TRIDECADAL ASSESSMENT OF MANGROVE COVER AND COVER CHANGE IN THE TRANSBOUNDARY AREAS OF KENYA AND TANZANIA BETWEEN 1986-2018

FREDRICK MUNGAI MBURU

A thesis submitted to Graduate School in partial fulfillment of the requirements for the Degree of Master of Science in Geography of Egerton University

EGERTON UNIVERSITY

OCTOBER, 2019

DECLARATION AND RECOMMENDATION

Declaration

I hereby declare that this thesis is my original work and has not been submitted for the award of a degree or any other award in any other university.

Signed………………………………………

Date……………………………………………….

Fredrick Mungai Mburu

NM13/14109/15

Recommendation

This thesis has been submitted for examination with our approval as University supervisors.

Signed………………………………………….

Date…………………………………………….

Dr. John M. Mironga, PhD

Department of Geography,

Egerton University,

Signed……………………………………………

Date………………………………………….

Dr. James G. Kairo, PhD

Department of Oceanography and Hydrography,

Kenya Marine and Fisheries Research Institute

P.O. Box 81651,

Mombasa.

DEDICATION

To my mother for her moral support throughout the writing of this thesis. To my siblings for their invaluable support, encouragement and inspiration throughout the research period. I will forever cherish your care and support.

ACKNOWLEDGEMENT

First is to thank Almighty God for the gift of life and perseverance through the process. I also wish to appreciate Egerton University for the opportunity to do my studies through the institution. Further is to extend my heart felt gratitude to the Faculty of Environment and Resource Development (FERD) and the Department of Geography for the assistance offered.

My special and sincere thanks goes to my supervisors Dr. John Mironga, Egerton University Department of Geography and Dr. James Kairo, Kenya Marine and Fisheries Research Institute (KMFRI) not forgetting Dr. Bernard Kirui of Natural Resource Department Egerton University. It is because of their guidance and advice that I have come this far. I also want to express my appreciation to the entire mangrove research team of KMFRI Shimoni and the community members in both Kenya and Tanzania for tirelessly dedicating their time and effort during data collection in the field.

I acknowledge financial support of the Flemish Interuniversity Council – University Development Cooperation (VLIR-UOS) through the TEAM project 'Transboundary coastal processes and human resource utilization patterns as a basis for a Kenya-Tanzania conservation area initiative (Trans-Coast)' ZEIN2016PR425.

ABSTRACT

Mangrove forests are among the most threatened ecosystems on earth. Some of these forests transverse national boundaries complicating their management due to differences in governance structures between countries. In order to improve the management of trans-boundary mangroves and associated biodiversity, regular monitoring of status and conditions of these forests is essential. The aim of the study was to create a better understanding of trans-boundary mangrove cover/ change and the current conditions of the ecosystem, with the aim of supporting joint management plans, regional policy formulation and better conservation strategies. The study adopted correlational research design. A systematic random sampling design was used in selection of sampling sites, where 120 plots were selected along the transboundary area. Remotely sensed data was used to estimate mangrove forest cover and analyze changes in forest conditions guided by the following study variables; area coverage of land use/cover, tree density, time, tree diameter at breast height, tree quality, number of stumps, species importance value, transboundary mangroves of Kenya and Tanzania. Image classification and analysis was conducted on Landsat images dating from 1986-2018 sentinel image, using hybrid unsupervised and supervised maximum likelihood classification algorithm. This was complemented by a detailed ground-truthing. Results indicate that the transboundary mangroves cover an estimated area of 11,906ha; 55% of which is in the Kenyan side and the rest in Tanzania. Generally transboundary mangroves recorded a continuous decline of 0.69%/year. Mangrove areas near human settlements within Tanga and Moa in Tanzania and Vanga and Funzi in Kenya, faced a higher degradation level over the last three decades. The Kenyan side of the transboundary area recorded more losses and degradation in comparison to the Tanzanian side. Over the entire study period, Vanga recorded the highest rate of mangrove loss at 27ha per annum followed by Tanga and Funzi at 14.5ha per annum and 12.3ha per annum respectively. Structural data indicated highest importance value of 113% and 100% for *Rhizophora mucronata* and *Ceriops tagal* respectively. The vegetation map obtained showed that the forest is dominated by *Ceriops* and *Rhizophora* with the mixed stand of *Ceriops* leading with 17% of the total area. A relationship was observed between other land use/ cover types change and mangrove cover change. Harvesting of mangroves for building poles and energy has contributed to major loss of mangroves in the region. For effective protection and conservation of mangroves along transboundary area of Kenya and Tanzania, the study recommends provision of alternative sources of energy and materials for construction without which mangrove loss and degradation is expected to continue.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

AFOLU	Agriculture Forestry and Land Use
CBD	Convention for Biological Diversity
CGK	County Government of Kwale
DBH	Diameter at Breast Height
DEM	Digital Elevation Model
DN	Digital Numbers
DPSIR	Drivers Pressure State Impacts Response
DRC	Democratic Republic of Congo
ENVI	Environment for Visualizing Images
ETM	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization of the United Nation
FBD	Forest and Beekeeping Department
GCP	Ground Control Points
GEF	Global Environmental Funds
GIS	Geographic Information System
GPS	Global Positioning System
GoK	Government of Kenya
GoT	Government of Tanzania
GT	Ground Truthing
ICRI	International Coral Reef Initiative
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
IUC	Iso cluster Unsupervised Classification
KMFRI	Kenya Marine and Fisheries Research Institute
KNBS	Kenya National Bureau of Statistics
KWS	Kenya Wildlife Service
LIDAR	Light Detection and Ranging
LULC	Land Use Land Cover
LULCC	Land Use Land Cover Change and Forestry
MAM	March April May
MLC	Maximum Likelihood Classification
MENR	Ministry of Environment and Natural Resource

