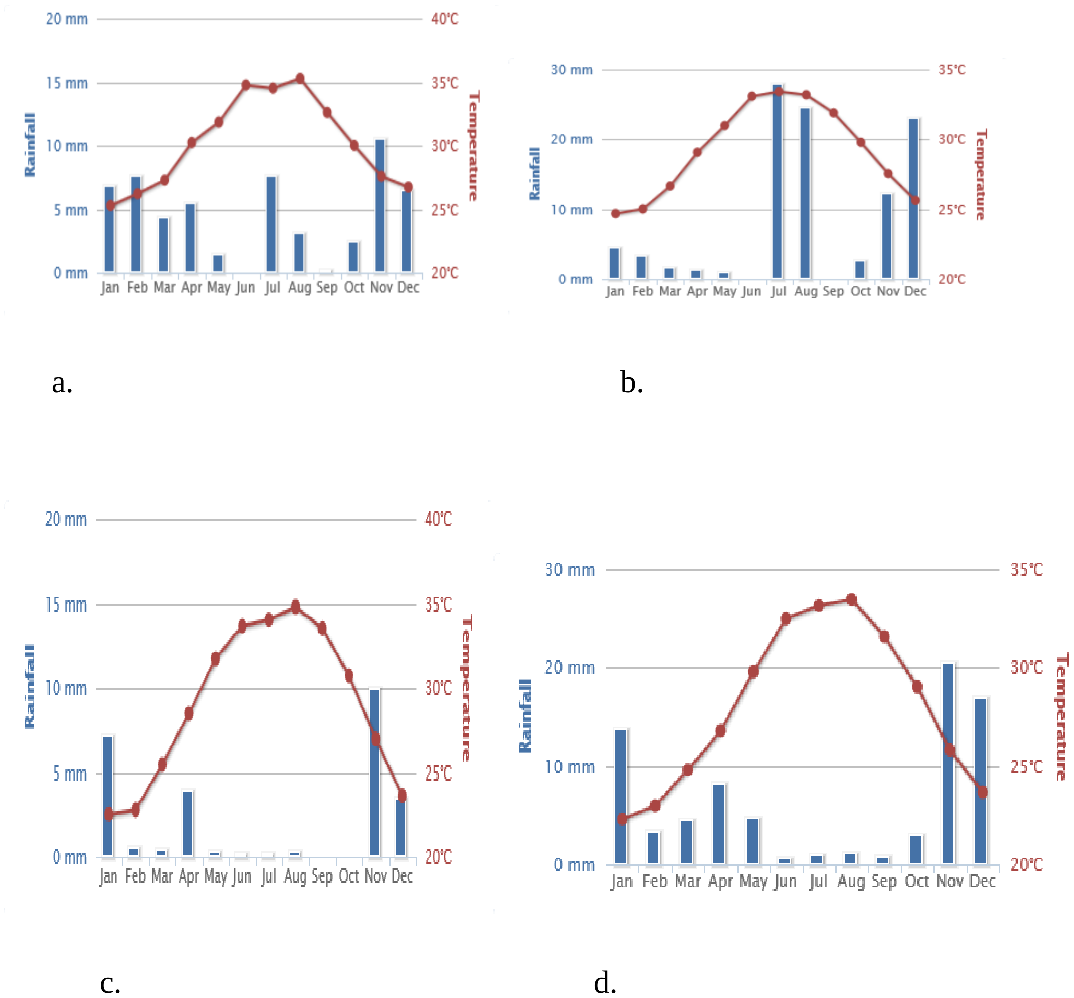

Figure 2: Average monthly temperature and rainfall for Eritrea from 1990-2009 in (a) Assab area, (b) Massawa area, (c) North, Berite area, (d) Dahlak Archipelago area (Source: The World Bank Group 2015).

2.3 Mangrove species and their status in Eritrea

There is little tree biodiversity and abundance of mangrove distribution along the Red Sea coast. This could be due to few tree species which can withstand high salinity, high temperature and less rainfall, anaerobic sediments and unstable substrate being present. This is also supported by Fatoyinbo and Simard (2013), who observed reduced mangrove area in the Indian Ocean and Red Sea compared to the length of coastline; this could be due to arid condition of the Red Sea region.

No comprehensive or extensive baseline information on the distribution, coverage, uses, and status is available in relation to mangrove areas along Eritrea's Red Sea Coast and Islands specifically. According to FAO (2005), recent Eritrea thematic mangrove studies describe four species of mangrove in an area of 6400 hectares. Fatoyinbo and Simard (2013) estimated mangrove area cover in Eritrea to be 4900 ha, see Table 1 below. According to the latter study, Eritrea can be categorized as the country with the largest mangrove area of the African Red Sea countries.

Table 1: Mangrove area estimated in Eritrea from literature

Year	Mangrove area (ha)	Source	Using/Methodology
1997	6400	FAO, (2007)	Remote sensing
2000-2005	6400	FAO, (2005)	Expert estimates based on the qualitative information currently available for this country
2010	7400	IFAD, project design report	Unpublished,
2010	10200	Spalding & Kainuma, (2010)	Landsat imagery map, review
2013	4900	Fatoyinbo & Simard, (2013)	ICESat/GLAS and SRTM

2.3.1 *Avicennia marina*

Avicennia marina is the most dominant mangrove species in Eritrea. Based on field work observation, this species grows and tolerates harsh saline environment in closed islands, which are characterized by high salinity due to high evaporation conditions. Mangroves exhibit several different types of mechanisms for copying with highly saline conditions.

Avicennia marina is able to take up sea water through their roots and excrete salt using salt glands located at the surface of their leaves (Liang *et al*., 2008)

Figure 3: *Avicennia marina*, Rasterma coast (left), algae covered pneumatophore *Avicennia marina*, Erwa Island (right) (photo were taken during field work as part of data).

2.3.2 *Rhizophora mucronata*

Rhizophora mucronata, also known as red mangrove, is the second most dominant mangrove species. They have special root structure called prop roots that are long, above-ground extensions reaching from the parent stem and anchoring in the water logged mud. These roots structure give strong support to mangrove stands and are used as nursery areas for small fauna (Figure 4).

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Figure 4: *Rhizophora mucronata* from Isratu Island (left) and *Rhizophora mucronata* propagules collected during field trip (right) (photo taken during field work).

2.3.3 *Ceriops tagal*

Ceriops tagal, is the third and least dominant mangrove species in Eritrea which is only found in a limited area. It is categorized under the *Rhizophoracea* family and displays similarity with *Rhizophora mucronata* in terms of the leaves and propagules. However, *Ceriops tagal* seems smaller in size when compared to *Rhizophora* and its propagules have less roundness with edges, when compared to *Rhizophora mucronata's* propagules. This is supported by Gissen *et al.*, (2007). According to International Union for Conservation of Nature (IUCN, 2010), this species is not mentioned as present in Eritrea, although residing in few African countries. See figure 5 below for *Ceriops tagal* distribution based on data from the IUCN Red List of Threatened species.

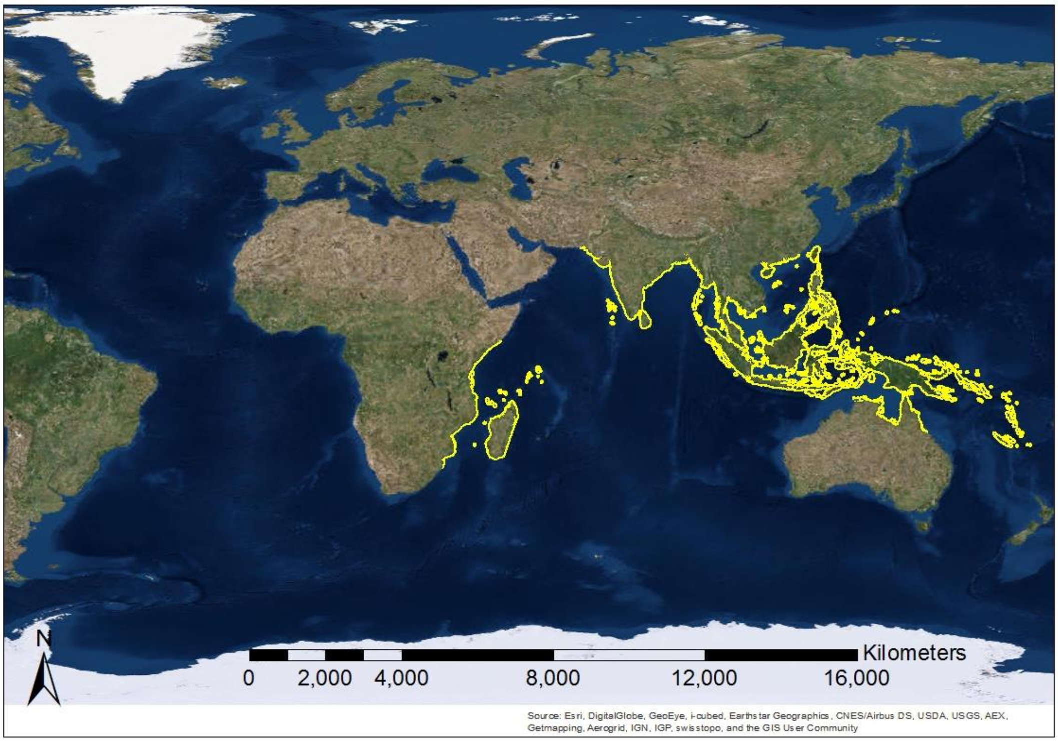

Figure 5: *Ceriops tagal* global extent (source: IUCN Red List of Threatened species, 2010)

2.4 Threats facing mangrove forest in Eritrea

Mangrove forest could face threats from different sources which can be categorized as either natural or anthropogenic threats. There are many factors contributing to the loss of valuable mangrove ecosystems. Clearing and cutting of mangroves are the main reasons for mangrove deforestation as in many countries people may not understand the importance of mangroves and plan to alter them for agricultural, urban expansion, fishing and the tourism industry and more recently shrimp farming (FAO, 2010)

2.4.1 Urban development and road construction, fresh water flow/seasonal stream diversion

After the country became independent in 1991, there has been much development. Although there was no detailed studies of the deforestation due to urban development, Massawa-Assab's new road construction and new road around the free zone in Massawa city (Figure 28) can contribute to mangrove forest and other associated fauna loss. Lack of proper urban development planning such as roads, jetties, buildings and bridges construction near to mangrove ecosystem can lead to the pollution of ecological habitat destruction. There are also other land based agricultural activities that can act as threats to mangroves. This can lead to increase sedimentation in and around mangrove roots as well as increased in salinity at mangrove sites (Wood *et al*., 2000).

2.4.2 Grazing and cutting/logging

Cutting and grazing are the two largest mangrove threats for mangroves adjacent to coastal and islands communities. Fishermen cut down mangrove tree during fishing, shell collection and sea cucumber harvesting. Mangrove forests are mainly cut down for cooking, boat repair and for temporary shelter. According to Semere *et al.*, (2008) mangrove trees in Eritrea are cut down for cooking and windbreaks, even though mangrove forest are found as ecologically important for eight bird species in Eritrea islands. In addition to cutting, communities herd domestic animals and graze them on mangrove leaves and seeds. Camel, goat and sheep are common livestock in the coastal communities (Figure 6).


Figure 6: Examples of Eritrea coastal inhabitants benefitting from mangrove forest

2.3.3 Natural threats

Some natural phenomena occurring due to climate changes can destroy mangrove forests. Natural events, such as tsunami and storms, as well as sediment movement and fresh water diversion may cause mangrove deforestation (Lacerda, 2002). Temperature rise followed by high evaporation may lead to increased sediment salinity in landward mangrove fringes and this may cause mangrove mortality (Huxham *et al.*, 2010). According to Khalil, (2004) mass mangrove mortality was reported in the Red Sea countries such as Sudan and Yemen due to environmental change like 1997/98 El-Nino.

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CHAPTER-3 THE STUDY AREAS

Mangrove surveys have been conducted along almost all the mangrove forest or patches of the Eritrean Red Sea coast and islands during 2006/07. The survey was conducted by mangrove team which was administrated by ECMIB project. Main objective of the survey was to assess mangrove forest structure and distribution along in Eritrea. Study areas include the northern tip bordering with Sudan, Dahlak Archipelago including Dahlak Kebir , Massawa , Zula, Gela'lo and the Harena area with their proximate islands. The southern study area lies mainly around Assab bay and extends from Barasole, Rastarma area to Haleb Island (approximately 45 km south of the port city of Assab. See Figure 7 mangrove survey area location.

Mangrove forest survey area

A. Southern (Barasole, Assab and nearby islands)

B. Gela'lo area –an extension of Zula bay area to Tio

C. Central coast (Massawa port city and Buri/Zula bay area)

D. Northern (Berite, Marsa Mubareka area)

E. Dahlak Archipelago

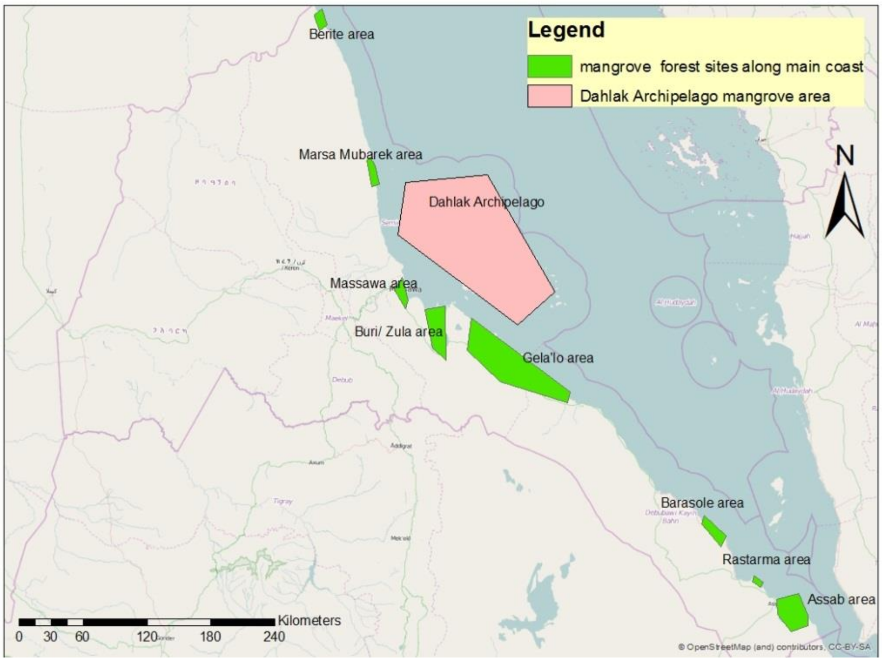


Figure 7: Mangrove forests study areas along Eritrea coast

3.1 Southern study area

3.1.1 Barasole area ($13^0$32.312 -$13^0$39.706'N)

Barasole is a village located along the Massawa- Assab road in the southern Red Sea region which is 120 km road distance from Assab port city to the north. The area on the lee ward side is characterized by black, rocky burned stone. Dense mangrove forests cover the shallow and closed intertidal and white sandy coast.

3.1.2 Assab bay area ($12^0$46.176' -$13^0$13.745'N)

Most of this mangrove study area is located in Assab bay. It extends from Rasterma coast to Assab port city and many small and large islands grouped and located in Assab bay within $12^0$46.176' -$13^0$13.745'N. In general strong current is observed around Assab offshore, this is thought to be due to the Indian Ocean current turbulences.

3.2. Gela'lo - Tio survey area

This study area covers large areas of the coast and nearby islands between Zula and Tio. It covers about 120 km road distance. This study area has a number of indented coastal landforms. Mangrove forest are distributed as patches in the majority of this study area, and as continuous forest in Harena located around Gela'lo. There is seasonal fresh water flowing into the sea at different locations area over a very wide and shallow intertidal area.

3.3 Central study area -including Massawa area and Zula area

3.3.1 Massawa area coast and Green Island

Mangrove trees extend along the coast to Hirgigo village. The Massawa area survey is located between $15^0$30.842'& $15^0$41.299'N latitude. See Figure 8

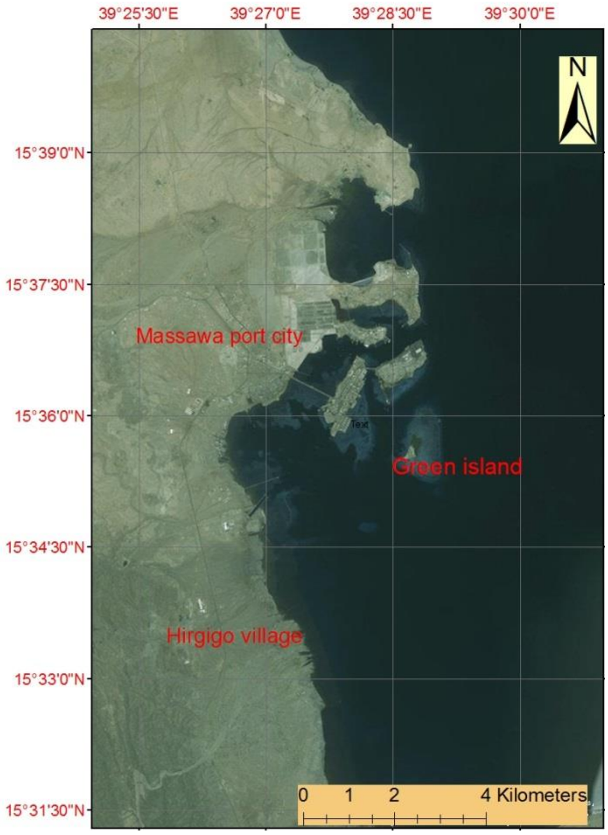


Figure 8: Massawa port city coast- study area

Green Island is the nearest island to Massawa which is characterized by dense *Avicennia marina* forest cover (approximately 50% of the island).

3.3.2 Zula area

The study area is located around the largest gulf in the Eritrean coast see figure 7. There are many villages located near to mangrove forests along this coastal study area. There is a seasonal fresh water flow to the sea in the western and south parts (Irafaile) of Zula bay. Dessie Island is adjacent to Zula bay. It is about 34 km distance from Massawa to the south. It is a village area characterized by hilly and mountainous terrain.

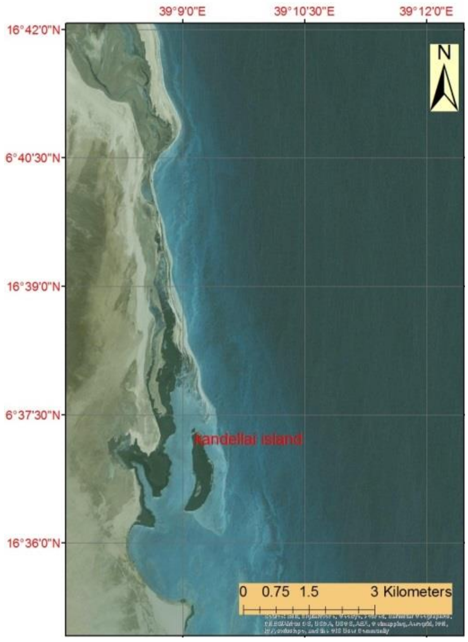
3.4. Northern coast –study area

3.4.1 Berite area

It is an area which is located between $17^0$55.134'N & $18^0$1.185'N at the most northerly boarder with Sudan. It is characterized by long muddy shallow intertidal areas. Dense mangrove forests are located in shallow and protected areas of the coast. Small mangrove patches found on a nearby island.