MPRU	Marine Park and Reserve Unit
NDVI	Normalized Difference Vegetation Index
OA	Overall Accuracy
OLI	Observation Land Imager
OND	October November December
PA	Producer's Accuracy
RC	Regeneration Class
REDD+	Reduced Emissions from Deforestation and forest Degradation
RMS	Root Mean Square
RS	Remote Sensing
SDGs	Sustainable Development Goals
SMLC	Supervised Maximum Likelihood Classifier
TBCA	Trans-Boundary Conservation Area
TFS	Tanzania Forest Service
TM	Thematic Mapper
UA	User's Accuracy
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
USA	United State of America
USGS	United States Geographical Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WIO	Western Indian Ocean
WWF	World Wide Fund for Nature

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Despite increased awareness of the value of mangroves in many parts of the world, the forests are reducing at a rate of 1-2% per annum (FAO, 2007; Polidoro *et al.,* 2010; Spalding *et al.,* 2010, Giri *et al.,* 2011), although recent studies have noted a declining trend on the rate across the tropics and sub-tropic region of the globe (Hamilton, & Casey, 2016; Thomas *et al.,* 2017). Nevertheless, significant variation in rates of deforestation between countries and regions, along with the continued decline in general mangrove status, through replacement of mature diverse forests by monospecific plantations and/or degradation of existing habitats (Hamilton, & Casey, 2016).

The rate of loss of mangrove cover has been found to be higher in the developing parts of the world including Asia where loss of up to 8% per annum have been observed (FAO, 2007; Polidoro *et al.,* 2010; Spalding *et al.,* 2010; Dan *et al.,* 2016). About 30-50% in the past half century (Duke *et al.,* 2007), and 20-35% of the original world's mangrove cover has been lost, in the last three decades (FAO, 2007; Spalding *et al.,* 2010; Thomas *et al.,* 2017). According to Hamilton & Casey, (2016) Southeast Asian recorded the highest rate of loss in 2000 to 2012 as compared to other regions of the world. At country level Indonesia topped the rank closely followed by Myanmar and Malaysia. The recorded high rate of mangrove loss in Asia and precisely Southeast Asia has been attributed to conversion of mangrove areas to aquaculture ponds which still holds among the current major anthropogenic threats to mangrove cover (Primavera, 2000; Thomas *et al.,* 2017).

Within the Western Indian Ocean (WIO) region high loss of mangrove cover have been recorded. For instance, between 1980 and 2005, Tanzania lost 18% of its mangroves; translating to loss of 0.7%/year. Similarly, Kenya lost 18% of its mangroves between 1985 and 2010; while Mozambique lost 27% of its mangroves between 1990 and 2002 (UNEP, 2009; FAO, 2005, 2007; Kirui *et al.,* 2012). Losses and degradation of mangroves have negative effects on fisheries, resource sustainability, shoreline stability, and community livelihood (UNEP, 2014; GoK, 2017; Obura *et al.,* 2017).

The trans-boundary area of Kenya and Tanzania encompasses highly significant marine and coastal resources to the communities living adjacent and along the coastline among which mangroves are central (UNEP, 2009, 2014). The mangroves in the area provides social-economic benefits as well as ecosystem services to the communities living within and adjacent to the forest (Kairo *et al., 2001*; Wang *et al.,* 2003; Tabor, *et al.,* 2010; UNEP, 2014; Bosire *et al.,* 2016). The trans-boundary area of Kenya and Tanzania has a rapidly growing human population with approximately 60% of the communities primarily depending on the marine and coastal resources including mangrove (UNEP, 2009, 2014; GoK, 2017). In Kenya, approximately 80% of the coastal communities are believed to primarily rely on the mangrove as direct source of livelihood, hence loss and degradation of mangroves means loss of livelihood and ecosystem services to the mangrove forests adjacent communities (Dahdouh-Guebas *et al.,* 2000; Huxham *et al.,* 2015; GoK, 2017).

Some mangrove areas around the world transverse territorial borders with different legislation, policies, planning and management structures (Spalding *et al.,* 2010; Giri *et al.,* 2011). These differences lead to poor institutional coordination and are a setback to the implementation of a conservation agenda in the affected areas (UNEP, 2014). To address these governance deficiencies, countries opt for Transboundary Conservation Area (TBCA) initiatives to manage areas of common interests. An example of such TBCA is Waterton-Glacier which was established in 1932 to protect the area between Kootenay lakes forest and Glacier national park in Canada and USA respectively (Dallen, 2009). Only a few TBCA exists in Africa, mostly due to institutional failures and inadequate capacity. Examples include: The Greater Virunga Landscape TBCA between DRC, Rwanda and Uganda in 1929; and Mount Elgon TBCA between Kenya and Uganda; Lubombo TBCA between South Africa, Mozambique and Swaziland; and Nyika Plateau located between Malawi and Zambia (UNEP, 2009).

Mnazi Bay/Quirimbas Complex stranding across the border of Tanzania and Mozambique is the only marine based TBCA in the WIO region. This seascape is characterized by dense stands of mangroves, coral reef, and seagrass beds. Mnazi Bay/Quirimbas TBCA has served to protect mangroves and associated biodiversity from illegal activities including unsustainable resource utilization, overfishing, pollution, and habitat conversion (Nicolau *et al.,* 2017)

Governments of Kenya and Tanzania have initiated plans to establish marine TBCA along the 175km coastline between Diani in Kenya and Tanga in Tanzania. Conservation issues in the proposed TBCA have been identified as: illegal and unsustainable removal of marine living resources; alteration of the freshwater flow; habitat degradation and transformation; pollution from domestic wastes; saltwater intrusion; climate change; and increased sedimentation associated with poor land use in the hinterlands. Consequences of these are; shortage of harvestable products, loss of marine biodiversity, reduction in fisheries, increased shoreline erosion, loss of livelihood, loss of potable water and resource use conflicts (Semesi, 1992; UNEP, 2009, 2014; MPRU & KWS, 2015; GoK, 2017). The overall objective of the TBCA is to contribute to regional integration by ensuring more effective, coherent and collective biodiversity management, in line with international and regional agreements and priorities for sustainable development and, to promote sustainable livelihoods (MPRU & KWS, 2015). To achieve goals and objectives of the TBCA, there is need to map current status and conditions of critical ecosystems including mangrove forest.

1.2 Statement of the Problem

The Kenya-Tanzania trans-boundary area is a reservoir of highly significant marine and coastal ecosystems. The mangroves in the area provides not only social-cultural and economic benefits but also ecological benefits to the communities living within and adjacent to the mangrove ecosystem. However, this trans-boundary mangroves ecosystem is prone to high risks of anthropogenic pressure through deforestation and degradation due to illegal harvesting, upland activities, flooding events and rapid increasing population along the coast of the two countries. Loss of mangroves' cover along the Kenya-Tanzania transboundary area, means loss of livelihood for adjacent communities. Additionally, loss and degradation of Kenya-Tanzania transboundary mangroves means loss of the critical ecosystem services.

To strengthen national and regional capacity in management that will ensure sustainable use of mangrove resources in the transboundary area of Kenya and Tanzania, it is vital to have up to date information on status, condition and the spatial-temporal change occurring within this region. Unavailability of consistent information on status and conditions of mangrove cover within the Kenya-Tanzania trans-boundary areas was identified as a gap to their sustainable management. The study aimed to address gap by generating accurate information of transboundary mangrove using modern technology of GIS and Remote Sensing.

1.3 Purpose of the study

This study sought to create a better understanding of trans-boundary mangrove cover/ change and the current conditions of the ecosystem, with the aim of supporting joint management plans, regional policy formulation and better conservation strategies.

1.4 Specific Objectives

i. To map out status, condition and trends of mangrove cover within the trans-boundary area between Gazi (Kenya) and Tanga (Tanzania) from 1986-2018.

ii. To characterize similarities and differences in mangrove forest condition across the Kenya-Tanzania boundary area.

iii. To determine the effect of land use practices on mangrove cover change within the trans-boundary area between Gazi (Kenya) and Tanga (Tanzania) from 1986-2018.

1.5 Research Questions

i. What is the status, condition and trends of mangrove cover within the trans-boundary area from Gazi (Kenya) to Tanga (Tanzania) for the period 1986-2018?

ii. What are the similarities and differences in mangrove cover and cover change across the Kenya –Tanzania trans-boundary area?

iii. What are the effects of land use practices on mangrove cover change within the trans-boundary region from Gazi (Kenya) to Tanga (Tanzania) for the period 1986 -2018?

1.6 Justification

The trans-boundary area of Kenya and Tanzania is a region of global significant that has been recognized by international bodies and conventions including (WWF) World Wide Fund for Nature and Convention on Biological Diversity (CBD) for harboring vital marine and coastal biodiversity. The area and associated ecosystem plays a critical role of social-economic importance to the coastal communities in the two countries. The loss and degradation of mangrove cover in both Kenya and Tanzania has led to increased coastal erosion (Kitheka *et al.,* 2002; Wang *et al.,* 2003; Kirui *et al.,* 2012), currently evident along the study area (personal observation). Coastal flooding and infrastructures' destruction, loss of critical flora and fauna endemic is predicted to occur as mangroves continue to be lost and degradation (Hiraishi *et al.,* 2014; Bosire *et al.,* 2014, 2016; Friess, 2016; Muhsoni *et al.,* 2018).

Mapping of mangrove status and condition within the trans-boundary area will provide, data appropriate for improved management of the resources in the area. Thus, placing the study in line with both global as well as national goals. As per the Kenyan Forest Act of 2016 and the 2002 Forest Act in Tanzania the study provides significant data and information that will enable establishment, development and sustainable management including conservation and rational utilization of forest resource for social and economic development of the country.

In line with the Kenyan Vision 2030 the field activities, data and information generated will play a crucial role in facilitating forestry activities including conservation that cuts across the social pillar. At global scale, the study activities fall in category 13 of global Sustainable Development Goals (SDGs) that concerns mitigation of climate change impacts through activities of agriculture, forestry and Land use (AFOLU) sectors. In addition, the study is in line with goal 12 on responsible conservation and production through sustainable forestry management, goal 14 and 15 on protection of mangroves as a biodiversity habitant and supply of life below water and on land respectively. By mapping out areas of high rate of mangrove cover loss where action is to be taken to reverse the process, the study will be facilitating achievement of target 12 on conservation of biodiversity of the Aichi targets.

1.7 Scope of the Study

The study mainly focused on understanding the status and current conditions of mangroves of the trans-boundary area from Diani in Kenya to Tanga in Tanzania, a Euclidean distance of 101.9km. The study utilized the current GIS and Remote Sensing techniques for data processing and interpretation. Forest structural data of the transboundary mangroves was collected and recorded in data sheet while the spatial information and associated attributed were obtained using a hand held GPS devices, while the secondary data (remotely sensed imagery were sourced freely from USGS Glovis website (http://glovis/usgs/gov). Landsat 5 to 8 and Sentinel 2 imagery were reviewed and only those with least cloud cover (cloud cover less than 10%) were acquired and used in this study.

1.8 Limitations of the Study

Persistent cloud cover over the study area posed a serious challenge. Thus, only the best quality data (least cloud cover and obtained during the same dry period) including 1986, 1991, 2003, 2016 and 2018 imagery were used in the study. During the ground truthing, some areas were inaccessible due to dense prop roots coupled with stem density affected GPS performance. Google earth pro with high spatial resolution helped to overcome some of these challenges.