3.4.2 Marsa Mubarek and Marsa Ibrahim study area

Surveyed coast and islands grouped in this study area include two large mangrove forests. These mangrove forests composed of: Marsa Mubarek with island of Kandellai and Marsa Ibrahim as well as two small and very nearby islands called Hamadan and Hamadan 1, forming large mangrove forests in the area (see Figure 9). They are located between 16^{0}29.975'and 16^{0}40.286'N latitude. This study area is named as - Marsa Mubarek in all sections of this study. Mangroves are located in protected areas where reduced current disturbance exist due to a very wide and shallow intertidal zone. The two big mangrove forests are around 10 km apart north–south, in a wide and arid lowland area along the coast. There seems to be two to three seasonal fresh water streams which flow through the mangrove forest to the sea.



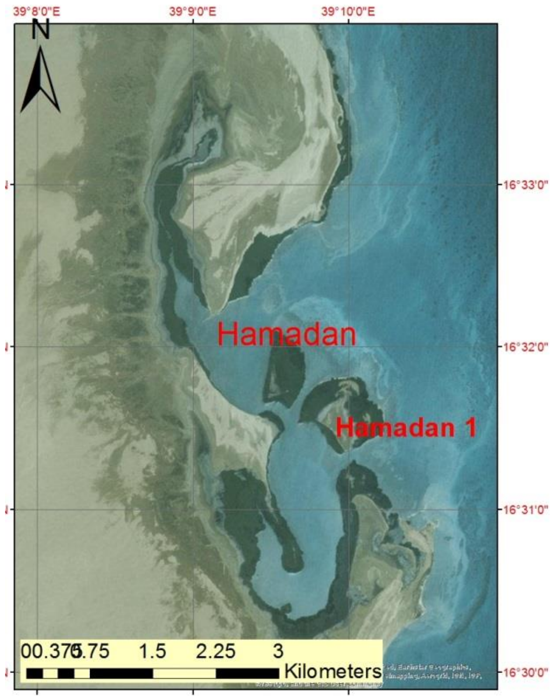


Figure 9: Berite study area bordering with Sudan-location (top), Marsa Mubarek area and near Kandellai Island (bottom left) and Marsa Ibrahim mangrove forest with the two closest islands (bottom right)

Three mangrove species are found in the study area. White muddy, brown silt is common soil type found in the *Rhizophora* and *Ceriops tagal* location. In some of the mangrove forest sites, sand dunes are elevated above the height of mangrove trees on landside.

3.5. Dahlak Archipelago study area

Mangrove forests grow on islands. A group of small and large islands form Dahlak Archipelago on the widest section of the Red Sea across Massawa. Most of the islands are constructed of dead corals, uplifted fringes, and channels as well as sand. These islands are well known for their diversity of marine organisms and avifauna, of them Dahlak Kebir is the largest island followed by Norah Island. Seven of them are permanently in-habited (Figure 1), most of them are fishermen, and in some islands signs of bivalve, mollusk collectors and sea cucumber camps are observed. Furthermore a few Eritrean navy bases are located on some of the islands.

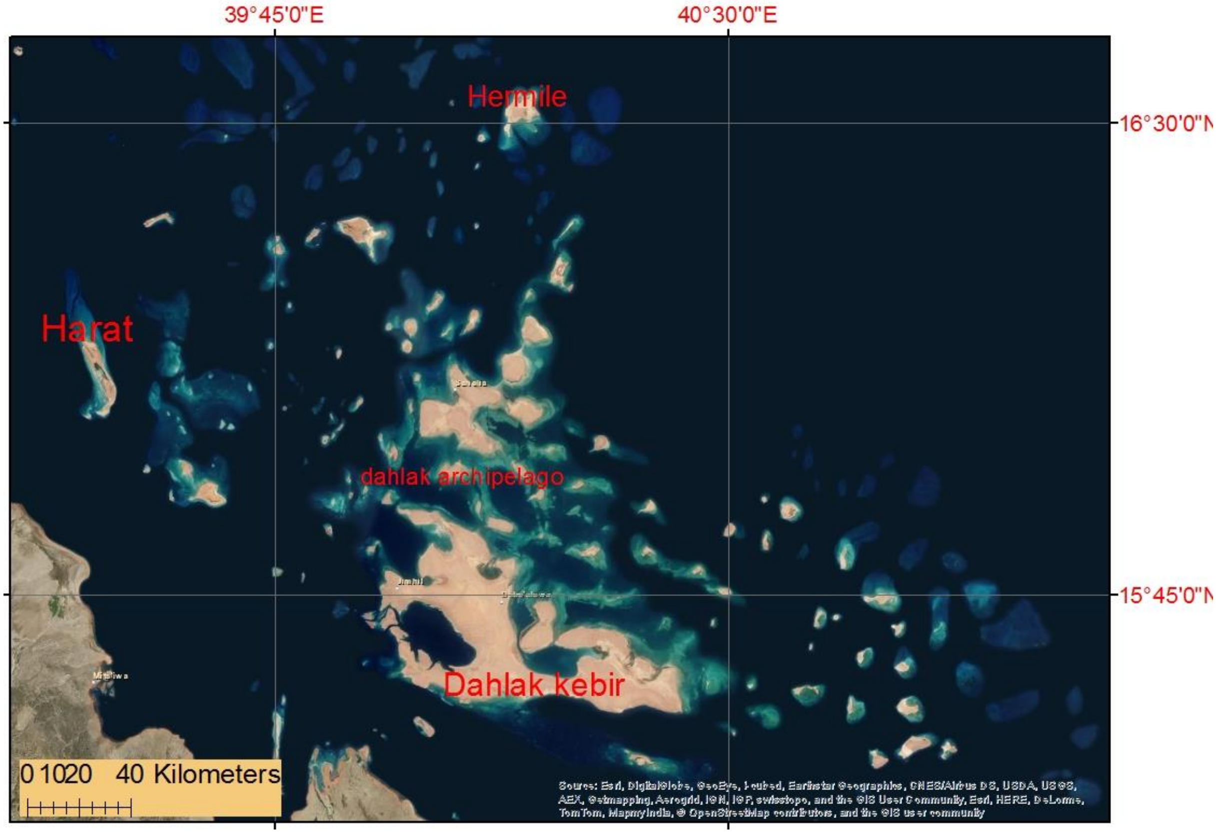


Figure 10: Dahlak Archipelago study area

CHAPTER 4: METHODOLOGY

4.1 Quantitative and qualitative mangrove field data collection

Various field data related to mangrove forest have been collected from the Eritrean Red Sea coast (see Figure 7) during 2006/7. The data includes tree height, diameter at breast height, number of seedling and associated fauna and floras as well as visual observation of natural and human impact intensities on mangrove forest. Data were collected using the Standard Survey Method. This method was developed by the Regional organization for the conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA).

A $100m^2$ area quadrants was used to measure quantitative mangrove tree structure such as height, girth at breast, number of mangrove trees and number of seedling. The numbers of quadrant ($10X10m^2$) per site were decided based on size and structure of mangrove forest (either small patches areas or forests). For large mangrove sites, a number of quadrants were applied approximately every 500 m apart for taking three samples at a time, taken perpendicular to the shore for collecting data on lee ward, sea and middle (between leeward and seaward). A small quadrant ($0.5X0.5m^2$) was placed randomly within the big quadrants in all the surveys to have data on pneumatophores i.e root structure of mangrove vegetation.

4.1.1 Recording vegetation data and analysis

Availability of species and their structural measurements were filled out in two tabular worksheets. Vegetation structure or quantitative data of mangrove trees (mangrove stands above ground in some height and has stem and branches) were recorded in the data sheet. Data on pneumatophores including their density and structure (are they branched, twisted, dead) were recorded from the small quadrant. Existence of mangrove associated flora and fauna were recorded in number and species.

Several materials were used for collecting the data. A Global Position System (GPS) was used to locate and record the coordinate of the quadrant position. Tree height (shortest and tallest tree) and girth at breast height size (the thinnest and thickest tree) within each quadrant was measured using a measuring meter. A digital camera was also used for taking pictures during the assessment period.

Quantitative data measurements can be analyzed using a statistical estimation method. Mangrove population densities were estimated from mean of mangrove density of the quadrants. Densities of mangrove in all the study areas of this thesis were calculated in order to compare between study areas and latitudes. Largest girth at breast height and maximum tree height, number of seedling vs mangrove tree density and maximum tree height against mangrove tree density per quadrant were analyzed through regression analysis.

Human impact assessment on mangrove forest was carried out along the Eritrea coast study areas. The recorded human and natural impacts on mangrove vegetation were based on ground truth observation. Human threats on mangrove forest can be due to cutting for different purposes such as for fire wood, fishing, grazing, shell collection, sea cucumber harvesting, and salt pan activities. On the other hand natural mortalities can be from sediment movement, cut of fresh water flow due to sand deposition or bank erosion or dieback diseases. They marked as high, moderate, low and No Record (NR) for identified threats. High= mangrove forest severely grazed by high number of domestic animal (mostly camel) or severely cut. Many trees even in the middle and inside mangrove forest are grazed or cut. Moderate= mangrove tree growing on outer fringes of stands are partly or severely grazed/cut. Low= some accessible trees on outer fringes are browsed/cut, NR= mangrove stands that are not affected.

4.2 Remote sensing data

Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 images for my study areas were downloaded and analyzed in ArcGIS. Spatio-temporal Landsat image analysis was focused on 10 years gap, for the periods of 1994, 2004 and 2014. Remote sensing Landsat images from these different time periods were used to map and determine whether there had been change in mangrove area cover. However there are no clear images of 2004 due to a scan line problem using Landsat 7 images and there are no even images of Landsat 5 from 2004 -2009 for the study areas. Therefore, only image data from years 2000 to 2003 were analyzed instead of those from year 2004 Landsat 7 images. The acquired Landsat images are processed in ArcMap 10.2 and followed figure 11 diagram. Different Landsat images have different band numbers and these bands are composed to create one single raster. False Color Composite bands (FCC) were generated using three available bands (Red, Green and Blue) combinations. Mangrove forest can be easily differentiated from open water, intertidal and dry categories based on their difference in spectral reflection. Supervised classification was used to classify the composed band images. Supervised classification is a process of classifying scene images based on selected training samples (see details on image process sub topic). Normalized Difference Vegetation Index (NDVI) is a measure or index of photosynthetic activities, which means greater the amount, the brighter the pixel will be (Jahari *et al.*, 2011). NDVI value was performed for identifying mangrove greenness along the study areas. GPS records from field work were also used for selecting mangrove category during the classification process.

4.2.1 Landsat data

Three Landsat images for each study area of years 1994, 2000/2002/2003 and 2014 were collected. The main characteristics of these collected images are described in the appendix i. Areas of interest (that include mangrove forest) for the study are within the collected datasets.

4.2.2 Landsat Image preparation

Avoiding of irrelevant (pixels) area from larger Landsat images was carried out by masking or extraction tools before analysis start. First, polygon shape files (masks) for every study area were prepared mainly by focusing on mangrove vegetation sites along the coast and islands by drawing in ArcMap. All the acquired and composed bands of Landsat images of study areas were clipped from larger multiband. Prepared shape files polygon has the same coordinates to every respective study areas.

4.2.3 Image processing - supervised classification and NDVI

Classification of Landsat images into categories is used to map and calculate area change. Composed bands of every study areas are categorized in to four classes such as open water, mangrove, intertidal and dryland.

Table 2: Assigned colors for categories

mangrove	(green)
dryland	(red)
intertidal	(yellow)
open water	(blue)

In this study, training samples which represent to each class are created in ArcMap using drawing tools on image classification toolbar. The training samples (to tell which pixels belong to which class) are selected based on False Color Composite (FCC) bands of Landsat images and field work experience of the study area. Selected training samples are grouped to the four classes, based on spectral similarities on training sample manager. Then signatures files were developed with equal cell weighing in which each cell in classes have the same prior probability. To make sure that classes are represented by training samples, checking or evaluating their spectral features are important. These were evaluated using histogram, scatterplot and statistics tools on training sample manager. Finally, Maximum Likelihood Classification tool (MLC) is selected to run classification process.

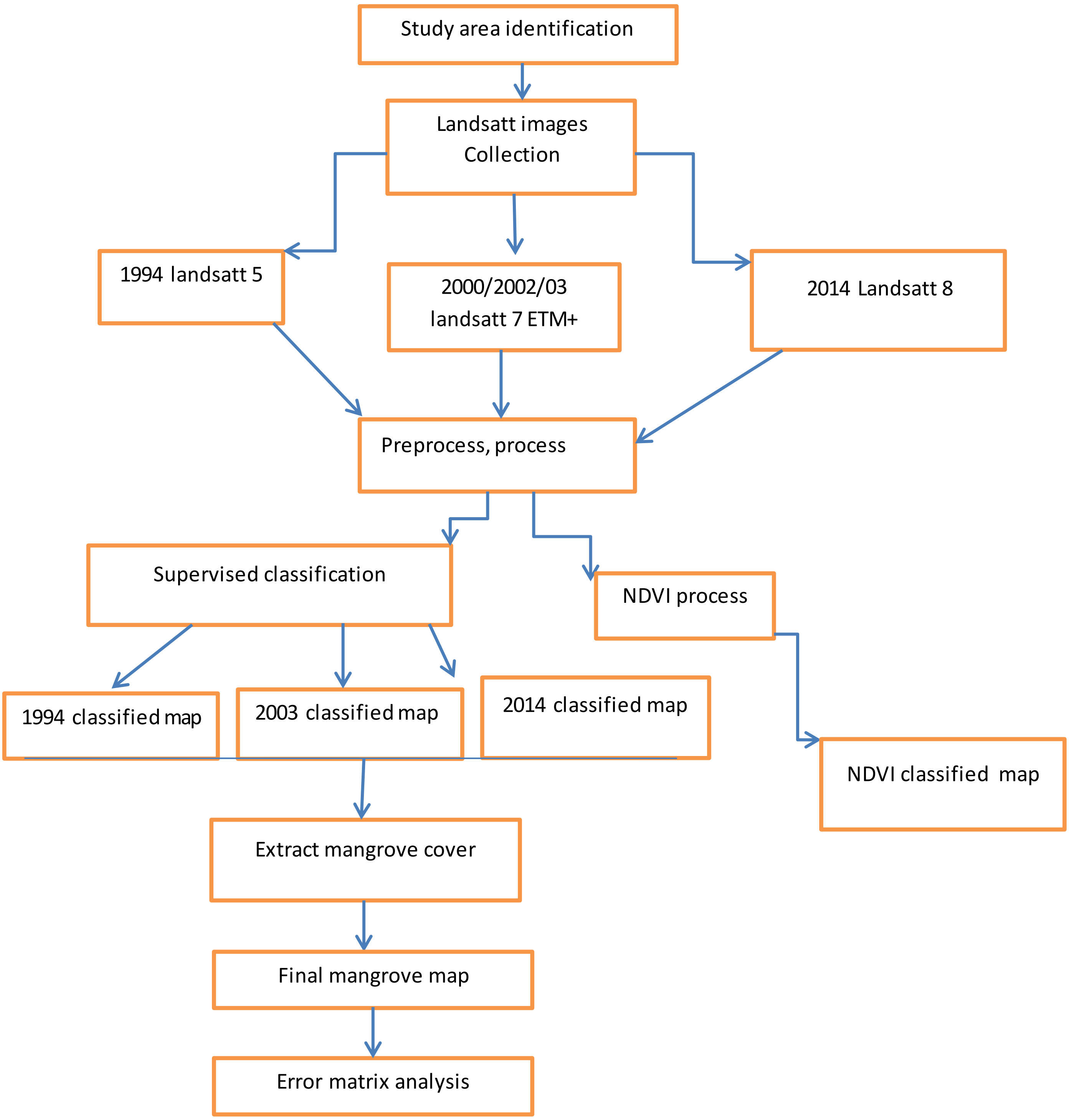


Figure 11: Diagram of remote sensing work flow

Mangrove forests area coverage for the specified years and sites were manipulated on ArcMap. Regression analysis was also used to determine whether a correlation exists between mangrove tree density per quadrant and their NDVI value. Vegetation indices are widely used as indicators for analyzing the variation of land cover among vegetation and other factors (Lee and Yeh, 2009). Vegetation absorbed red visible light and reflected near infrared. NDVI value (ranges from -1 to +1) were calculated in ArcGIS using a given mathematical algorithm in which the red value is subtracted from near infrared value and divided by the sum of red and near- infrared bands.

Finally, mangrove NDVI value between -1 and +1 were regressed with both mangrove density per quadrant and latitude. Mean NDVI value difference between 1994 and 2014 was tested using sample paired t test in Excel.

4.2.4 Accuracy assessment

Classified Landsat image has to be assessed for its compatibility to show how much it truly represented the real ground. Supervised classification is evaluated using an error matrix which is the most widely promoted and used method of accuracy assessment (Foody, 2002). A number (depending on the size of category type) of references points are randomly selected within their respective classes of multi band images. Created shape file points were assigned their respective class type before converting to reference point raster. Combining raster point reference and classified classes lead to creating an error matrix table through the pivot tool. The Eritrea Red Sea coast lies across two Universal Transverse Mercator (UTM). The Used shape files were projected to the WGS_1984 UTM ZONE_37 for Gela'lo area and above to northern as well as Dahlak Archipelago study area parts and WGS_1984 UTM ZONE_38 for southern study areas in order to match with their respective Landsat image characteristics. Producers accuracy, users accuracy and kappa coefficient and over all accuracy have been calculated in Microsoft Excel after exporting matrix table from ArcMap. Kappa coefficient (a discrete multivariate technique) was used to interpret the result of the error matrix. It incorporates the off diagonals observation of the rows and columns as well as the diagonal to give a more robust assessment accuracy than overall accuracy measures. It is calculated as:

$$k = \frac{N * \sum_{i=1}^{n} xii - \sum_{i=1}^{n} (x\,i + * \, x + i)}{\mathrm{N}^2 - \sum_{i=1}^{n} (xi + * \, x + i)} \qquad \text{(Congalton, 1991)}$$

Where, k= kappa coefficient, N = the total number of reference sites, n = the number of rows, xii = number in i column and i row, $xi+$ is sum of i rows and $x+i$ is sum of i columns

4.2.5 Mangrove forest area change

Changes in mangrove area cover at each study areas were calculated. To ascertain the extent and scale of mangrove forest area change, first mangrove forest area in each study area and specified study period were extracted.

Weighed overall accuracy assessment of the classified mangrove area map was calculated. Every classified study area map was reclassified and mangrove cover was extracted and then multiplied by their respective overall accuracy divided by the sum of all the extracted mangrove forest per selected timescale.

Weighed mean of overall accuracy % = sum (mangrove area of study area x overall accuracy of each study area)/ sum of mangrove area cover

CHAPTER 5: RESULT

5.1 Quantitative and qualitative mangrove field data analysis

Mangrove measurement results, mangrove species type and their status are described here.

Major mangrove forests are distributed from the middle toward the south (Gela'lo- Assab area) coast of the country; see figure 45 in appendix ii and summary Table 13. Most of the good mangrove forest cover is found in area with suitable substrate where fresh water mixes with the sea.