1.9 Assumptions of the Study

The first assumption of the study is that the land cover disturbances, are rare events over large geographical area to occur within a short period. Secondly, the spatially land cover disturbance is a continuous process over time. Thirdly, the difference in the time of image acquisition had insignificant influence on land use/cover along the TBCA area. Finally, the least cloud cover percentage on the imagery was insignificant to influence the results.

1.10 Definition of Operational Key Terms and Concepts

Cover change: Refers to the modification from initial physical land type to another different land type because of natural or human interruptions.

Degradation: changes in mangrove forest cover which negatively affect the structure or functionality of the forest stand and thus lowering the capacity to supply products and or services.

Dense mangrove forest: A forest with tree canopy density of more than 40%.

Forest: Land with tree canopy cover of more than 10 percent and area of more than 0.5ha.

Geographic Information Systems: A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information (Kennedy, 2013).

Hotspots: These are area**s** with high rate of land cover change exceeding a certain threshold (e.g. a yearly deforestation rate above 0.4%).

Hot Spots Analysis: A mapping technique interested in the identification of clustering of spatial phenomena.

Land cover: Implies the physical or natural state of the Earth's surface. In simpler terms, it refers to the observed physical and biological cover of the Earth's land as vegetation or man-made features.

Land use: The manner in which human beings utilizes the land surface and its resources. Land use reflects the total of arrangements, activities, and inputs undertaken in a certain land cover type (a set of human actions). The social and economic purposes for which land is managed (e.g., grazing, crop growing, timber extraction, conservation) is a land use characteristic.

Mangrove forest: These are woody inter-tidal trees and shrubs growing in saline sediment in the coastal zone with low oxygen soils and hyper salinity.

Plot/quadrant: The specific area of study within the study site measuring 10m by 10m where mangrove structural data was obtained.

Protected area: Any area of intertidal or sub-tidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment. Areas under Kenya Wildlife Service or Marine Park Reserve Unit.

Remote Sensing: Is the process of collecting and interpreting information about the environment and the surface of the earth from a distance without physical contact with the target object. (Kennedy, 2013).

Sparse mangrove forest: A forest with tree canopy density of less than 40%.

Supervised maximum likelihood classification technique: an approach where classifier guesses the probability with which specific pixel belongs to a specific class by use of specific training classes created by the user.

Unsupervised ISO-cluster classification technique: an approach where the outcomes that is groupings of pixels with common characteristics are based on the software analysis of an image without the user providing sample classes.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The review of the literature has been guided by the objectives of the study where, the mangrove status, conditions, and trends of cover change have been discussed. The driver of mangrove cover change including land use/cover change have been reviewed narrowing down from global to regional scale. In addition, the approaches used in assessment of mangrove cover and cover change particularly the GIS and Remote Sensing technologies have also been reviewed. The legal framework guiding management and use of mangroves in both Kenya and Tanzania were reviewed and highlighted. Finally, the conceptual framework that guided the study has been presented at the end of the chapter.

2.2 Transboundary Resources

Transboundary Resource is the movement of biological and physical resources or of impacts linked to these resources traversing political boundaries (international borders) (Okumu, 2010). In accordance with the Charter of the United Nations and the principles of international law, States have the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction (Utton, 2019). Management and issues of sharing of resources that are within international borders falls under principle 2 of the Rio Declaration. Further, a need for an integrated approach to the and planning utilization and management of transboundary natural resources is emphasized in chapter 18 of Agenda 21 with a special focus on international river basins. The chapter also highlights on the importance of sharing management experience.

Among the shared transboundary resources in Africa are forests, lakes, mountains, rivers and river basins, aquifers, wildlife and land (Altchenko and Villholth, 2013). Specific examples are as follows: transboundary lakes that include Lake Turkana in east Africa shared by Kenya and Ethiopia; Lake Chad in west Africa shared by Niger, Cameroon, Chad and Nigeria; Lake Malawi in east southern Africa shared by Tanzania, Malawi and Mozambique; Lake Victoria in east Africa at the border of Uganda, Tanzania and Kenya and Lake Albert in east central Africa between Democratic Republic of Congo and Uganda (Hanson and Owusu, 2014).

Secondly is river that includes river Nile that flows across Uganda, Southern Sudan, Sudan, Egypt to Mediterranean Sea; river Limpopo across Mozambique, Zimbabwe, Botswana and South Africa; river Umba between Kenya and Tanzania; and Orange River shared by Namibia and Lesotho (Altchenko and Villholth, 2013). Last but not the least are the National parks in the African continent that includes Virungu heartland in east central Africa bordering Rwanda, Democratic Republic of Congo and Uganda; the W-Aryl-Pendjari national Park in west Africa falling between Burkina Faso, Niger and Benin; Serengeti National park in Tanzania and Maasai Mara game reserve in Kenya; Kruger national park shared by Zimbabwe Mozambique and South Africa; and finally the Congo basin forest in west and central Africa shared by Democratic Republic of Congo, Republic of Congo, Gabon, Central Africa, Equatorial Guinea and Cameroon (Hanson and Owusu, 2014).

To mention just but a few of the many challenges faced in utilization and management of these transboundary resources is different economic development levels between countries, lack of international systems to enforce agreements, trust issues among nations sharing the resources and untimely and poor agreements (Linell *et al.,* 2019) Generally, an important and critical challenge that cuts across is limited/lack of solid data on environmental issues and absence of appropriate financing management of the transboundary resources thus making collaboration challenging (Linell *et al.,* 2019).

2.3 Mangroves Cover, Condition and its Benefits at Global and Regional Scale

Mangroves are inter-tidal forests typically found along coastline in the sub-tropics and tropics area around the world (FAO, 2005). According to Giri *et al.,* (2016) 42% of the global mangrove cover is found in Asia taking the highest percentage followed by Africa with 21%, North/central America with 15%, Oceania 12% and South America 11% being the least percentage of the global mangrove cover.

There are 73 mangrove species in the world approximately more than half are found in Asia while a quarter that is 17 mangrove species are found in Africa (Duke *et al*., 2007; Spalding *et al.*, 2010). Among the 17 species in Africa, nine of them are found in East Africa region while the remaining eight species are dominant in the West Africa region (UNEP, 2007). Africa accounts for about 21% of the global mangrove cover, which is equivalent to about 3.2 million ha (Giri *et al.,* 2011; Bosire *et al.*, 2016). According to FAO (2007), mangrove ecosystem in Africa occurs in three major sub-sections comprising the Western Indian Ocean, which accounts for 37% of Africa mangrove cover, the Eastern Atlantic that accounts for about 49%

of the continent's mangrove cover and lastly the Central Atlantic accounting for the remaining 14%.

The Kenya-Tanzania trans-boundary mangroves, falls within the Western Indian Ocean global sub-region that stretches from southern Somalia through Kenya, Tanzania, Mozambique, Seychelles, Madagascar coast to South Africa. These mangroves support the greatest flora and fauna diversity in the whole of African continent (UNEP, 2014). Moreover, WIO mangroves also provide habitats for many populations of birds and fishery.

Different species of mangrove in the WIO region occurs in a zonation pattern (FAO, 1994; Kairo *et al.,* 2008; Obade *et al.,* 2009). *Sonneratia Alba* occurs commonly in the muddy soils on the seaward side of the shoreline. This is followed by *Rhizophora mucronata* on muddy soil, *Bruguiera gymnorrhiza* and *Ceriops tagal* on the landward side. *Heritiera littoralis* is mostly found on low salinity areas like estuary mouths as well as riverbanks. *Xylocarpus granatum* mainly grows on higher ground where fresh water has more influence. *Avicennia marina* on the other hand displays a disjunct zonation pattern across the intertidal zone thus is present in the most landward and the seaward fringe of mangrove forest at certain locations along the Kenyan coast (Dahdouh-Guebas *et al.,* 2004). *Xylocarpus moluccensis* and *Bruguiera gymnorrhiza* growing along the riverbanks. *Lumnitzera racemosa* is mostly found on the outermost zone landward. The zonation pattern is not always permanent due to disturbances where regeneration of heavily harvested species may fail to occur and the area may end up being colonized by the pioneer species (Kairo *et al.,* 2001; Bosire *et al.,* 2003; Dahdouh-Guebas *et al.,* 2004; Gok, 2017).

Mangrove ecosystem provides goods and services that enables the communities living within and adjacent to the ecosystem to meets their livelihood needs. Economically, the coastal communities within the transboundary area exploit mangroves to obtain wood and non-wood products thus earning them a living from the sale of these products (FAO, 2005, Bosire *et al*., 2016). In both Kenya and Tanzania, among the wood products are timber and poles (used as construction materials for houses and boats), firewood, charcoal, dyes, fodder for livestock (Kairo *et al.,* 2001; Wang *et al.,* 2005; Bandeira *et al.,* 2009, Kirui *et al.,* 2012). On the other hand, the non-timber products obtained from mangrove ecosystem includes honey, food in form of crabs and fish caught inside the forest as well as medicinal values of different mangrove species (UNEP, 2009, 2014; Huxham *et al.,* 2015). In Tanzania side of the TBCA mangrove wood has been used in the heating process in the sector which has been pointed out as a possible threat to the mangrove ecosystem (Wang *et al.*, 2005; Bandeira *et al.*, 2009; UNEP, 2009)

Ecologically, like the rest of the globe mangroves of the transboundary area of Kenya and Tanzania provide habitats for birds, vertebrates as well as non-vertebrates, serves as nursery grounds to numerous fish and marine fauna, prevent siltation of coral reefs, provide and contribute to organic matter and nutrients to primary and secondary production of coastal ecosystems (Obura, *et al.*, 2017). It also provides sink trap for pollutants by filtering land run-off as well as remixing terrestrial organic matter (FAO, 2005). Mangroves have demonstrated the existence of food web that is dependent on organic production of mangrove swamps (UNEP, 2014; Bosire *et al*., 2016).

The other critical role of mangroves in the trans-boundary area is coastal stabilization and protection from natural catastrophes as well as eroding effects of wave energy (Kairo *et al.,* 2001). Mangroves on one hand, help to protect housing, agricultural farms and other infrastructures from adversities of waves and Tsunamis, while on the other hand it provides protection of coastal and marine ecosystems (FAO, 2005; UNEP, 2014). Mangroves have been estimated to have five-ten times capacity to capture and store carbon as compared to equivalent area of healthy terrestrial forest (Alongi, 2012). When degraded, co-benefits provided by mangroves are greatly diminished along with the ecosystems' capacity to sequester carbon.

2.4 Trends and Drivers of Mangroves Cover Change

Empirical studies on mangrove forest cover all over the globe have indicated decline on the spatial coverage over the recent past at a high rate ranging 1-2%/annum (FAO, 2005; UNEP, 2007, 2016; Kairo, *et al.*, 2008; Giri *et al.*, 2008, 2011, 2014; Kirui, *et al.,* 2012; Bosire, *et al.,* 2014, 2016; Hamilton, & Casey, 2016; Thomas *et al.*, 2017). About half of the original global mangrove cover has been lost through both natural and anthropogenic activities (UNEP, 2007, 2014). One third (1/3) of total mangrove in Asia may have been lost between 1980-1990 period that resulted to about 16% of world's mangrove species elevated to risk of extinction (Richards & Friess, 2016; Thomas *et al.*, 2017).