5.1.1 Mangrove species

There are two families and three mangrove species found in this survey. These three species are mentioned in Table 3. *Avicennia marina*: Majority of mangrove forests are dominated by the highly tolerant *Avicennia marina*, found alone or together with the other two species in different soil types and a variety of zones (leeward, middle and seaward zones).

Rhizophora mucronata: was found in 24 sites (quadrants) in the coasts of north, south and many surveyed islands. In many of the quadrants this species is found alone. The exact location (latitude and longitude) of this species is recorded and mapped in figure 12 top.

Ceriops tagal: Ceriop tagal is located inside a big mangrove forest especially in Marsa Ibrahim (16.53404N, 39.15978E), and Hamadan 1 island (16 ^{o}32'01.7"N, 39 ^{o}9'35.8"E) and Hamadan island (16^{o}31'42.2"N, 39^{o}10'04"E) which is located closely to the aforementioned bays in mixed (clay, muddy, sandy) sediment types.

Table 3: Identified families and species mangrove in the study areas.

No.	Family	Species	Common name	Local name
1	*Rhizophoraceae*	*Rhizophora mucronata*	Red mangrove	Abu gandela
2	*Rhizophoraceae*	*Ceriops tagal*	-	-
3	*Avicceniaceae*	*Avicennia marina*	Forsk	shora

No *Rhizophora mucronata* and *Ceriops tagal* are recorded on survey quadrants above 16^{0}45'N in Eritrean Red Sea coast and islands, see figure 12 below.

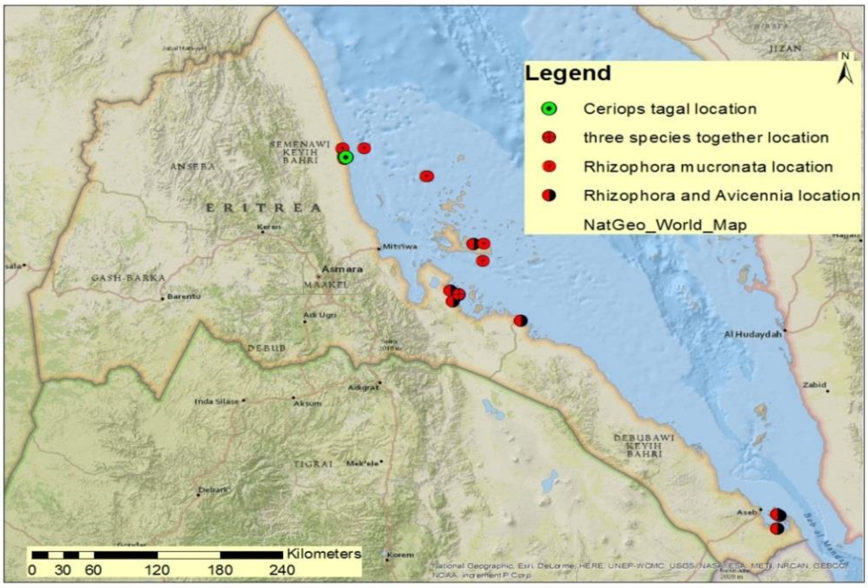


Figure 12: *Rhizophora mucronata* and *Ceriops tagal* species location with/without *Avicennia marina* (top), field trip photo of *Rhizophora mucronata* from Isratu Island (bottom left) and mixed *R. mucronata* with *Avicennia marina* mangrove forest south of Dahlak Island (bottom right)

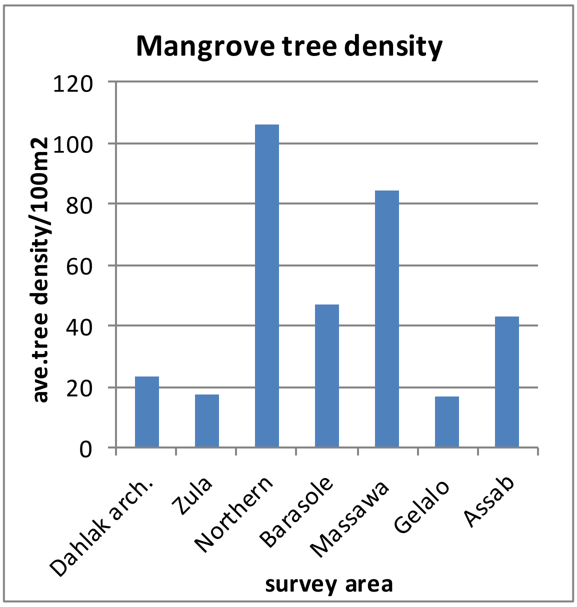
5.1.2 Mangrove tree structure

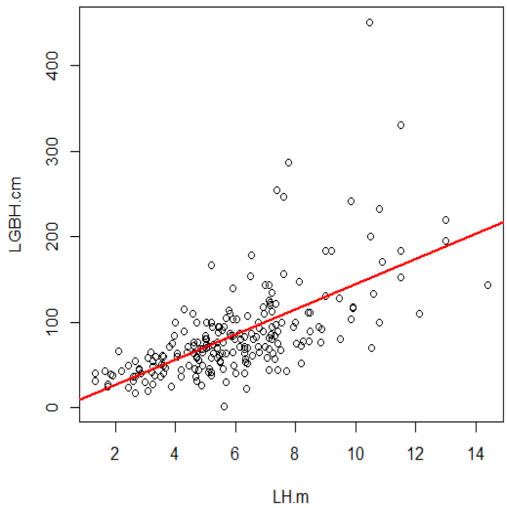
Mean population of mangrove tree density per quadrant is calculated.

Sample mean = 41.2 tree/ quadrant after eliminating outlier

Mangrove population mean density per quadrant = 41.2 +/- 44.8 tree standard deviation and standard error 3.1

Mean number of seedling =2118.95 seedling/ha





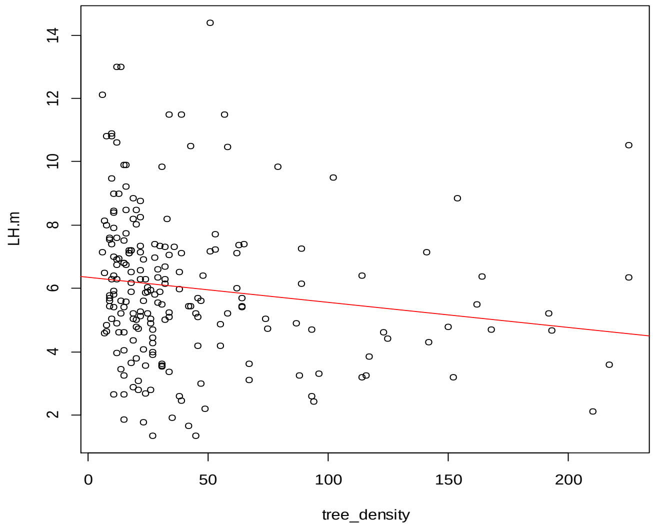


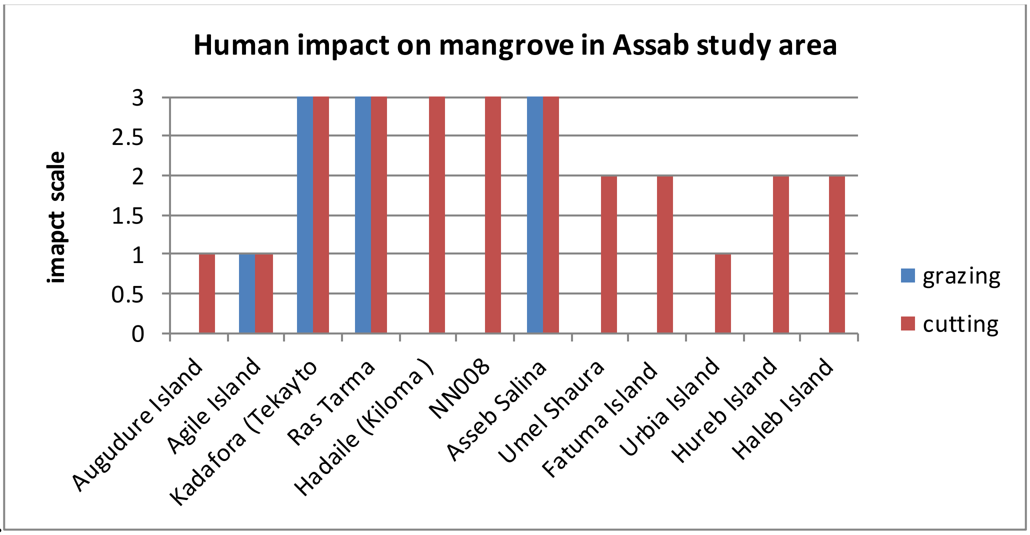
Figure 13: Mangrove tree density bar graph along the Eritrean Red Sea coast and islands study areas (top left), maximum height of mangrove tree (m) vs largest Girth at Breast Height (cm) per 100 m^2 quadrant (top right) and max.height vs mangrove tree density per 100m^2 (bottom)

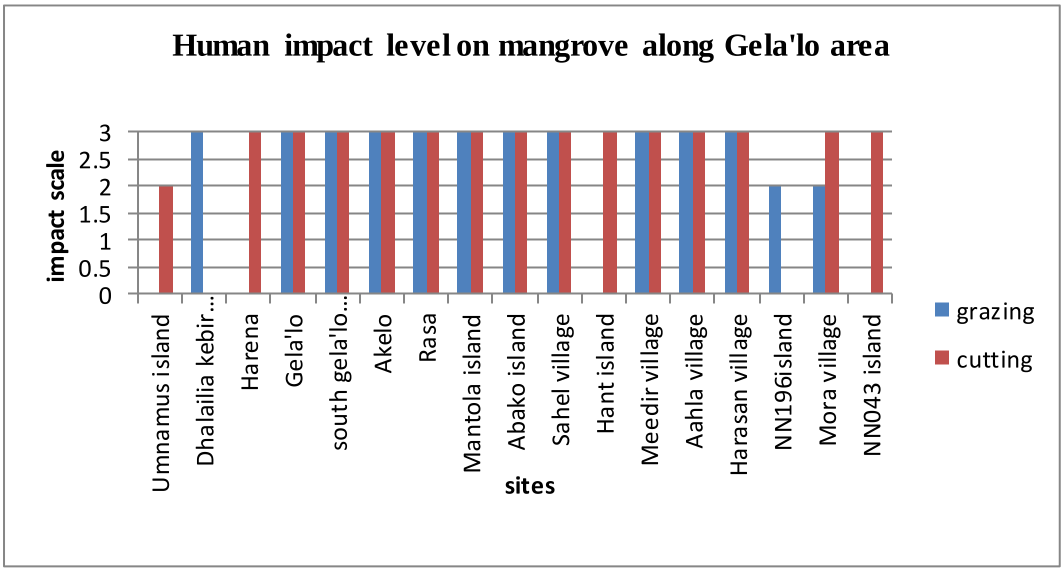
Denser mangrove stands per quadrant were found in northern survey area including Marsa Mubarek, Marsa Ibrahim and Berite. Less dense mangrove stands are observed in Zula and Gela'lo study areas which had a calculated density of less than 20 trees per 100 m^2 (Figure 13). Max.tree height and girth at breast height are significantly correlated at p-value: < 2.2e-16. Most of the tree stands are between 4 and 8 meter maximum height and 50 to 100 cm girth at breast height. Mangrove tree density vs maximum height were also significantly related at p-value: 0.03015.

5.1.3 Mangrove Threats

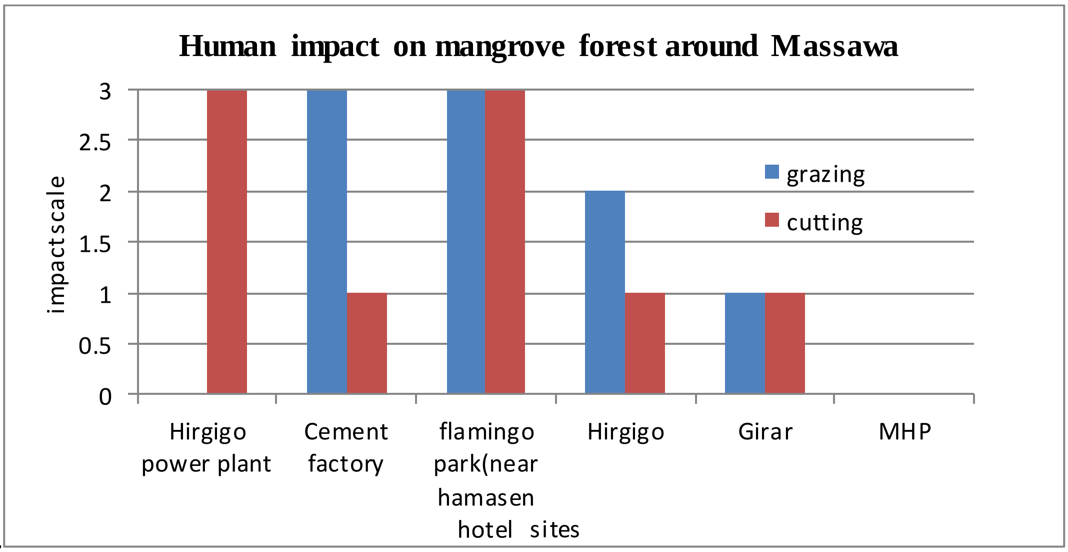
Human anthropogenic such as the felling of mangrove tree for timber, fishing activities and bivalve and mollusks collection and grazing vary from low to high across the study areas. Camel grazing on mangrove trees was observed during survey and can contribute to mangrove cover loss. Grazed mangrove tree per quadrant in percentage were recorded during the survey and are found related to mangrove area lost although it is not strong, see figure 15. A further replicate of the quadrant would have probably help to achieve significant correlation. There were more cutting threat than grazing along the Assab study area (Figure 14, a).

a.

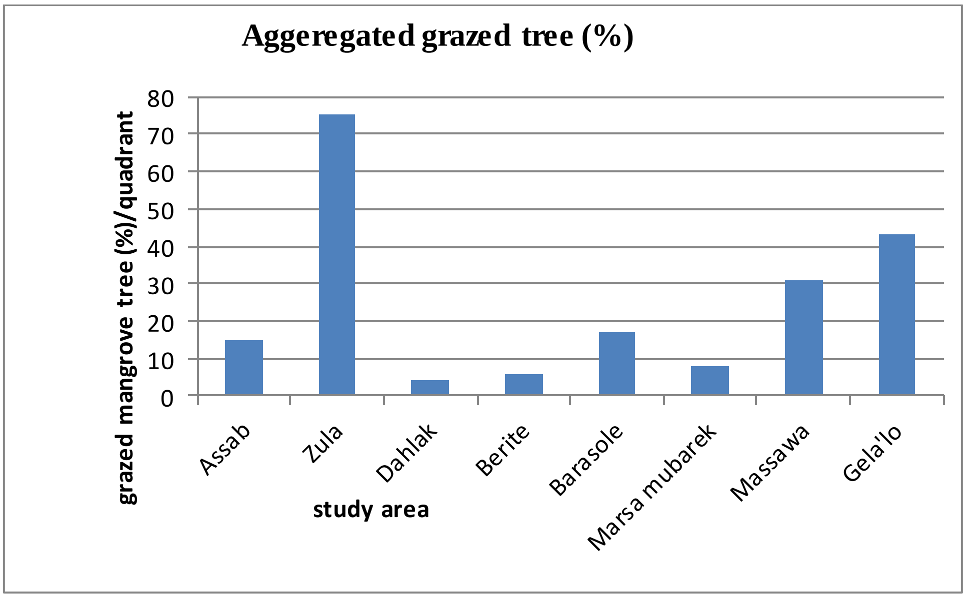



Human impact level on mangrove along Gela'lo area
impact scale
3
2.5
2
1.5
1
0.5
0
Umnamus island
Dhalailia kebir...
Harena
Gela'lo
south gela'lo...
Akelo
Rasa
Mantola island
Abako island
Sahel village
Hant island
Meedir village
Aahla village
Harasan village
NN196island
Mora village
NN043 island
sites
grazing
cutting

b.


Human impact on mangrove forest around Massawa
impact scale
3
2.5
2
1.5
1
0.5
0
Hirgigo power plant
Cement factory
flamingo park(near hamasen hotel
Hirgigo
Girar
MHP
sites
grazing
cutting

c.


Aggeregated grazed tree (%)
grazed mangrove tree (%)/quadrant
80
70
60
50
40
30
20
10
0
Assab
Zula
Dahlak
Berite
Barasole
Marsa mubarek
Massawa
Gela'lo
study area

d.

 e. (source: Big Mario, 2010)

Figure 14: Degree of human threats on mangrove vs survey sites: Assab and Barasole (a), Dahlak Archipelago (b), Massawa area (c) and percentage Grazed mangrove tree vs mangrove study area (d), stressed mangrove around Tio (e)

Local communities and fishermen use mangrove forest differently at different sites. From the above graph both cutting and grazed on mangrove were common in Gela'lo area. However no grazing on islands of this study area. Cutting on mangrove were higher in Assab area and varies within quadrant along Massawa area.

Table 4: Aggregated grazed tree (%) on mangrove

Site	Grazed tree (%)	Mangrove area lost (%) (1994-2014)
Assab area	15	7.6
Zula area	75	23.5
Dahlak archi.	4	6.2
Berite area	6	13.8
Barasole area	17	23.9
Gela'lo area	43	12.9

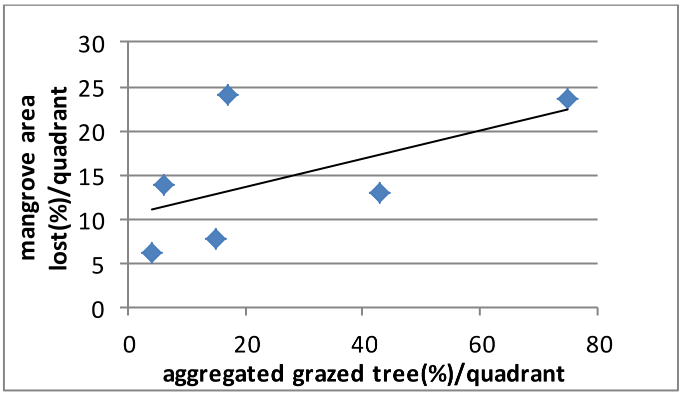


Figure 15: Aggregated grazed tree vs area lost along Eritrea coast

5.1.4 Natural mangrove mortality

Massive mangrove forest mortality was observed in around eighty ha along the northern coast. Sediment deposited on mangrove roots during water exchange can influence this ecosystem. This required a detailed study to gain further understanding of the cause for the loss of valuable tree cover. Upper most top dying mangrove leaves can lead to dying mangrove tree. Aggregated top dying mangrove tree percentage per quadrant increased with latitude (Figure 16 below).

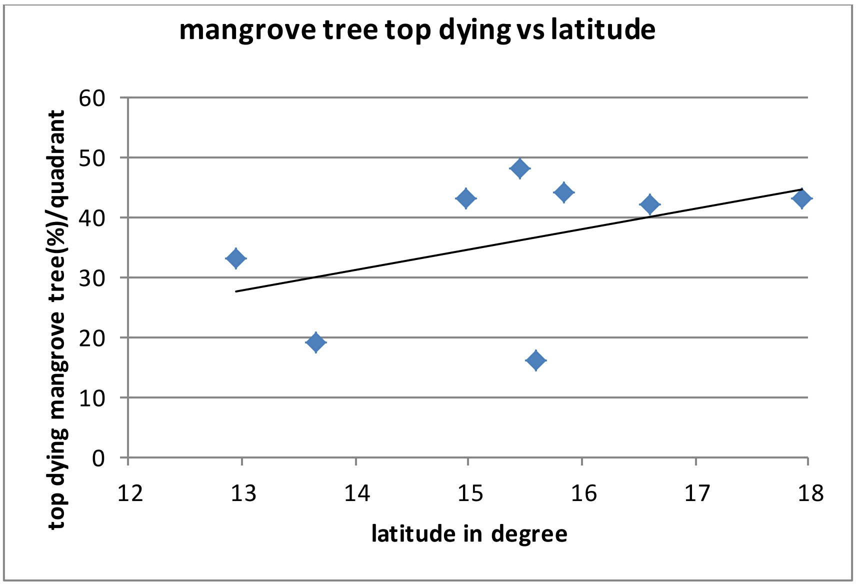


Figure 16: Aggregated top dying mangrove tree per $100m^2$ quadrant vs latitude

5.2 Result - Remote sensing data analysis

Mangrove distribution were mapped and found as two aggregations such as patches and forest form. Majority of mangrove forest extent are located in southern and central part of the study area. Mangrove vegetated areas have been extracted and yielded approximately 8900, 7800 and 8200 hectares in the study time period of 1994, 2003 and 2014, respectively (Table 13**)**.

Southern part

Including Barasole , Rastarma and Assab port city area.

5.2.1 Assab area -Landsat 5 TM, December 15th 1994

Mangrove forests cover around Assab port city and neighboring islands have been mapped from the image acquired on December the 15th of 1994. Technical Characteristics of the image are available in appendix i Table 15. Denser mangrove forest was observed in protected or bay areas in southern parts of this study area, and less dense, small and patches of mangrove are observed along the coast to the upper part of the map. Field survey GPS records match the extracted mangrove vegetation sites.

5.2.1.1 Supervised classification

The image of the study area is classified in to dry land, intertidal land, and open water and mangrove categories. FCC (321) RGB composite bands give red color for vegetation which is used a base for setting training samples. As shown in figure 17.

.

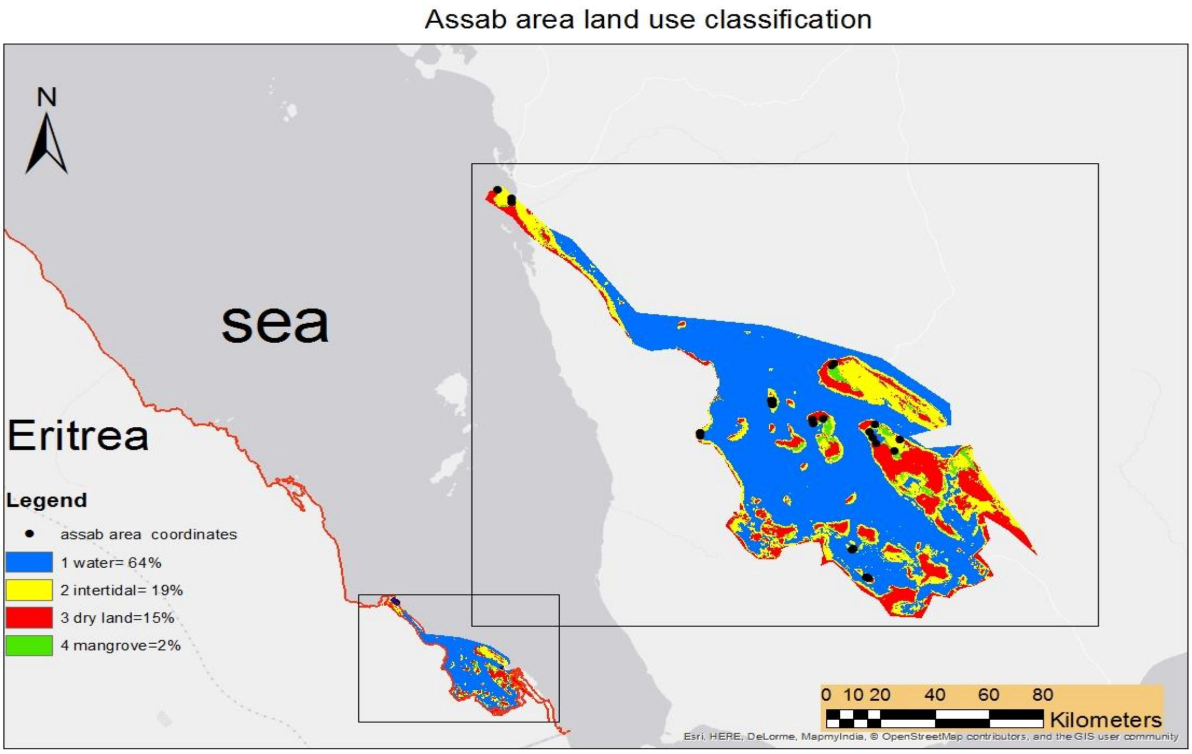


Figure 15: December 15, 1994 classified image with the percentage composition of categories map. Black dots show field work GPS recordings on mangrove sites.

An accuracy assessment has been performed for each Classified Land cover map to evaluate acceptability of the classifications. Supervised classification of Landsat 8 dated on 19th October 2014 has 98.2% and 97.57% overall accuracy and kappa coefficient respectively (see Table 5). Whereas the classified images from 1994 and 2003 have an overall accuracy of 97.3% and 95.6 %. Error matrixes for Landsat images 2003 and 1994 classification accuracy assessments are shown in Appendix iii.

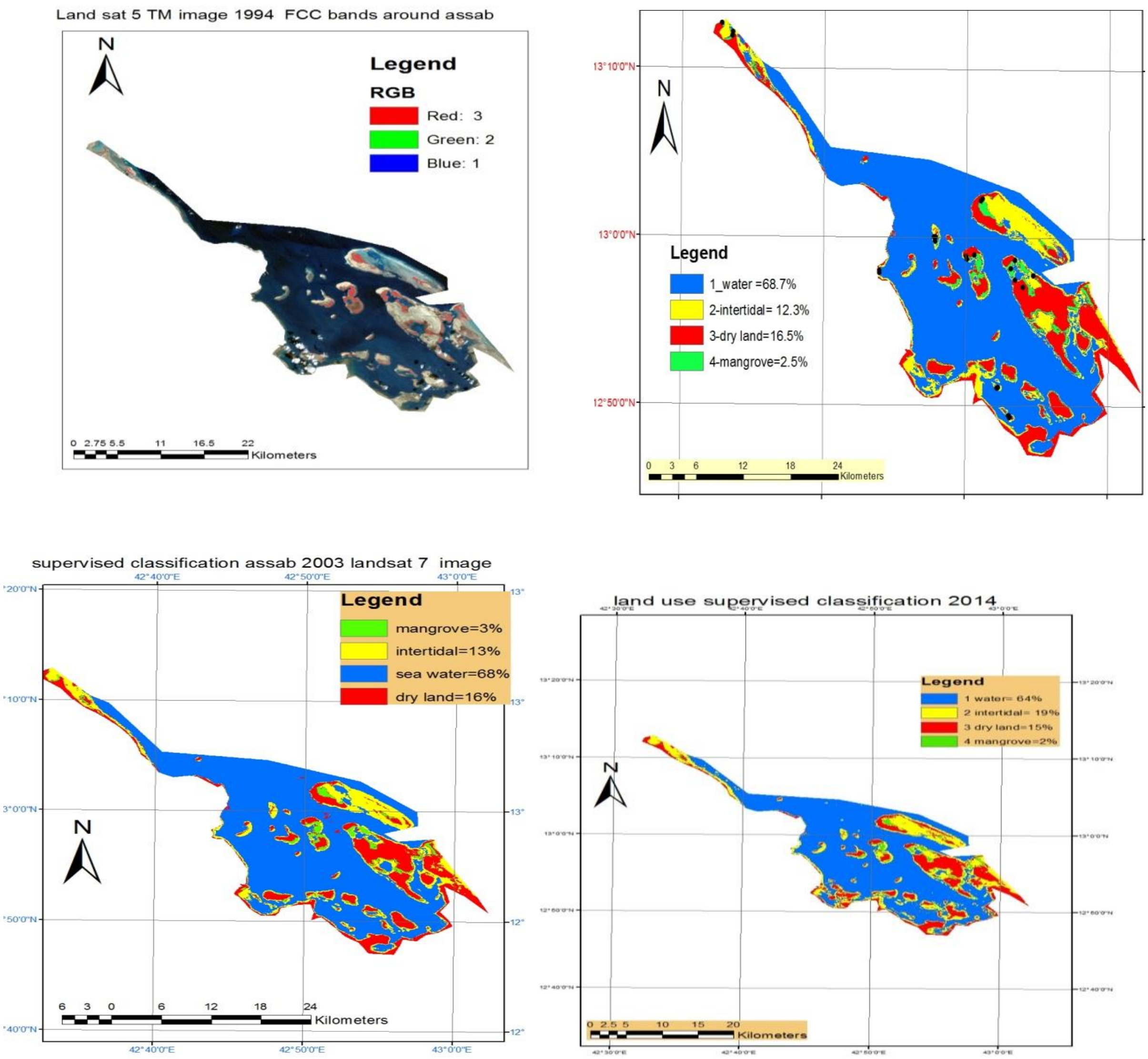


Figure 17: False Color Composite bands FCC (321) (top left), supervised classification land cover map of: 1994 Landsat 5 image (top right), Landsat 7 image 2003 (bottom left) and 2014 Landsat 8 image (bottom right)

Table 5: Error matrix of supervised classification 2014 image around the Assab study area

overall accuracy(%)=98.2
kappa= 0.976

	reference points					
Class	Mangrove	intertidal	dry land	open water	total in rows	users accuracy(%)
mangrove	20	1	1	0	22	90.9
intertidal	0	29	0	0	29	100
dry land	0	0	30	0	30	100
open water	0	0	0	30	30	100
total in column	20	30	31	30	111	

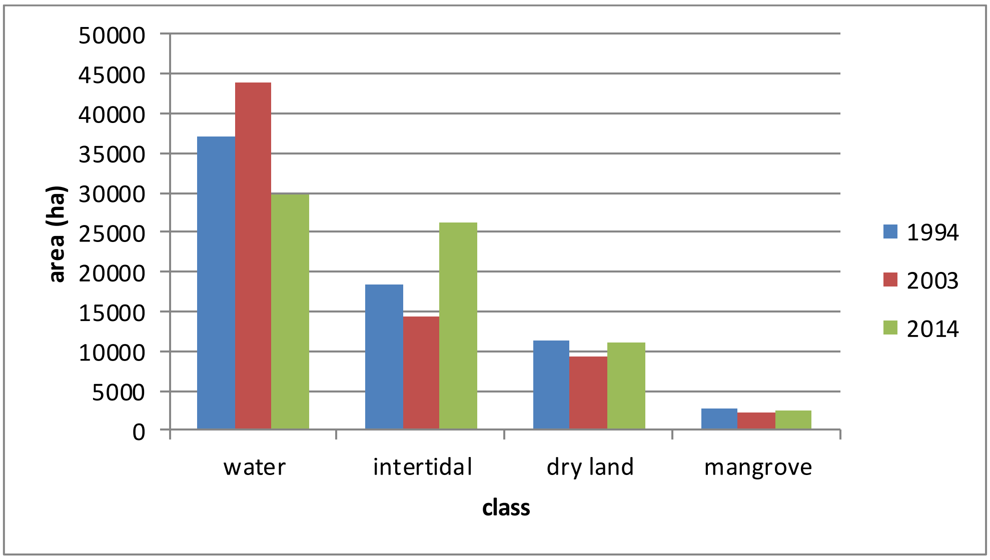
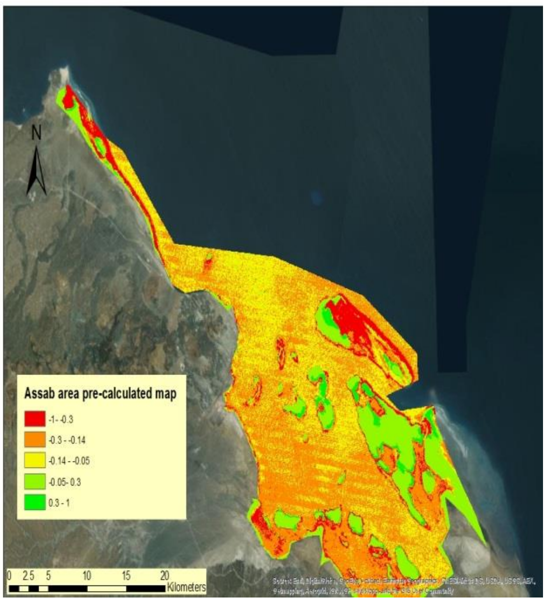
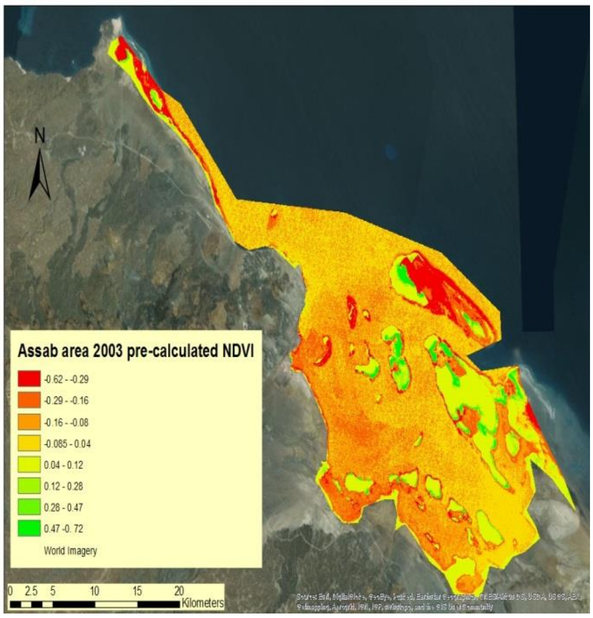


Figure 18: Histogram of classes’ area around Assab

Figure 18 shows the land cover of Assab area in 1994, 2003 and 2014 produced by using supervised classification. Highest mangrove area cover was detected in 1994 with approximately 2700 ha with approximately 4 % of the classified map. However the mangrove area was decreased in 2014 to approximately 2500 ha.

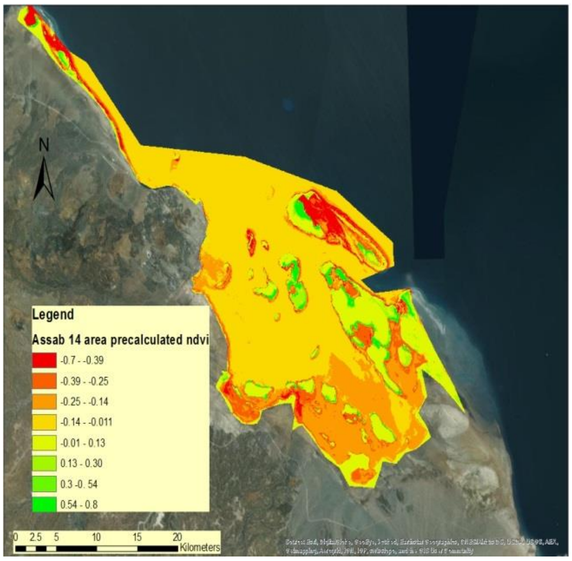
5.2.1.2 Mangrove NDVI value

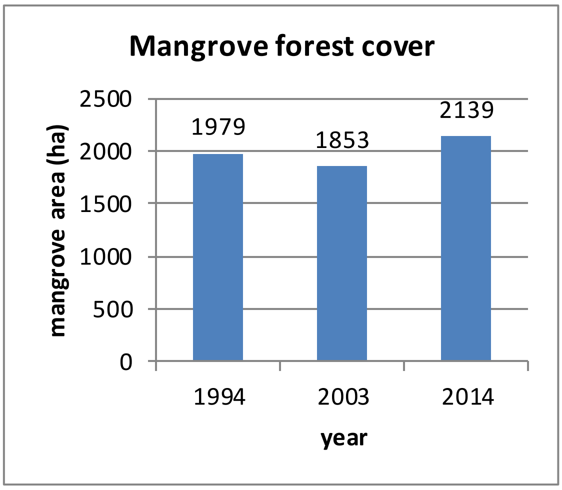




a,

b.





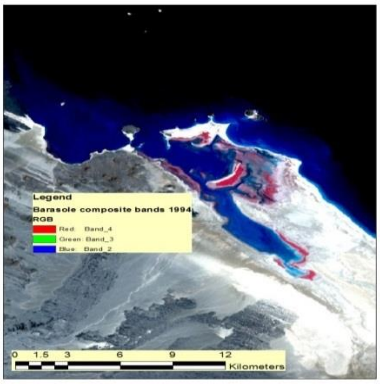
c d

Figure 19: Assab area, mangrove map from pre-calculated NDVI value of images 1994 (a), 2003 (b) and 2014 (c) and pre-calculated (healthy) mangrove area cover >= 0.3 NDVI value threshold (d).

Extracted healthy mangrove vegetation cover has been extracted from pre-calculated NDVI value of Landsat images of 1994, 2003 and 2014. A fixed threshold NDVI value>=0.3 was used to extract mangrove cover. There were less mangroves in greenness cover in 2003 compared to the other two. An area of 1979 ha mangrove forest acquired for 15th, December 1994 Landsat images, approximately 1853 ha from15th, February 2003 Landsat image and 2139 ha of mangrove forest from 19th, October 2014 Landsat image were extracted.

5.2.2 Barasole area

Mangrove forest covered an area of approximately 342, 263 and 260 ha in 1994, 2003 and 2014, respectively.