The mangrove forest cover change in Africa have indicated a downward trend, where in Central and West Africa regions in a period of the past two and a half decades, approximately 20-30% of mangrove forest cover has been lost (Feka, & Ajonina, 2011). Similarly, high rates of mangrove cover have been recorded within the Western Indian Ocean (WIO) region.

Approximately 18-27% of the initial WIO mangrove cover have been lost in the last three decades (UNEP, 2009; FAO, 2007; Kirui *et al.*, 2012).

The factors affecting mangroves are closely related to the pattern and practices of land use as well as the water resource in the areas adjacent to and upstream of mangrove forest cover (Thomas *et al.,* 2017). Globally, the aquaculture industry has been identified as the main driver of mangrove cover loss over the last 30 years (Giri *et al.*, 2008; Richards & Friess, 2016). This was particularly observed in South East Asia and parts of Latin America. Other identified drivers are urbanization, climate change, mining, forestry and agriculture which have also contributed to mangrove deforestation but ranks lower than aquaculture activities over the same period (Richards & Friess, 2016). Directly, the causes of mangrove degradation in the East African region are clearing of mangrove areas for solar salt works and aquaculture, cutting down of mangroves for firewood and building material, mangrove clearing for urban development as well as human settlement. Indirectly, loss and degradation of mangroves through increased sedimentation in the mangrove areas and reduction in supply of fresh water to mangrove areas (Bandeira *et al.*, 2009; Kairo, 2008; UNEP, 2007; FAO, 2005; Bosire *et al*., 2016).

Mangrove forest in Kenya are faced by both natural and anthropogenic threats which has resulted to loss of about 20% of the initial forest cover in 1980s (GoK, 2017). According to the national mangrove management plan the identified anthropogenic threats in Kenya are: over-exploitation of wood products, conversion of mangrove areas to other land uses, aquaculture, pollution and sedimentation, diversion and damming of rivers, and infrastructure & development. Additionally, the natural threats include extreme weather event 1997/98 El nino, pest infestation and desiccation. Over-extraction of mangrove poles for export has left the mangrove forest cover in poor condition in terms of quality (Bosire *et al.,* 2014). This has also left some areas risking extinction of species like *Xylocupus granatum* and *Heritiera Littoralis* in Kilifi and Kwale counties (Bosire *et al*., 2016). Oil pollution through spillage at Mombasa port caused a great negative effect on mangroves at Makupa creek whereby, there has been frequent re-oiling of the area from the sunken reservoir of oil (Kairo *et al.*, 2001; Bosire *et al*., 2016). Although the ranking of threats and benefits of mangroves small variation between coastal counties, Illegal harvesting ranks as the highest threat while construction poles rank highest in benefits of mangroves at country level (GoK, 2017). Unlike other counties fish production rank as the number one benefit in Kwale county (Table 1).

Table 1: Ranking of benefits and major threats of mangroves in Kwale County as perceived by community

Rank	Benefits	Threats to Mangroves
1.	Fish production	Illegal harvesting
2.	Construction poles	Conversion to rice farms
3.	Firewood	Climate change
4.	Air purification	Destructive fishing methods
5.	Shoreline protection	Strong winds

Source: GoK, (2017)

Mangroves are among the traded commodities in Tanzania, where poles sourced from mangrove wood are used locally as construction material and making fish traps and exported to the neighbouring regions (Bandeira *et al.,* 2009). Wood from mangrove is used for commercial salt production and fish processing (Wang *et al.,* 2005). Mangrove forests support bee-keeping activities as an alternative income source to the coastal communities (Kairo *et al.,* 2001). Construction of solar evaporation pans for salt exploitation is another major threat in the country as there exist about 30 salt works in Bagamoyo alone (Bosire *et al*., 2016). An increasing pollution from upland sources is impacting productivity of mangroves through heavy metal traces deposit that have been reported on Msimbazi mangroves (Bandeira *et al.,* 2009; Bosire *et al*., 2016).

The rapid growth of the urban centers especially the capital Dar es Salaam at a rate of 6.75% per annum is a threat to mangroves in the area (Bandeira *et al.,* 2009). The mangroves in this area are not only cleared for construction material but also to create more space for new buildings, infrastructure like ports, hotels and also for the purpose of agriculture (Bosire *et al*., 2016). Lastly, is the rapid expansion of human population that has led to rapid reduction on the mangrove cover with an example of Zanzibar where in Michanvi the mangrove forest cover reduced from 800ha in 1948 to about 43ha in 1989 (Wang *et al.,* 2005). Between 1990 and 1992, the demand for wood required for building material alone rose by tenfold which is expected to continue with the continued rapid population increase (Bosire *et al*., 2016). Apart from the past heavy exploitation of the mangrove, threats still exist on the mangroves in

Tanzania, as it is feared that in future more mangroves will be lost to pawn aquaculture (Bandeira *et al.*, 2009).

2.5 Land Use/ Cover Change and its Impacts on Mangroves

Land use/cover change all around the world has continuously been driven by the ever increasing demand for food, biofuel as well as raw materials (Gibbs *et al*., 2010). The projections to the future indicate that land use and land cover change (LULCC) will continue with the continued increase in global affluence and population (FAO, 2015). Despite the benefits accrued from large scale LULCC, consequences like biodiversity loss and provisional services that are in many cases not taken into account before the conversion also occurs (Gibbs *et al*., 2010). LULCC studies have been carried out in different parts of the world to understand the temporal-spatial change and implications resulting from the same (Lambin *et al.,* 2003; Gibbs *et al*., 2010; Simon and Gregory, 2014; Marchant *et al*., 2018; FAO, 2015). Simon and Gregory (2014) found out that there were observable changes in the land use and land cover (LULC) patterns. Increase in the forest cover was found as the most substantial land cover change observed in the study area, this was attributed to the depopulation experienced in the region, which resulted to agricultural abandonment (Simon and Gregory, 2014).