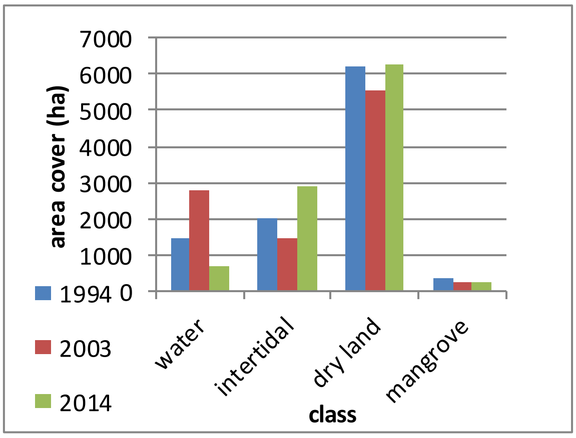


Figure 21: FCC image 2014 around Barasole, red color shows mangrove forest (left), categories area extent around Barasole (right)

Table 6: Error matrix of classified Landsat image 1994 -Barasole area

over all accuracy(%)	97.3					
kappa	0.96					
			reference points			
Class	mangrove	intertidal	dry land	open water	total in rows	users accuracy(%)
mangrove	17	0	0	0	17	100
intertidal	0	31	0	1	32	96.9
dry land	2	0	31	0	33	93.9
open water	0	0	0	29	29	100
total in column	19	31	31	30	111	
producers accuracy(%)	89.5	100	100	96.67		

5.2.3 Central zone Study area - Massawa port city area

Includes Massawa area, and Zula bay

5.2.3.1 Massawa area (15030.842’-15041.299’N)

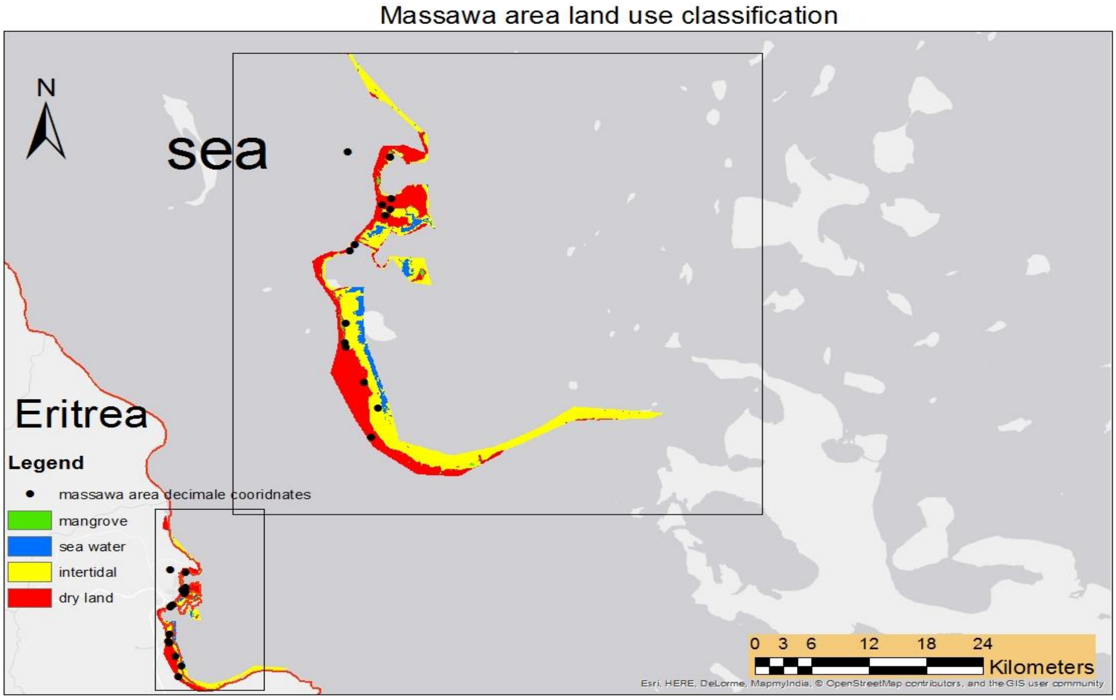


Figure 22: Massawa area MLC classification with mangrove survey GPS record .NB. there is one GPS reading is misplaced on the figure due to error in recording

Mangrove cover has been extracted or calculated using supervised and pre-calculated NDVI value of health mangrove vegetation.

18th November 1994 Image classification

An area of 98 ha mangrove cover was extracted from MLC land cover which has an overall accuracy 87% see table 7.

Table 7: Error matrix of Landsat 5 image 1994 -Massawa area

over all accuarcy(%)		87				
kappa		0.83				
			reference points			
Classified	Mangrove	intertidal	dry land	open water	reference point	users accuarcy(%)
Mangrove	10	1	0	0	11	67
intetidal	2	23	0	0	25	77
dry land	3	6	30	0	39	100
open water	0	0	0	20	20	100
total	15	30	30	20	95	
producers accuracy(%)	91	92	77	100		

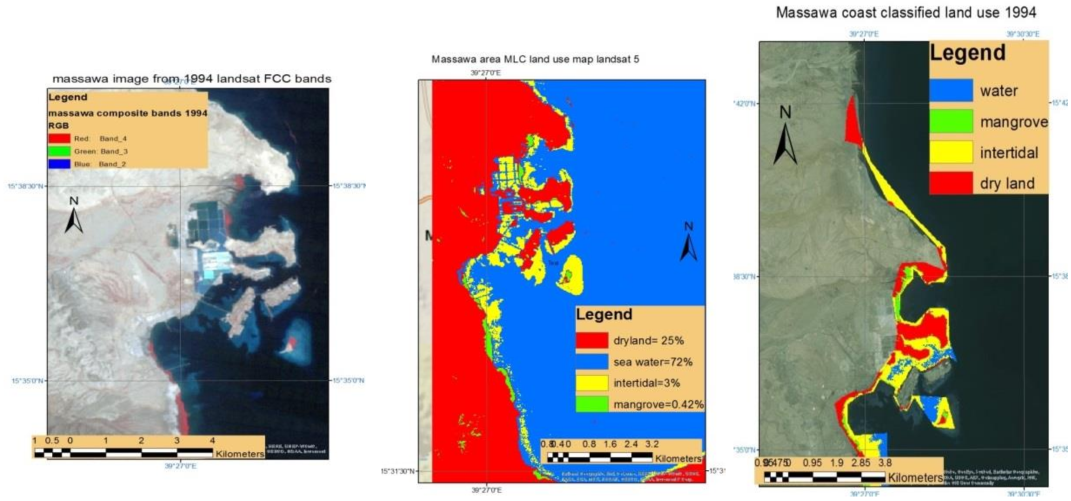


Figure 24: Massawa area FCC map 1994 red color shows mangrove vegetation (left), Massawa area categories supervised classification map based on FCC and field experience (middle), land cover map clipped to mangrove sites to avoid from non-mangrove vegetation (right)

29th September, 2002 Massawa area classification

The classified image map of 29th September 2002 has mapped using the same techniques as the previous image analysis. About 158 ha mangrove area has been extracted from this image Landsat 7 using supervised classification**.** The supervised classification of this Landsat image has an overall accuracy 96.3%, see error matrix table in appendix iii.

18th June, 2014 Massawa area - classification Landsat image2014

A total area of 198 ha of mangroves cover were extracted from other non-mangrove land cover type along Massawa port city coast and its nearest island, which is called Green Island. The supervised classification of this Landsat image has an overall accuracy 97.3%. See figure 25 below

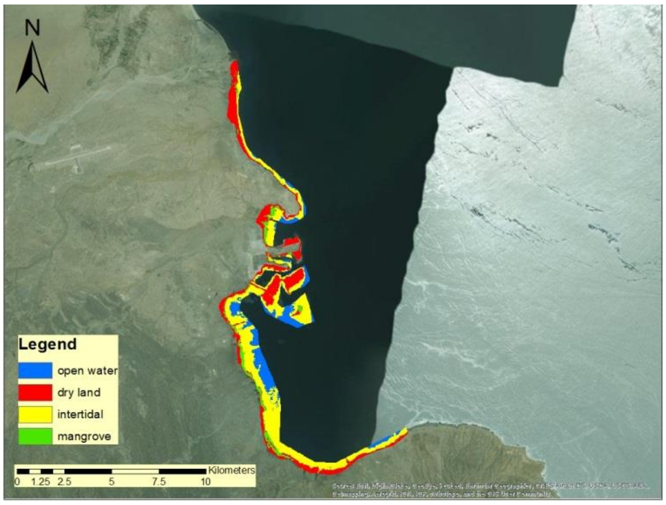


Figure 25: MLC map of Landsat image18th, June 2014 clipped to mangrove site

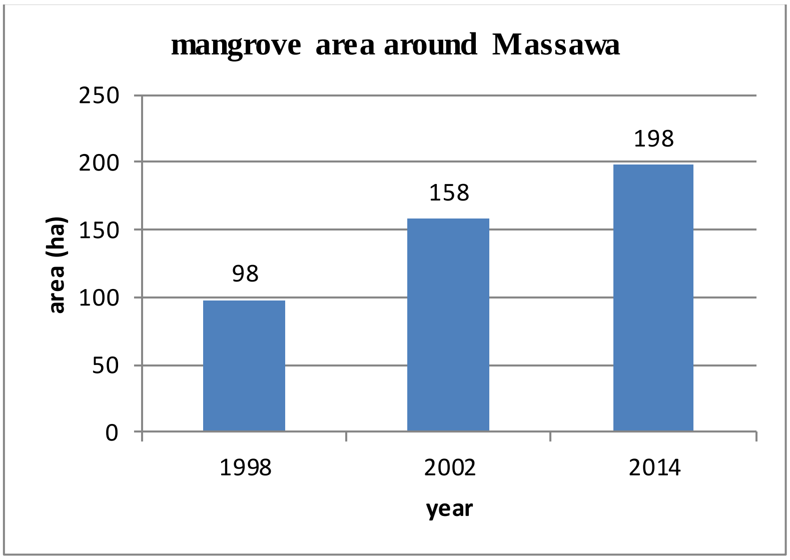


Figure 26: Mangrove forest area cover 1994, 2002 and 2014 around Massawa port city

Mangrove cover has been extracted or calculated using supervised and pre-calculated NDVI value of healthy mangrove vegetation in the study area. There is a general increase of mangrove area cover according to supervised classification for each study time period.

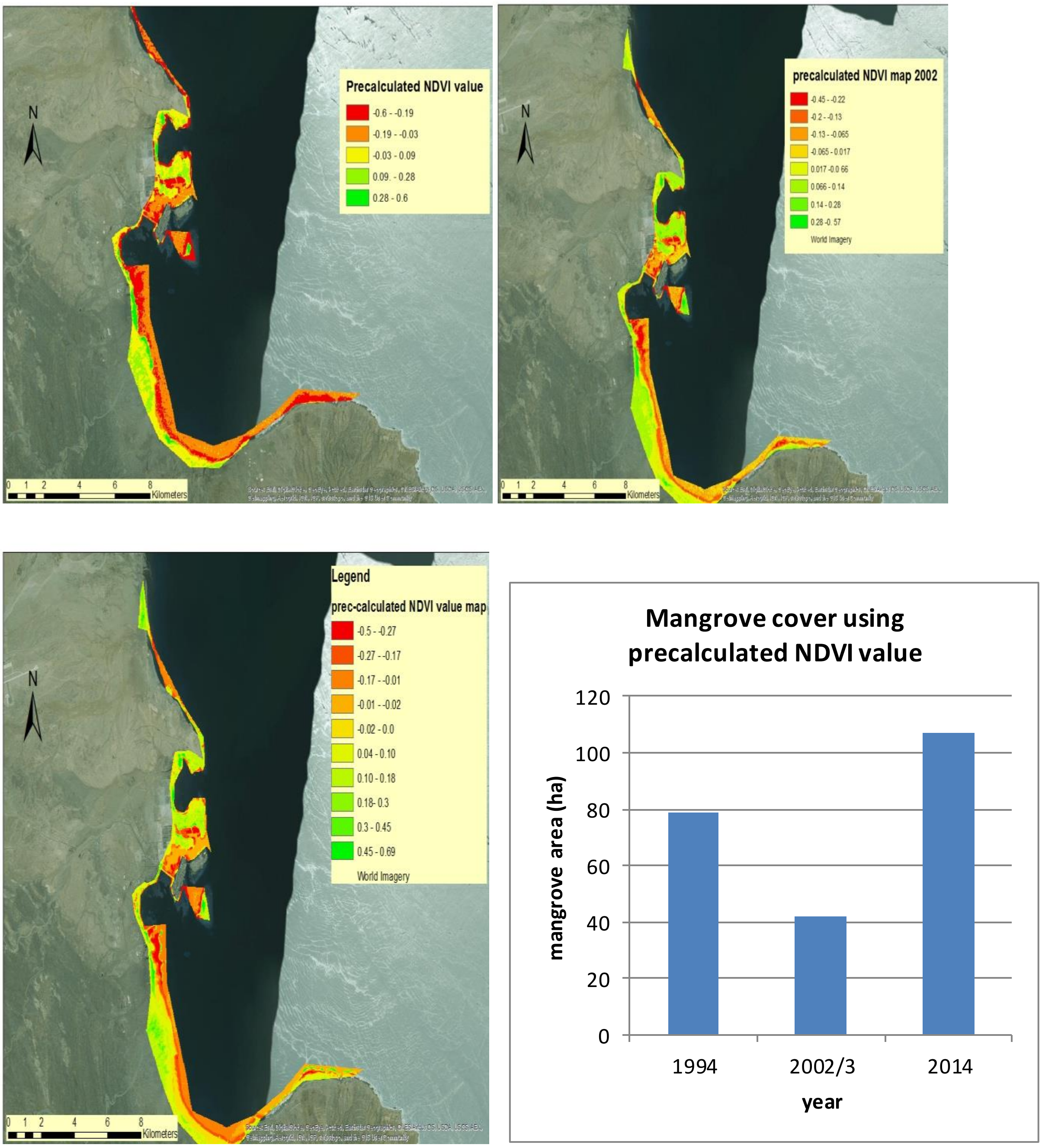


Figure 27: Massawa area comparing categories cover between pre-calculated NDVI value map at different period from Landsat 5 image 1994 (top left), 2002 (top right) and Landsat 8 image 2014(bottom left).histogram shows mangrove area extracted from pre-calculated NDVI(bottom right)

Massawa area land cover.

There was urban development around mangrove sites within Massawa city between the studies time period. Grar, a former salt farm place has been changed to dry land as shown figure below. There were mangrove forests until 2009, in the place where new road is constructed.

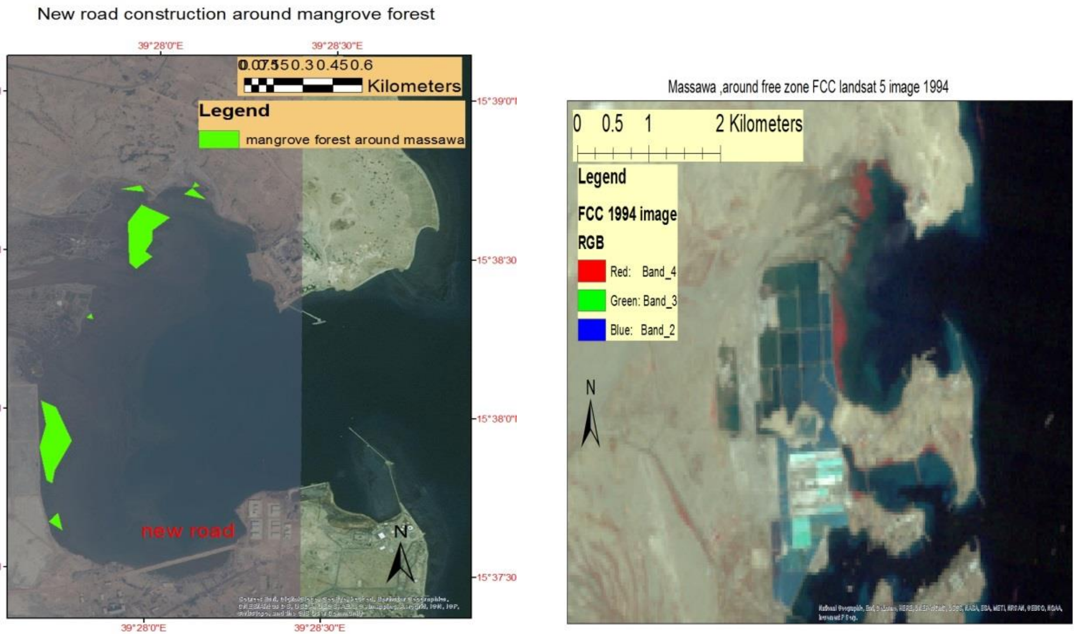


Figure 28: Difference in land cover type around Massawa 2014 (left) and 1994 landsat image (right)

5.2.3.2 Zula area ($15^0$4.023’-$15^0$32.194’N)

Details of land cover composition along Zula coast are seen on figure 31 using the assigned colors. Reclassified and extracted mangrove vegetation distributes as patches along Zula bay and nearby villages including Dessie Island, covering an area of approximately 216, 208 and 165 ha in 1994, 2002 and 2014 respectively. Generally, the total mangrove area cover was declining (a decrease of approximately 50 ha mangrove cover from 1994 to 2014) in the study time lapse period. See error matrix table in appendix iii for assessing 2002 and 2014 Landsat image classification.

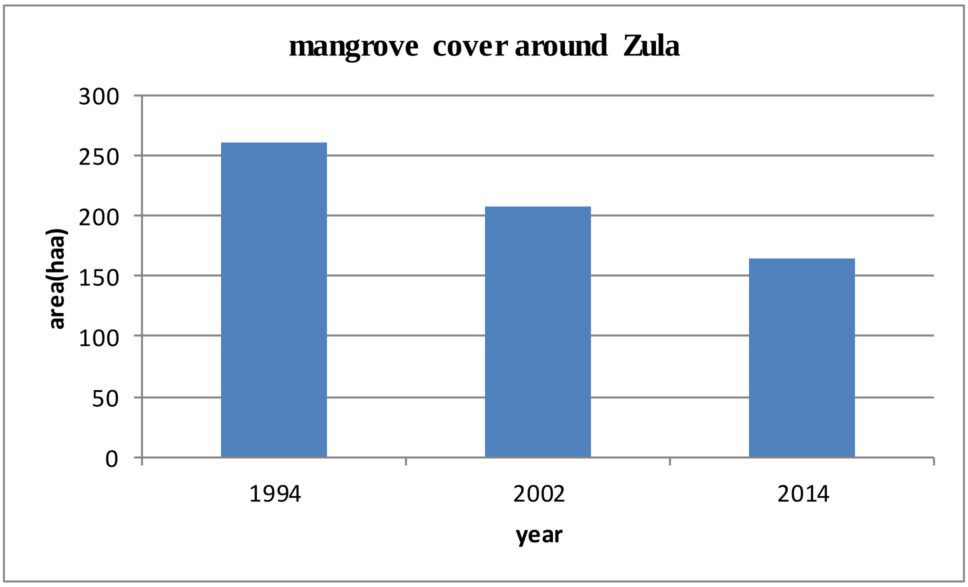
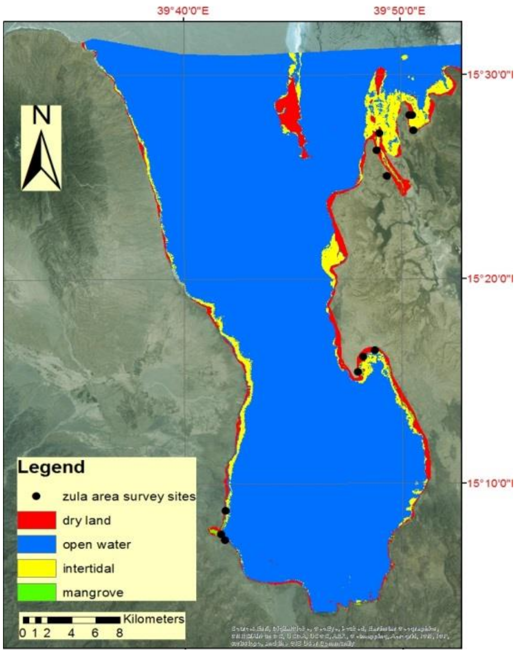
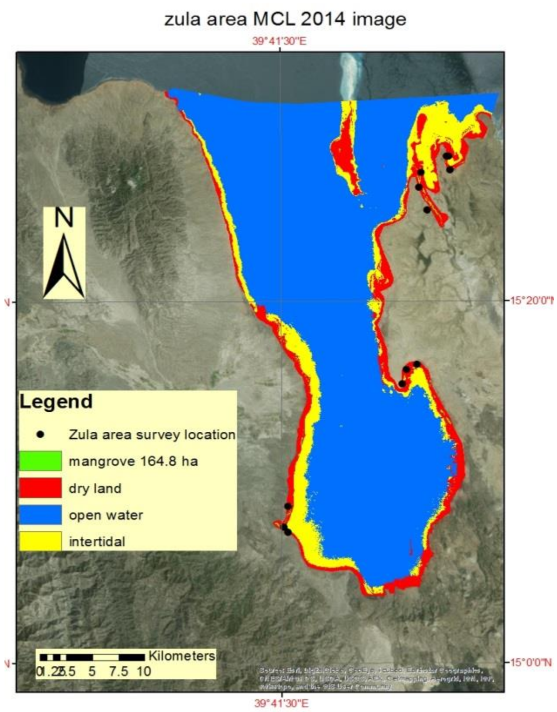