In Asia as well as parts of Latin America studies in these regions show evidence of LULCC, where for mangrove cover change and loss has been directly linked to conversion of mangrove areas to agricultural and aquaculture farms (FAO, 2007; Polidoro *et al.*, 2010; Spalding *et al.*, 2010; Giri *et al.,* 2011, 2014). An assessment of LULC patterns in southern coastal region in Nigeria indicated significant influence of adjacent land use/cover to mangrove cover change (Yaw, and Edmund, 2006). These changes were found to be social economic factors as well as environmentally related factors. According to FAO (2015) a continued reduction of forest cover continues in Africa even within forest falling under protected area. This has been attributed to management challenges of forested areas in the region (inadequate resources and personnel) and forest fires that have also affected the quantity and quality of forest cover (FAO, 2005). Africa as a continent accounted for about 56% of the global loss in the period 1990 to 2000, which is about 52 million hectares of forest cover (Lambin *et al.*, 2003). The main cause of land cover change in East African region includes overgrazing, encroachments, agriculture expansion and illegal logging, which are still taking place in the region (Marchant *et al.*, 2018).

In Tanzania, specifically the coastal region experienced an increase in urban and settlement areas, which corresponded to rapid rise in population size (Wang *et al.*, 2005). About 93%

increase of built up areas was recorded in a span of 10 years from 1990 to 2000 for the whole of Tanzania's coastal region. The study found out a substantial reduction in mangrove cover in which was associated with overharvesting of mangroves for charcoal-making, firewood, boat-making, building poles as well as clearance of the mangrove regions for commercial development, road construction, solar saltpans, agriculture and settlement development.

In Kenya, the assessment on land use/land cover change especially along the coast indicates generally an increase in human population/settlement, reduction in mangrove cover and an increase in agricultural farms (Kirui *et al.,* 2012; Kihia, 2014). These changes were attributed to anthropogenic activity within the regions. An analysis of distribution and mangrove change detection in Tudor and Mwache creeks, Mombasa, Kenya revealed loss in mangrove forest coverage by over 80% between 1992 and 2009 with loses closely linked to land use changes within the study area (Bosire *et al.,* 2014).

2.6 Landsat and Sentinel Satellites

This are earth observing equipment revolving around the earth to gather data (Kwok, 2018). Landsat and sentinel satellites carry sensors that record portion of electromagnetic spectrum as it reflects from the earth surface (Kwok, 2018). The acquired digital data by the sensors mounted on the satellites is then converted to images (Notti *et al.,* 2018).

Landsat with seven successful missions over 40 years has and continues to acquire land surface data at moderate spatial resolution that is 30m for spectral bands and 60m for thermal infrared (Turner *et al.,* 2015). Over time since 1970s Landsat sensor and missions have to great extent improved in terms of spatial, spectral, geometric, radiometric performance, products and data availability (Notti *et al.,* 2018). The advancements from Landsat 1 to 6 Thematic Mapper (TM), 7 Enhanced Thematic Mapper plus (ETM+), 8 Observation Land Imager (OLI) have acquired and achieved with nearly continuous record of global land surface data since its inception (Table 2) (Wulder *et al.,* 2016; Notti *et al.,* 2018).

Table 2: Information on Advancements and Developments in Landsat

Instrument	Launched	Terminated	Description
Landsat 1	July 23, 1972	January 6, 1978	Originally named Earth Resources Technology Satellite 1. Landsat 1 carried two vital instruments; a camera built by the Radio Corporation of America (RCA) known as the Return Beam Vidicon (RVB). As well as a Multi spectral Scanner (MSS) built by the Hughes Aircraft Company.

Instrument	Launched	Terminated	Description
Landsat 2	January 22, 1975	February 25, 1982	Nearly identical copy of Landsat 1. Payload consisting of a Return Beam Vidicon (RBV) and a Multi spectral Scanner (MSS). The specifications of these instruments were identical to Landsat 1.
Landsat 3	March 5, 1978	March 31, 1983	Nearly identical copy of Landsat 1 and Landsat 2. Payload consisting of a Return Beam Vidicon (RBV) as well as a Multi spectral Scanner (MSS). Included with the MSS was a short-lived thermal band. MSS data was considered more scientifically applicable than the RBV which was rarely used for engineering evaluation purposes.
Landsat 4	July 16, 1982	December 14, 1993	Landsat 4 carried an updated Multi Spectral Scanner (MSS) used on previous Landsat missions, as well as a Thematic Mapper.
Landsat 5	March 1, 1984	June 5, 2013	Nearly identical copy of Landsat 4. Longest Earth-observing satellite mission in history. Designed and built at the same time as Landsat 4, this satellite carried the same payload consisting of a Multi Spectral Scanner (MSS) as well as a Thematic Mapper.
Landsat 6	October 5, 1993	October 5, 1993	Failed to reach orbit. Landsat 6 was an upgraded version of its predecessors. Carrying the same Multi spectral Scanner (MSS) but also carrying an Enhanced Thematic Mapper, which added a 15m-resolution panchromatic band.
Landsat 7	April 15, 1999	Still active	Operating with scan line corrector disabled since May 2003. The main component on Landsat 7 was the Enhanced Thematic Mapper Plus (ETM+). Still consisting of the 15m-resolution panchromatic band, but also includes a full aperture calibration. This allows for 5% absolute radiometric calibration.
Landsat 8	February 11, 2013	Still active	Originally named Landsat Data Continuity Mission from launch until May 30, 2013, when NASA operations were turned over to USGS. Landsat 8 has two sensors with its payload, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS).