Figure 30: Extracted mangrove cover map around Zula in time period





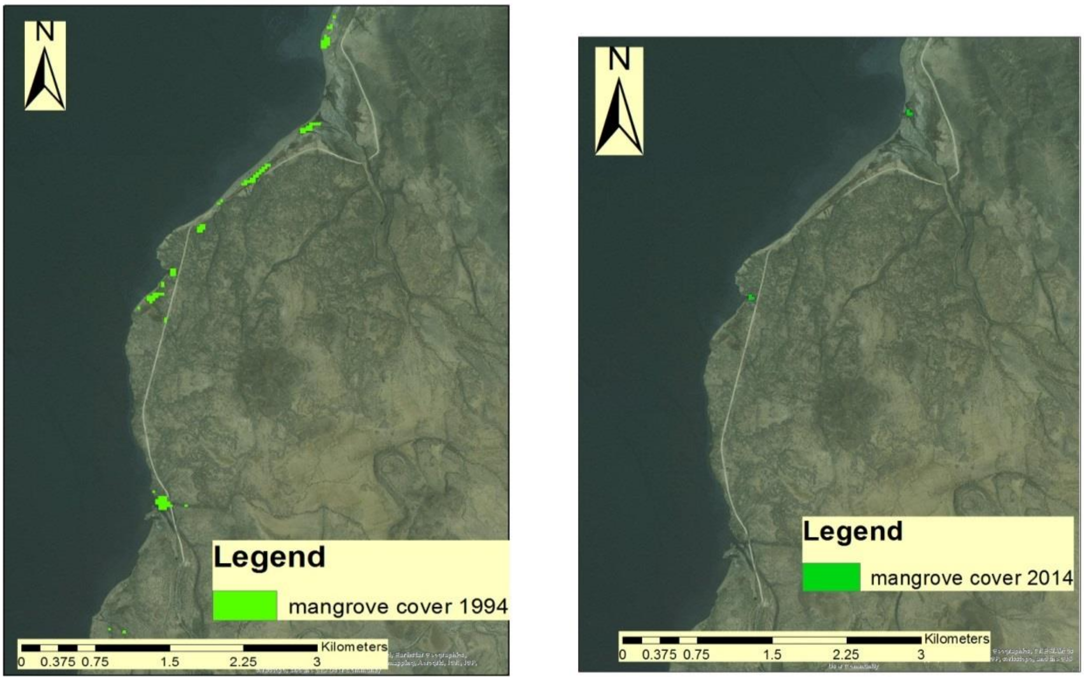


Figure 31: Buri peninsula area MLC land cover map 1994 (top left) and 2014 (top right), extracted mangrove forest from Landsat image 1994 before the Massawa–Assab road constructed (bottom left), in the same area mangrove cover extracted from Landsat image 2014 after the road constructed (bottom right)

Table 8: Error matrix of classified Landsat image 1994 Zula area

overall accuracy(%)=95.4
kappa= 0.94

	reference points					
Classiefied	mangrove	intertidal	dry land	open water	total in rows	users accuracy(%)
mangrove	20	0	1	0	21	95.2
intertidal	0	24	0	0	24	100
dry land	0	0	29	0	29	100
open water	0	4	0	31	35	88.6
total in column	20	28	30	31	109	
producers accuracy(%)	100	85.7	96.7	100		

Figure 32: An example of former mangrove cover changed to dry along Buri (Zula) coast, green color indicates of mangrove vegetation forest in 1994, but they were absent in 2002(right)

Mangrove area cover change has been detected along the study area coast especially on the place where fresh water meets the sea. Grazing on mangrove forest in most of this study areas was also intense (see Table 4).

5.2.4. Gela'lo area

Large mangrove area cover is calculated in this study area. Mangrove forest extracted cover 1% of classified Landsat images 2014 around the study area and yielded 2507 ha.

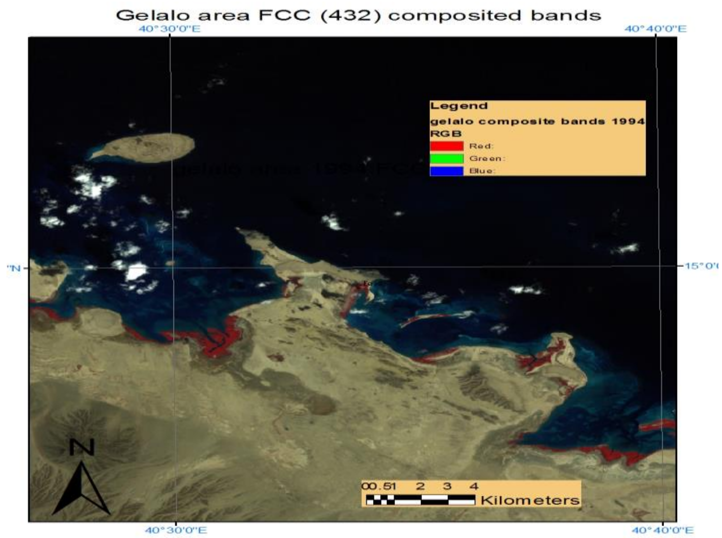


Figure 33: FCC of acquired image 1994 around Gela'lo study area

Table 9: Error matrix table Gela'lo area 2014

over all accuracy(%) =92						
Kappa =0.89						
			reference points			
classifed	mangrove	intertidal	dry land	open water	total in rows	users accuracy
mangrove	22	0	0	1	23	95.7
intertidal	4	31	0	1	36	86.1
dry land	4	0	31	0	35	88.6
open water	0	0	0	30	30	100
total in column	30	31	31	32	124	
producers accuracy(%)	73	100	100	94		

Mangrove cover shows decreasing in Gela'lo study area from 1994 to 2000 and from 2000 to 2014. See summary Table 13 (Assume mangrove area in cloud cover section remain unchanged) see figure mangrove area covered by cloud in appendix ii. Mangrove forest cover was estimated around 500 ha visually during survey period in the Harena village area (which is located around cloud cover section).

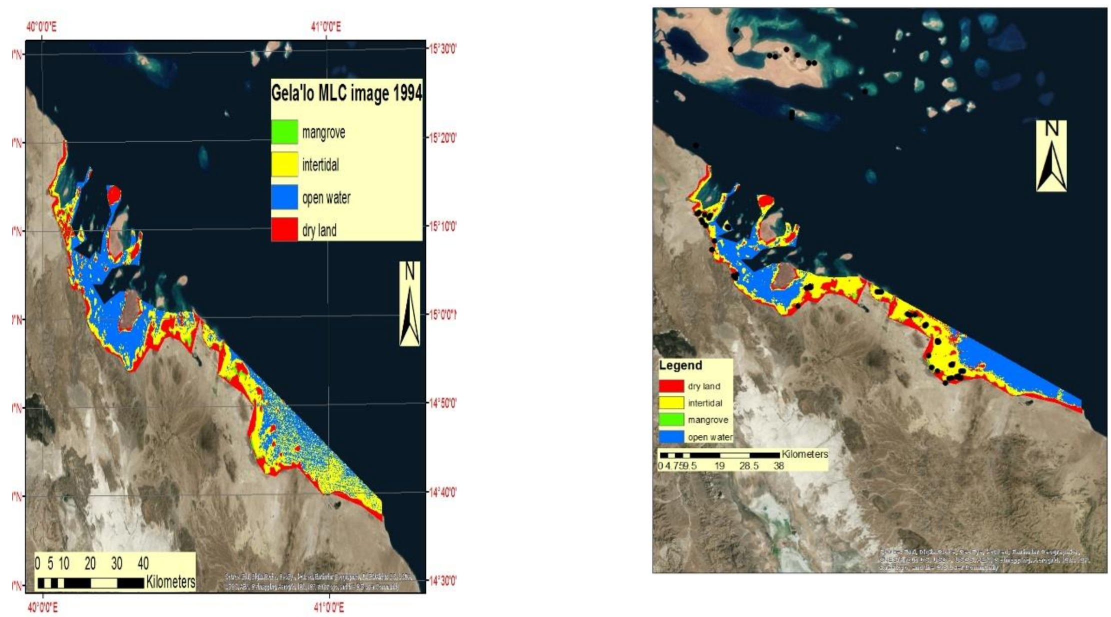
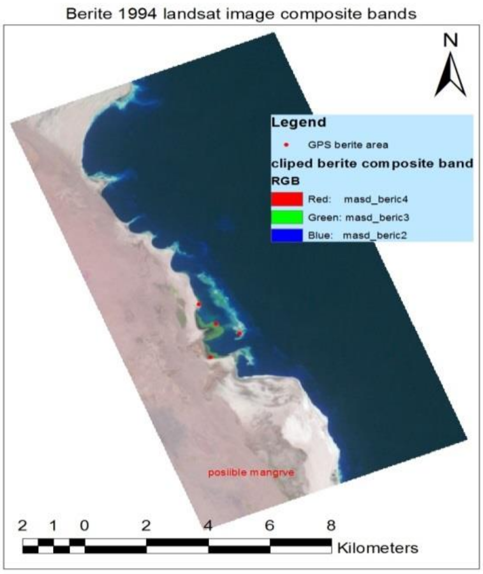


Figure 34: Gela'lo area image classification 1994 (left) and 2014 (right)

5.2.5 Northern Part

5.2.5.1 Berite ($17^0$55.134'N-$18^0$1.185'N)

Mangrove forest is found as dense forest in shallow intertidal near the border with Sudan. Berite study area classification yielded mangrove forest cover extracted as approximately 42, 39 and 36 ha in 1994, 2003 and 2014 respectively as shown in the summary table 13.



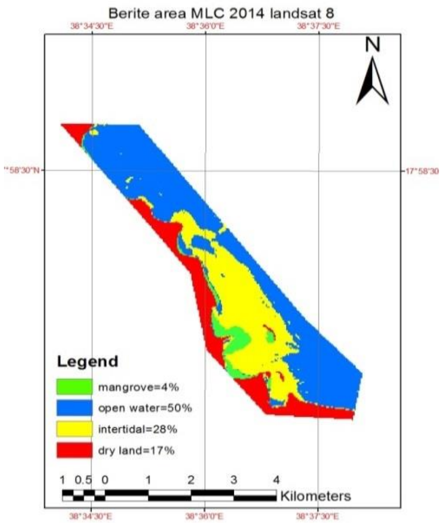


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Figure 35: Berite area image classification map composite band with survey GPS record (left), and classified image 2014 (right)

Table 10: Error matrix of classified Landsat image 1994 around Berite

over all accurac(%)=99						
kappa =0.98						
		reference points				
classified	mangrove	intertidal	dry land	water	total reference pnts	users accuracy(%)
mangrove	18	0	0	0	18	100
intertidal	1	30	0	0	31	96.8
dry land	0	0	30	0	30	100
water	0	0	0	21	21	100
total	19	30	30	21	100	
producers accuracy(%)	94.7	100	100	100		

5.2.5.2 Marsa Mubarek and Marsa Ibrahim area ($16^0$29.975’-$16^0$40.286’N)

These two bays and the two adjacent islands; Hamadan and Hamada 1 form an area of mangrove forest in a semi-desert coast approximately 72-82 miles north of Massawa port city. Images classification map of 2014 yielded 85.5% overall classification accuracy while images from the 2002 classified map yielded a 97.98 % overall accuracy classification.

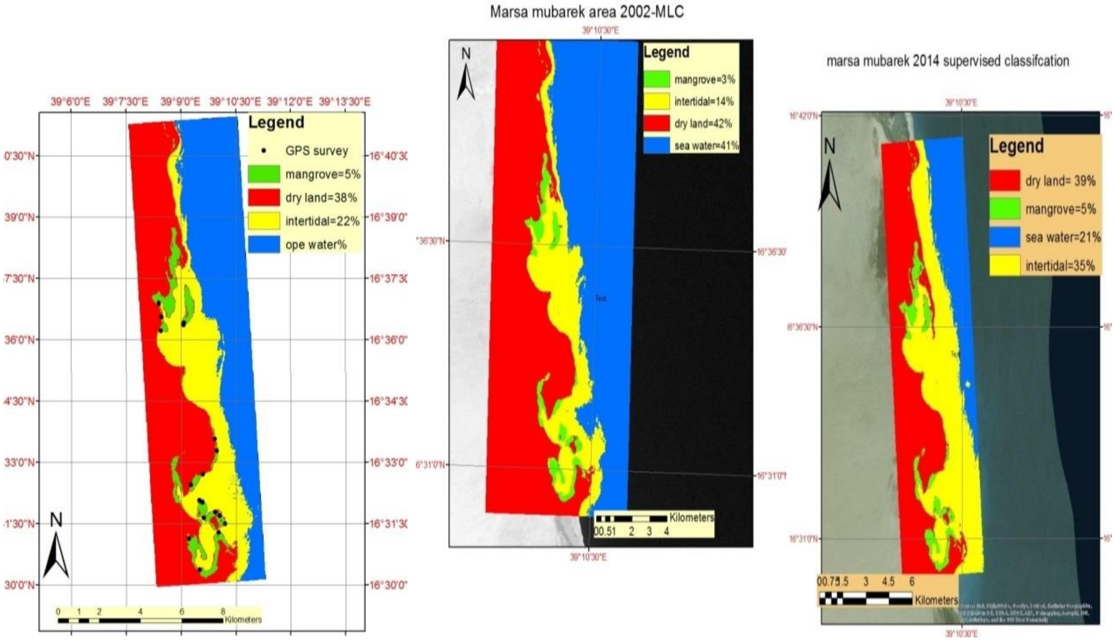


Figure 36: Marsa mubarek & Marsa Ibrahim area mangrove forest in 1994, 2002 and 2014 respectively from left to right. Green color shows mangrove and black spots show field work GPS record

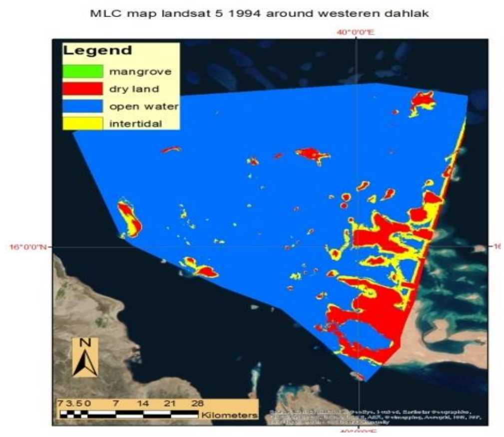
Table 11: Error matrix of classified Landsat image 2014-Marsa Mubarek area

over all accuracy(%)=85.5
kappa= 0.81

	reference point					
classified	mangrove	intertidal	dry land	open water	total in row	users accuracy(%)
mangrove	18	1	0	0	19	94.7
intertidal	0	19	0	8	27	70.4
dry land	2	1	21	0	24	87.5
open water	0	0	0	13	13	100
total in column	20	21	21	21	83	
producers accuracy(%)	90	90.5	100	61.9		

5.2.6 Dahlak Archipelago ($15^0$26.632'-$16^0$42.182'N)

Mangrove forests are located in a sheltered area with suitable substrates in which mangrove thrive. Some islands have very large and old mangrove forest in elevated and closed pond areas and receive water through seepage. Image classification for study areas around eastern and western Dahlak Archipelago, and Defnin island which is located far north yielded mangrove map and area coverage of 1659 ha in 1994, 1338 in 2002/03(assuming there was no change in mangrove cover between 2002 and 2003 in Dahlak Archipelago) and 1556 ha in 2014.



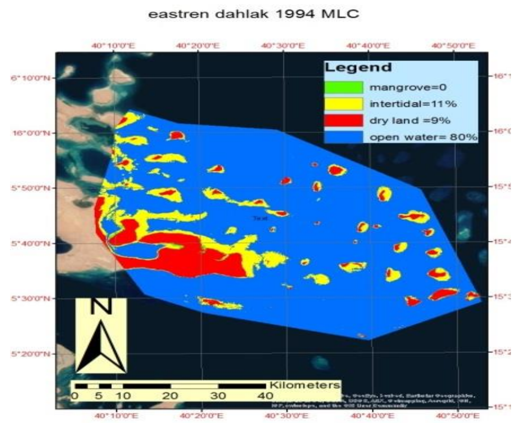


Figure 37: Western Dahlak categories cover (left**)** and eastern Dahlak categories (right)

Table 12: weighted over all accuracy of mangrove cover along the study areas

Study area	1994		2014	
	Area (ha)	overall accuracy (%)	Area (ha)	Overall accuracy (%)
Assab	2728	97.3	2522	98.2
Massawa	98	87	198	97.3
Zula	216	94.5	165	98.6
Gela'lo	3339	92	2907	92
Dahlak archi.	1659	97.5	1556	85
Marsa Mubarek	512	100	590	85.5
Berite	42	99	36	99
Barasole	342	97.3	260	100
total	8936.45		8234	
weighed overall accuracy		**95.30%**		**92.70%**

According to the classified images of all the study areas, approximately 7.7% of mangrove forest area covered in 1994 had declined in 2014 which is approximately 700 ha mangrove cover was lost over the last two decades.

About 12% of error in both 1994 and 2014 weighted overall classification of mangrove map area was found as shown table 12 above.

Table 13: summary table area covers (ha) by class along all the study areas in time period

year	class	Assab area	Massawa area	Zula area	Gea'lo area	Dahlak area	Berite	Barasole area	Marsa Mubarek	total area
	water	37126	1331	72463	60372	803820	440	1474.56	3899	
	intertidal	18384	664	3901	42474	138871	758	2016.54	2419	
1994	dry land	11337	611	3416	27154	96443	415	6223.68	4271	
	Mangrove	**2728**	**98**	**216**	**3339**	**1659**	**42**	**342**	**512**	8936
	total	69577	2704	79996	133339	1040793	1655	10057	11101	
	water	43808	747	66046	64533.5	788419	201	2796	5434	
	intertidal	14246	970	7160	38864	92818	1155	1475.64	2693	
2003	dry land	9256	828	6617	26894	158636	274	5522.13	2455	
	mangrove	**2267**	**159**	**208**	**3049**	**1338**	**39**	**263**	**519**	7842
	total	69577	2704	80031	133341	1041211	1669	10057	11101	
	water	29691	442	61942	50843	771531	58.41	664.2	2289	
	intertidal	26242	1273	9674	51788	183580	1304	2878.74	3921	
2014	dry land	11122	791	8215	27795	104358	261	6246.45	4302	
	mangrove	**2522**	**198**	**165**	**2907**	**1556**	**45**	**260**	**590**	8243
	total	69577	2704	79996	133333	1061025	1668	10049.4	11102	

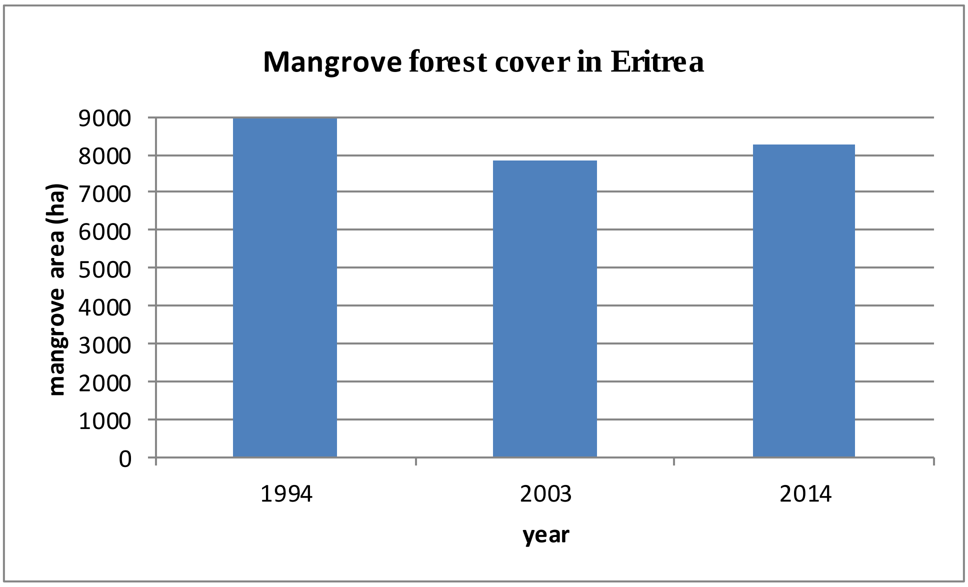
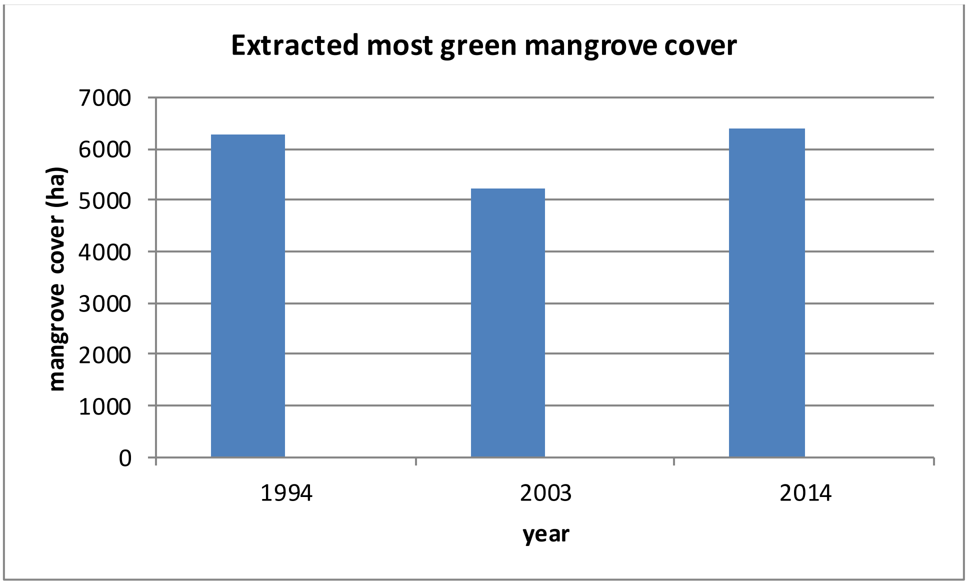


Figure 38: Estimated Eritrea mangrove forests cover

There was a decline of mangrove forest area between the years 1994 and 2014. There has been about 7.7% of the original mangrove area cover in 1994 lost over the last two decades (assume mangrove cover in Gela'lo area in 2000 and 2003; mangrove cover in Massawa, Zula, Marsa Mubarek and western Dahlak study areas has no change between 2002 and 2003)

Pre-calculated NDVI value (threshold>=0.3) related to mangrove structure



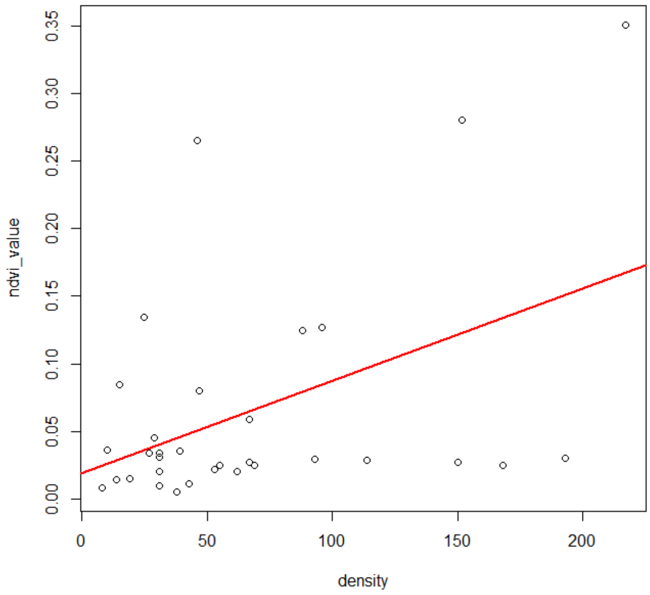


Figure 41: NDVI value of Landsat image 2014 against tree density northern red sea survey sites

Calculated mangrove NDVI from 2014 Landsat imagery against mangrove tree density (assume number of tree during field work time and 2014 in the quadrants are the same) looks positive trend as shown on the above graph related to the northern study area which was denser per quadrant. Regression analysis between mangrove tree density per quadrant and calculated NDVI value is significant at $p = 0.0104$ figure 41.

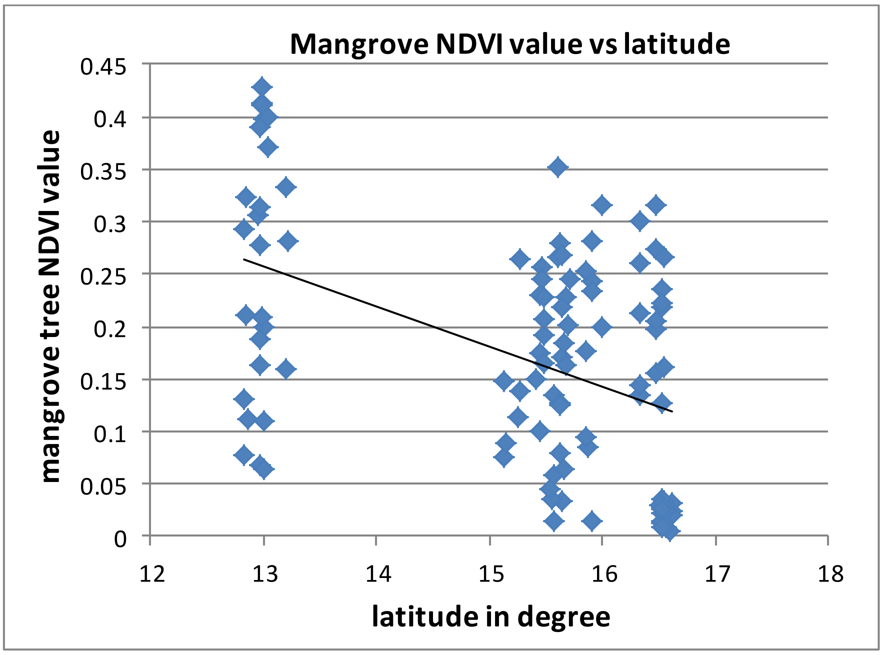


Figure 42: Identified NDVI value of mangrove from Landsat image (2014) on GPS (quadrant) record with latitude

There is a general decrease of NDVI value as latitude increase. More abundant and healthier (greenness) mangrove forest per pixel is distributed in southern study area. NDVI value mean difference between 1994 and 2014 was hypothesized and tested using t. test at 0.05 of significance level. This was found to be t value as 0.025 with p-value 0.49 which is greater than 0.05, so there was no significant statistical difference.

CHAPTER 6: DISCUSSION

6.1 Identified mangrove species, distribution and their structural status

Three mangrove species and two families are found at the study area. These are *Avicennia marina*, *Rhizophora mucronata* and *Ceriops tagal*. Most Eritrea mangrove forest are pure forests of *Avicennnia marina* species. This species was found in almost the entire visited mangrove survey sites along coast and islands in patch and forest forms especially in areas of the coast characterized by reduced storm events. In a few areas, they were observed to grow to very large sizes with trees greater than 14 m as shown in figure 13 on some closed islands, lagoons and suitable coastal areas. This could be due to the fact that most of these islands are less accessible to local population. According to Global Biodiversity Information Facilities (GBIF) this species are identified around Green Island and small islands outside Massawa port city and were found to grow up to 5 m tall, as recorded in 1988 (GBIF –Sweden, 2013).

Rhizophora mucronata: The second dominant species was being recorded in 24 quadrants alone or in combine with other two. This species is found mostly in contact with sea water as shown figure12.

Ceriops tagal, was recorded in 4 quadrants during assessment survey. This species was the only record in the Red Sea, according to the species list by country in the world mangrove atlas (Spalding *et al.*, 2010). This places Eritrea higher in both mangrove abundance for African Red Sea countries and mangrove diversity in the Red Sea, even the whole Middle East. The World Atlas Mangrove (2010) mentioned the location of *Ceriop*s species based on Eritrea's Ministry of Marine Resource, (1998) "*Ceriops tagal* is recorded from Museri Island in the southern Dahlak Archipelago. This may the only record within the Red Sea". However, this study confirmed the existences of this species in other four locations along Eritrea Red Sea Coast and Islands. Clear geographical locations of the two less abundant mangrove species with/without *Avicennia marina* have been identified, figure 12.

Based on this study, approximately 8200 ha and three species of mangrove forest are distributed along the Eritrea coast in 2014. This is higher than mangrove area covered in neighbor countries such as Sudan, Djibouti and much higher than Egypt (Fatoyinbo and Simard, 2013). Globally above 1.5 million ha and 73 mangrove species are recorded according to Spalding *et al.*, (2010). New research by scientist using new satellite shows true mangrove area distribution is about 12.3% less than the aforementioned world mangrove area coverage (Giri *et al.*, 2011).

The result of this study indicates approximately 72% of mangrove forest for 1994 in Eritrea was distributed in southern (Gela'lo-Assab) part of Eritrea's coast. Large continuous mangrove forests are found around Gela'lo and Assab bay. Higher rainfall, freshwater flow and tropical climate are observed for the southern part, see figure 2. As a projection of the Indian Ocean, water exchange is more pronounced due to monsoon winds in southern part than in the northern part (Naheed, 2015). A less saline environment combined with nutrients from the Indian Ocean may give an advantage to the denser mangroves along southern red sea coast (Kumar *et al.,* 2010).

Mangrove structure analysis shows maximum tree height and maximum diameter at girth have a highly significant relationship especially until tree become around 8m in height. Mangrove tree density per quadrant was also related with maximum height significantly, the number of trees increases as maximum mangrove trees height decrease. This could be due to competition for nutrients or space. Average mangrove tree density per quadrant along the coast such as Zula and Gela'lo were less than the other study areas. This could be due to considerable impact from the coastal population (Table 4). Northern study area part are also less favorable for residence.

6.2 Mangrove Threats

Drought, rapid and short floods as well as anthropogenic impacts constitute mangrove threats in Eritrea. Human impact on mangrove is inevitable and a major cause of mangrove area change. This discussion is supported by Gilbert and Janssen (1998). Grazing threats were more common on main coast than in islands such as in Gela'alo area, see figure 14 a-c on the human impact measured in study area. Cutting/logging and grazing ranges between moderate to higher record around villages. Grazing, especially by camels and cutting mangrove were reported as relevant threat in the Red sea region (FAO, 2007). These threats, sedimentation as seen in Zula, tree felling, top dying tree and in addition to increasing occurrence of drought are noticeable threats along Eritrea's coast. Grazed or cut mangrove forest is characterized by short, dwarf stunted trees, and scattered old mangrove as noticed during field work along villages such as Barasole, Zula , Tio (see figure 14 e) and Sihlet. This shows that local population use mangrove forest in their daily activities. Fishermen employment increased above double from 1992 and 2000. There were 1414 fishermen in 1992 (Reynolds *et al.*,

1993) and 3500 as primary sector in 2000 (FAO, 2002). A sign of Eritrea Navy camp near a few study areas could explain the elective cutting on *Rhizophora mucronata* and *Avicennia*. The effect of anthropogenic influences on mangroves are noticed more than those from natural impact over the last few decades (Lavieren, 2012).

Generally, pollution due to oil leaks from ships, sewages, refuse and garbage such as bottles, plastic and other could become a serious threat for mangrove forests, especially those in the vicinity of cities and villages. These can cover pneumatophores and cause suffocation and subsequent death and these are considered as anthropogenic threat to mangrove along eastern Africa (FAO, 2007), although further detailed studies are required in order to fully understand impact they can have on Eritrea mangrove forests.

Unplanned urban development around mangrove ecosystems can disturb the marine ecosystem. Road construction along the Massawa-Assab axis is the main land based mangrove threats. Mangrove forest in Wadi area along the coast is becoming stressed due to fresh water being blocked or diverted for agriculture (Shumway, 1999). Modification of drainage can also lead to sedimentation and nutrient load change to coastal ecosystem (UNEP/GPA, 2006). Mangrove spectral reflectance in Massawa free zone shows different NDVI value before and after road construction. They had higher value = 0.12 in 2002 image before road constructed and 0.061 in 2014 after constructed. This tells that mangrove vegetation is in stressed condition.

An area of approximately 80 ha of mangrove displayed mass mortality around the Marsa Mubarek in the northern coast (personal observation). A timescale and cause of mortality investigation is required. Environmental data such as pH, sediment type and climatic condition of that area over time and mangrove response to climate change may to help to understand the cause of mangrove lost. The Landsat image for that mangrove during the specified time period showed no difference. Therefore no data or evidence for mortality of the mangrove vegetation in this area was available at least for this study. That lost could have happened before the selected timescale for this study. However, there was clear change in mangrove area around Zula. Remote sensing analysis enabled and identified a difference in mangrove sites during the study's timescale along the Zula coast. This supported field trip observation that young mangrove stand were dry on that area. The Massawa-Assab road constructed during this period lies parallel to the sea located to the west of the deforested mangrove area.

Mangrove tree with top dying uppermost and outermost branches were recorded during the survey and are found related with latitude although not strongly. This could be due to increasing drought or little rainfall as move to north part of Eritrea. (Figure 2). However, top dying tree could be also due to tree diseases or stress from grazing.

6.3 Mangrove area change/loss over the last two decades

Mangrove area change in all the study areas have been calculated in this study. There was a declining trend in mangrove cover in all study areas except Massawa and Marsa Mubarek. Entire mangrove patches were lost in areas along western Zula and near road construction sites. However, there was shrinkage of mangrove area coverage in most of the bigger forest study areas based on change of NDVI value difference for the same pixel and mangrove area calculated. There was approximately 8900 ha mangrove area cover distributed throughout the study areas in 1994. This had declined to an area of approximately 8200 ha in 2014 with 8% error during Landsat image classification. This error could be derived from different source as will discuss on uncertainties sub-subtopic.

Based on this study, Eritrea lost approximately 35 ha mangrove per year over the last two decades. It is not much as compared to an average 4,450 ha general forest lost per year between 1990 and 2010 in the nation (FAO, 2010). Approximately 500.000, and 3.6 million ha mangrove forest was lost in Africa and the world (between 1980 and 2005), respectively (FAO, 2007). Approximately 35% of the global mangrove forests have disappeared between 1980 and 2000 and the loss has increased to 50% in some countries (Valiela *et al.,* 2001, Mumby *et al.*, 2004).

Increasing mangrove vegetation in between 2003-2014 could be due to images collected from Landsat 8 were better for classification analysis or due to errors derived during Landsat image analysis. No data are available that can support for mangrove forest increase in Marsa Mubarek. However, there was mangrove plantation project in about 10 km coast around Massawa.. The plantation project was conducted by the Manzanar project over study's timescale. Around 700,000 mangrove seedlings were planted by the project (Sato, 2006).

Mangrove density and NDVI value are found to generally decrease with increasing latitude. In addition to being adjacent to the Indian Ocean as discussed in above, coastal topographic features such as having indented and semi closed areas at many sections of this coastline could be a contributable explanation as to why healthier mangroves are to be found in the south. This is similar to the discussion that mangrove forest biomass is found to decrease with increasing latitude generally (Along, 2002).

Over all NDVI mean value in 1994 and 2014 is similar although there are changes in interims of NDVI value per pixel. Data (NDVI value) from afforested and cloud affected study areas were not included. Acquired dates for Landsat images (see appendix i) and site difference could make data noise. Generally, from November to March it is a time of cloudy and rainy seasons and a period from May to September is summer; which is a very hot season with dusty conditions sometimes along the study areas. Normally it is expected more green vegetation during rainy season.

6.4 Uncertainties and limitations

Uncertainties and errors can happen at different levels of this study. Calculated errors could be due to humans. Instruments errors are inevitable in such a process. Human errors in a few mangrove GPS readings were investigated during importing to ArcMap. Missing images for specific areas and times lead to fluctuate date of image acquisition and could contribute to some error. Satellite Landsat image for 2002/03 Gela'lo area were not available from the data sources therefore these were replaced with images from the same areas for 2000. Furthermore, the spectral reflection from city trees was similar to that of mangrove forest; this was overcome by drawing and delineating a mask focusing only on mangrove vegetation sites. Field work experience and former knowledge of the areas assists when faced with such challenges. Cloud cover and cloud shadows in and around the mangrove forest rendered it difficult to classify Landsat images. In the investigation for Gela'lo study, challenges were encountered when extracting mangrove cover. In most of the instances, errors encountered were minimized and double checked in order to reduce the error margin.

Tidal range during image taking can affect map classification especially between intertidal and water cover. Tide ranges 0.25-1.19 m (max. tidal range 1.65m) around Massawa port city and 0.09-0.60 m (max. tidal range 0.65m) around Assab port city (Meteo 365 Group, 2015). Mud can be seen as bare land during low tide and intertidal during high tide. It can also affect young mangrove shoots in some areas which could be covered or half covered during high tide. Dry land and intertidal with salt remained after evaporation had similar spectral reflectance and could be reasons for dry land area fluctuation during image analysis of this study.

CHAPTER 7: CONCLUSION

Previous studies on Eritrea mangroves are limited to regional and global remote sensing, and they mention different mangrove area cover. In general, approximately 700 ha mangrove cover or 7.8% of the original mangrove cover in 1994 had declined by 2014. There was a significant mangrove area change. Human anthropologic threat on mangrove could be reasons for the loss .Natural mortality around seasonal freshwater flow due to sedimentation could be other reasons for the loss of mangrove forest in the study areas, although there is a need to further study mangrove health status within the context of environmental climate. The largest mangrove forest extent is found along Gela'lo- Tio coast and islands of the identified study areas.

This study confirms the extent of three mangrove species and their GPS location based on the assessment applied in 211 quadrants and in 71 mangrove sites along Eritrea's Red Sea Coast and Islands.

Supervised classification of remote sensing images has potential for mapping mangrove area extent. Since supervised classification maps of all collected images have statistical report analysis and have high overall accuracy assessment and kappa coefficient in the majority of error matrix tables of the classification yielded above 80%, so it is acceptable to use as a mapping method for the study area. According to Viera & Garrett (2005) calculated kappa coefficient value between 0. 81 and 0.99 is interpreted as almost perfect agreement type.

Based on this study mangrove density and NDVI values are generally decreased with increase in latitude. Statistically, no mean NDVI value difference between1994 and 2014 was found.

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Appendix i

Table 14: Characteristics of Landsat 5 TM 1994, Landsat 7 ETM+ and Landsat 8 (2014) Around Massawa Port City, Marsa mubarek, Zula and western Dahlak archepelago

	1994	**2002**	**2014**
Land sat id	LT51690491994322xxx02	LE71690492002272SGS00	LC81690492014169LGN00
Datum	WGS84	WGS84	WGS84
WRS_PATH	169	169	169
WRS_ROW	49	49	49
Date acquired	11/18/1994	9/29/2002	6/18/2014
Spacecraft ID	Landsat5 TM	Landsat 7	Landsat 8
Number of bands	7	7	11
Resolution	30 m	30 m	30m
Map projection	UTM_ZONE_37	UTM_ZONE_37	UTM_ZONE_37

Table 15: Characteristics of Landsat 5 TM (1994), Landsat 7(2003) and Landsat 8 (2014) Around Assab Port City

	1994	2003	2014
Landsat scene id	LT51660511994349AAA02	LE71660512003046SGS00	LC81660512014292LGN00
Datum	WGS84	WGS84	WGS84
WRS_PATH	166	166	166
WRS_ROW	51	51	51
Date acquired	12/15/1994	2003-02-15	2014-10-19
Spacecraft ID	Landsat 5	Landsat 7	Landsat 8
Band numbers	7	8	11
Resolution	30 m	30m	30m
Map projection	UTM_ZONE_38	UTM_ZONE_38	UTM_ZONE_38

Table 16: Characteristics of Landsat 5 TM (1994), Landsat 7 (2003) and Landsat 8(2014) around eastern Dahlak Archipelago

Easteren Dahlak

	1994	2003	2014
Landsat scene id		LE71680492003044 SGS00	LC81680502014258LGN00
Datum	WGS84	WGS84	WGS84
WRS_PATH		168	168
WRS_ROW		49	50
DATE_ACQUIRED		2003-02-13	9/15/2014
SPACECRAFT_ID	Landsat 5	LANDSAT_7	Landsat 8
Number of bands	7	8	11
Resolution	30 m	30m	30m
Map projection	UTM_ZONE_37	UTM_ZONE_37	UTM_ZONE_37

Table 17: Gela'lo area Landsat image characteristics

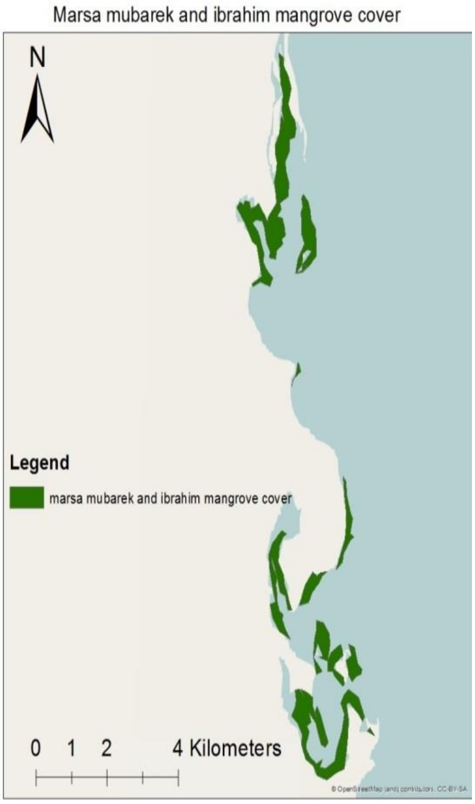
	1994	2000 (cloud cover 10%)	2014
Landsat scene id	LT51680501994347XXX03	LT51680502000236XXX02	LC81680502014258LGN00
Datum	WGS84	WGS84	WGS84
WRS_PATH	168	168	168
WRS_ROW	50	50	50
DATE_ACQUIRED	1994-12-13	8/23/2000	9/15/2014
SPACECRAFT_ID	Landsat 5	LANDSAT 5	Landsat 8
Number of bands	7	7	11
Resolution	30 m	30m	30m
Map projection	UTM_ZONE_37	UTM_ZONE_37	UTM_ZONE_37

Table 19: Wavelength region and description of Landsat TM bands

Band number and description	Wave length (micrometers)	Resolution (meters)	Used for
Band 1 –blue-green	0.45-0.52	30	responsible for analyzing of land use, soil, and vegetation characteristics
Band 2- green	0.52-0.60	30	correspond to green reflectance of healthy vegetation
Band 3- red	0.63-0.69	30	One of important bands for vegetation corresponds to red chlorophyll absorption of green plants.
Band 4 -Near Infra-Red	0.76-0.90	30	Corresponding to amount of vegetation biomass available in the seen, separating land-water contrast, soil-crop and vegetation type.
Band 5- shortwave IR	1.55-1.75	30	analyzing drought and used to discriminate between cloud, ice making and snow
Band 6-Thermal	10.40-12.50	120* (30)	
Band 7- shortwave IR	2.08-2.35	30	discriminating and different geological rock formation

Appendix ii:

Eritrea Red Sea coast and island study areas mangrove maps



A, b,

‖

Dahlak area mangrove area map
N
Musseri
Legend
dahlak mangrove area
0 2.75 5.5 11 Kilometers
© OpenStreetMap (and) contributors, CC-BY-SA

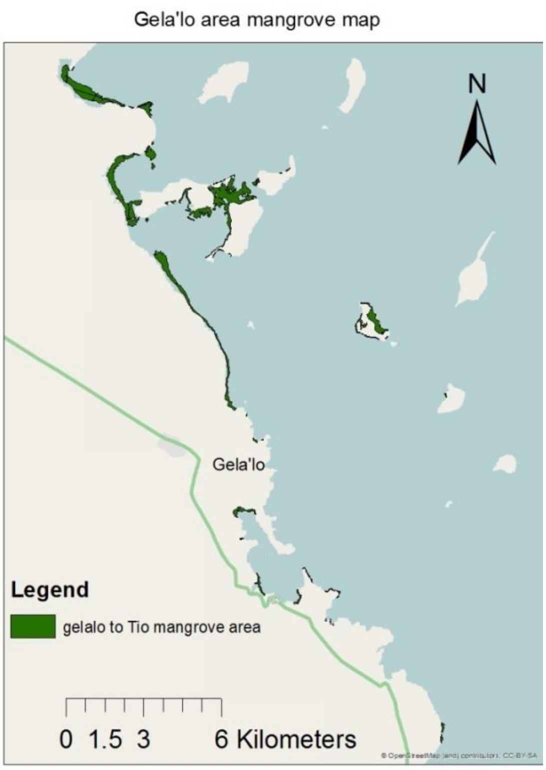
C,

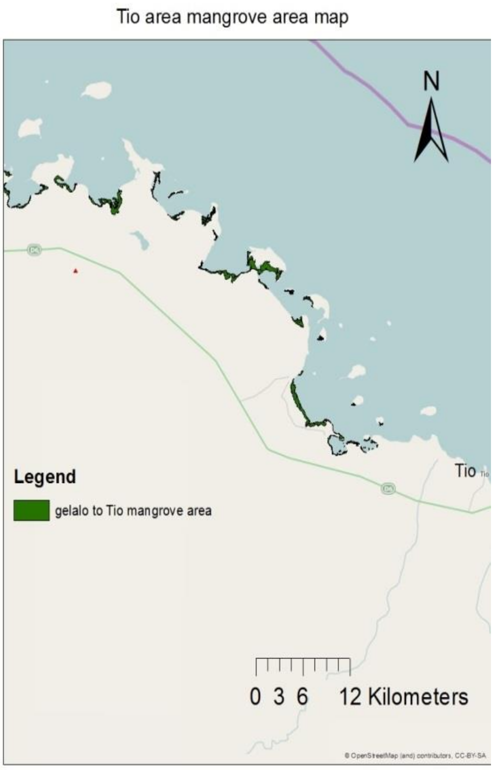
Massawa area mangrove map
N
Massawa
Green island
Hirgigo
Legend
0 1 2 4 Kilometers

Harat island
N
Legend
Harat mangrove forest
0 1 2 4 Kilometers

Norah to Hermil island mangrove cover
N
Legend
Norah to hermil mangrove area
0 4.25 8.5 17 Kilometers

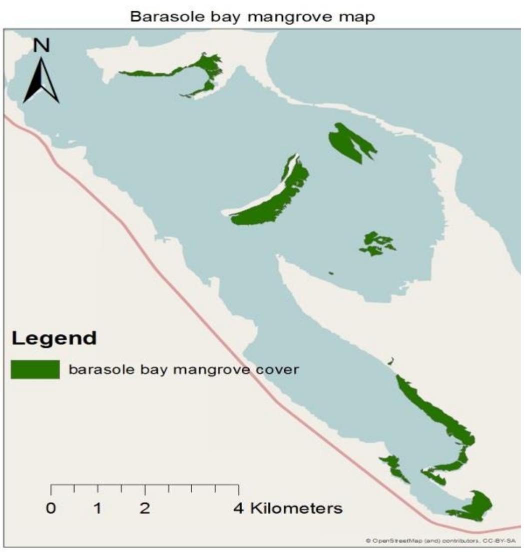
d. e. f





g

h



I,

j

Figure 44 *:* Mangrove cover map produced from NDVI Landsat image 2014 along Eritrea red sea coast and islands study area, Berite area (a), marsa Mubarek and Ibrahim (b), Dahlak kebir area, red points shows mangrove survey location (c), Massawa port city area (d), Harat island (e) , Norah to Herimel islands (f), Gela’lo area (g), Tio area (h), Barasole area (i) and Assab port city and nearby islands study areas (j).

Figure 45: Eritrea mangrove forest distribution map.

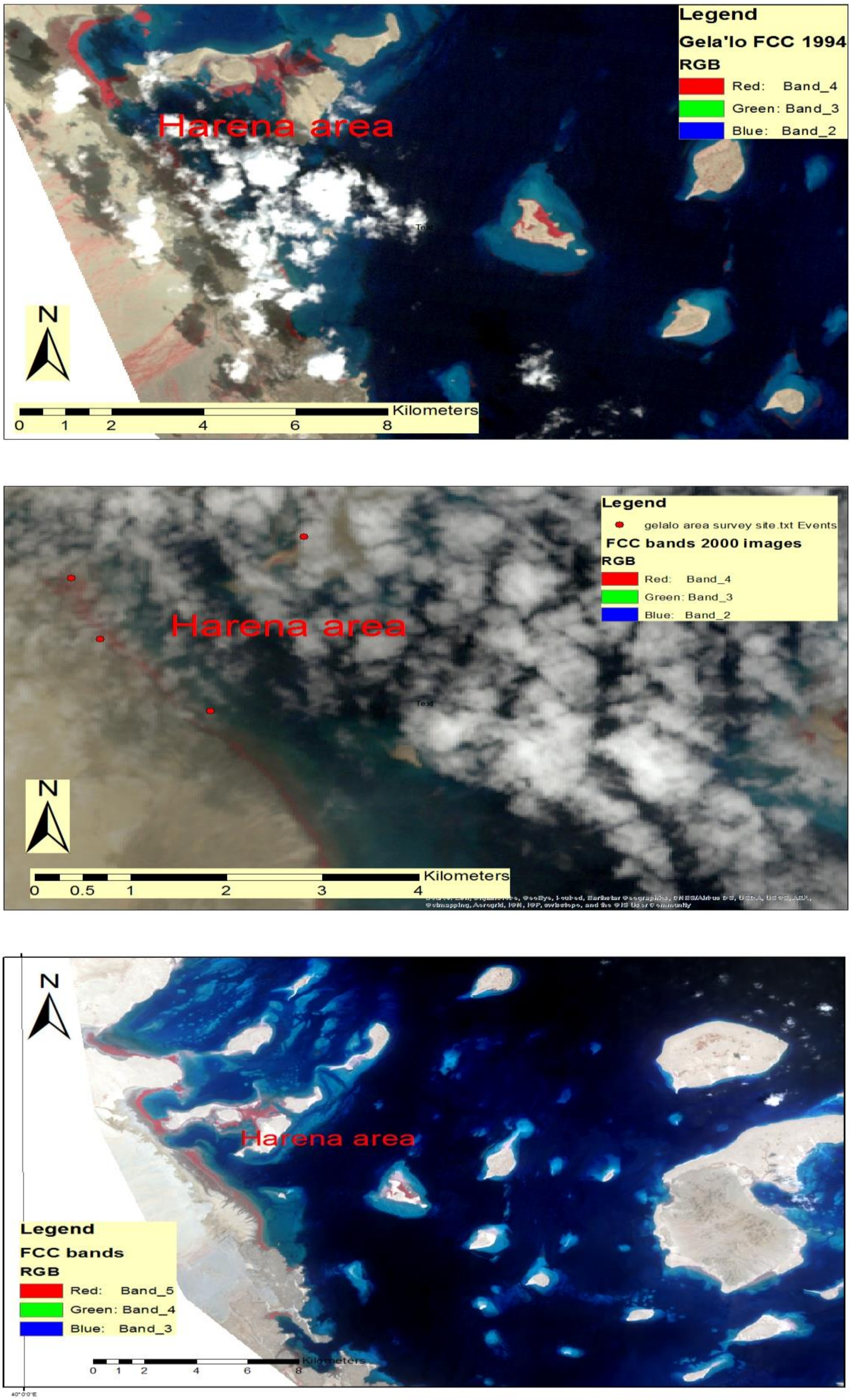


Figure 46: Gela'lo area FCC image red color along the coast indicates mangrove forest in 1994 (above), 2000 (middle) and 2014 (bottom) , red points indicate survey location

Appendix iii

Error matrix of classified Landsat image 1994

Berite area

over all accuracy (%) = 99

kappa = 0.98

	reference points					
classified	mangrove	intertidal	dry land	water	total in rows	users accuracy(%)
mangrove	18	0	0	0	18	100
intertidal	1	30	0	0	31	96.8
dry land	0	0	30	0	30	100
water	0	0	0	21	21	100
total in column	19	30	30	21	100	
producers accuracy(%)	94.7	100	100	100		

Error matrix of classified Landsat image 2014 -Berite area

Over all accuracy (%)=99

Kappa= 0.982

	reference points					
Classified	mangrove	intertidal	dry land	water	total in rows	users accuracy(%)
mangrove	19	1	0	0	20	95
intertidal	0	30	0	0	30	100
dry land	0	0	30	0	30	100
water	0	0	0	20	20	100
total in column	19	31	30	20	100	
producers accuracy(%)	100	96.8	100	100		

Error matrix table of classified Landsat image 2002 - Massawa area

over all accurancy =	96.3%					
Kappa =	0.95					
			reference points			
classified	mangrove	intertidal	dry land	open water	refrence pt total	users accuarcy(%)
Mangrove	13	0	0	1	14	81
intertidal	1	31	0	0	32	100
dry land	2	0	30	0	32	100
open water	0	0	0	31	31	97
total	16	31	30	32	109	
produced accuacry(%)	93	97	94	94		

Error matrix of classified Landsat image 2014 –Massawa area

overall accuracy =	97.3					
Kappa =	0.9					
			reference points			
Class	mangrove	intertidal	dry land	open water	Total in rows	users accuarcy(%)
mngrove	17	0	0	0	17	100
intertidal	1	30	0	0	31	96.8
dry land	2	0	31	0	33	93.9
open water	0	0	0	29	29	100
Total in column	20	30	31	29	110	
producer accuracy	85	100	100	100		

Error matrix of classified Landsat image 1994 – Barasole area

over all accuracy (%)	97.3					
kappa	0.96					
			reference points			
Class	mangrove	intertidal	dryland	open water	total in rows	users accuracy(%)
mangrove	17	0	0	0	17	100
intertidal	0	31	0	1	32	96.9
dry land	2	0	31	0	33	93.9
open water	0	0	0	29	29	100
total in column	19	31	31	30	111	
producers accuracy(%)	89.5	100	100	96.67		

Error matrix of classified Landsat image 1994 –Assab area

overall accuracy(%)	97.3					
kappa	0.96					
			reference point			
Classied	mangrove	intertidal	dry land	open water	total in rows	users accuarcy(%)
mngrove	17	0	0	0	17	100
intertidal	1	30	0	0	31	96.8
dry land	2	0	31	0	33	93.9
open water	0	0	0	29	29	100
total in column	20	30	31	29	110	
producer accuracy	85	100	100		100	

Error matrix of classified Landsat image 2003 –Assab area

over all accuracy(%)=95.6						
kappa=0.94						
			reference point			
Class	mangrove	intertidal	dry land	open water	total in rows	Users accuray(%)
mangrove	15	0	0	0	15	100
intertidal	2	31	0	0	33	93.94
dry land	2	1	31	0	34	91.2
open water	0	0	0	31	31	100
total in column	19	32	31	31	113	
producer accuracy(%)	78.9	96.9	100	100		

Error matrix of classified image2014- Marsa Mubarek

over all accuracy (%)	= 85.54					
kappa	= 0.81					
		reference point				
classified	mangrove	intertidal	dry land	open water	total in row	users accuracy(%)
mangrove	18	1	0	0	19	94.7
intertidal	0	19	0	8	27	70.4
dry land	2	1	21	0	24	87.5
open water	0	0	0	13	13	100
total in column	20	21	21	21	83	
producers accuracy(%)	90	90.5	100	61.9		

Error matrix of classified Landsat image 2014 -Gela'lo area

over all accuracy(%)=92
kappa=0.89

	reference points					
classififed	mangrove	intertidal	dry land	open water	total in rows	users accuracy
mangrove	22	0	0	1	23	95.7
intertidal	4	31	0	1	36	86.1
dry land	4	0	31	0	35	88.6
open water	0	0	0	30	30	100
total in column	30	31	31	32	124	
producers accuracy(%)	73	100	100	94		

Error matrix classified Landsat image 2002- Zula area

overall accuracy (%)= 82.9
kappa= 0.77

	reference points					
Class	mangrove	intertidal	dry land	open water	total in rows	users accuracy(%)
mangrove	19	0	0	1	20	95
intertidal	0	30	0	0	30	100
dry land	0	9	21	0	30	70
open water	0	0	9	22	31	70.96
total in column	19	39	30	23	111	
producers accuracy (%)	100	76.9	70	95.7		