Source: Wulder *et al.*, (2016)

Sentinel on the other hand is more recent earth observation mission by European Union systematically acquiring optical at high spatial resolution of 10m to 60m over land and coastal waters. The first satellite was launched in 2015 (Sentinel 2A) followed by (Sentinel 2B) in 2017 (Kwok, 2018).

The products from Landsat and Sentinel have a wide range of application from agriculture, fire, natural disaster, human health, energy, forest and water management (Notti *et al.*, 2018). On land use land use change Landsat products provides critical and irreplaceable observation capability across a wide scale (Pettorelli *et al.*, 2014). At different spatial resolution imagery selection for various utilization varies with pros and cons (Table 3).

Table 3: Advantages and Disadvantages of Medium and High Resolution Images

Advantages of Medium Resolution Images	**Advantages of High Resolution Images**
• Huge image selection option • Ability of remote sensing analysis from spectral bands • Historical perspective	• High level of details • Ability of tasking according to requirement
Disadvantages of Medium Resolution Images	**Disadvantages of High Resolution Images**
• Low level of detail	• High cost • Small area coverage • Lower availability

Source: Notti *et al.,* (2018)

2.5 Remote Sensing and GIS in Mangrove Assessment and Management

Remote Sensing and GIS technology have been widely used to carry out analysis and assessment of land cover and land cover change all over the globe (Wang *et al.,* 2005; UNEP, 2007; USGS, 2013; Dos Santos and da Silva, 2013). In mangrove management, Remote Sensing and GIS approaches have been used, in describing occurrence and distribution of mangroves. Further, Remote Sensing is used in establishing baselines for measuring change in the ecological character of mangroves, and assessing the extent and rate of mangrove wetland loss or degradation (FAO, 2005, 2007; Kairo *et al.*, 2008; Bandeira *et al.*, 2009; Giri *et al.*, 2015; Kirui *et al.*, 2012). Remote Sensing has been considered an appropriate modern technology in assessing the (LULCC) at both small and large scale, where the traditional field-based approaches such as observation may not effectively and appropriately deliver (Pimm *et al.,* 2015).

According to Dahdouh-Guebas *et al.,* (2000), the appropriate functions within a GIS environment, that enables assessment and analysis of mangrove ecosystem for management includes; buffering a neighborhood function that aids in determining a spatial envelop around a given feature. Second is classification, a detailed technique of purposefully removing detailed information from and inputting data sets. Third is the automatic catchment delineation involving generation of drainage lines of a given water catchment through use of DEM (Digital Elevation Model). Fourth is forest Structure retrieval by use of LIDAR (Light Detection and Ranging) which creates a high resolution digital models; species identification where, significant detailed information like tree type, height and density is obtained and last but not the least is biomass estimation where a combination of long wavebands and short wavebands enables the estimation of biomass.

In the contemporary world, GIS technology has become more integrated with Remote Sensing technology such that they work hand in hand to achieve a given specific objective (Pimm *et al.,* 2015). In other words, the large volumes of the increasing remotely sensed data about the earth surface may be of little or no use without GIS technology to provide storage and analysis capability to such voluminous data to synthesize the required information to decision makers (Liu *et al.,* 2013). Conversely, without Remote Sensing technology, GIS would not be as effective as currently has been. This being the case, the study utilized the technology to carry out the assessment of land use/cover in the study area.

2.6 Legal and Policy Frameworks Governing Use and Management of Mangroves in Kenya and Tanzania

In Tanzania mangrove forests falls under the department of Forest and Bee Keeping with the mandate to issue licenses for harvest and export of the resource in the country. Although Tanzania Forest Service (TFS) under Ministry of Natural Resource and Tourism was established to conserve and manage national forest resources, forests on public land and bee reserves, the Department of Forest and Bee Keeping still play the role of review and overseeing implementation of forest legislation, policies and laws. The policies and legal framework relating to mangroves includes Forest Act (2002) that encompasses mandates of designations of mangrove forest resources and encourages community based mangrove management.

Since some of the mangrove systems falls under the protected area, the Marine Park and Reserve Act (1994) directly plays a role in management and use of the resource. The goal of the Act is to ensure protection, conservation as well as species and genetic diversity restoration of the biotic and abiotic marine resource and ecosystem within marine and coastal areas in which mangrove ecosystem is central.in addition, the National Environmental Policy of 1997 whose focus is on environmental conservation and effective use of the natural resources. Next is the National Integration Coastal Environmental Management Strategy of 2003 that plays an important role of outlining commitments to sustainable governance, champions the Integrated Coastal Management as well as establishing the foundation for coastal governance in United Republic of Tanzania. Last but not the least is the Environmental Management Act of 2004 the main piece of legal framework of the environment in Tanzania providing a legal and institutional framework for sustainable mangrove management.

In Kenya, all forest including mangrove forests are under the jurisdiction of the Kenya Forest Service. The Kenyan constitution offers a guiding principle through which governance and use of land and the environment is undertaken. Forest policy and legislation relating to mangroves includes Forest Policy of 2014, Forest Act (2005), Forest Conservation Management Act (2016) and Kenya Forest Service Strategic Plan 2014/2017. As some of the mangroves systems in the country falls under the protected areas, those systems are managed under the jurisdiction of the Wildlife Conservation and Management Act of 2013. The Act authorizes the Kenya Wildlife Service (KFS) to enter into agreement with other competent bodies for protection of wildlife and their habitants. Next is the Environmental Management and Conservation Act of 1999, 2015 that addresses the conservation of environment issues as well as safeguarding against environmental degradation within and outside the gazette areas under natural resources. Under the land policies and legislation article 11(1), the Land Act of 2012 mandates the land commission to take appropriate action in maintaining public land with endemic or endangered species including protected areas or critical habitats. Lastly is the County Government Act of 2012 that ensures adequate environmental protection through integrated county planning and management under the devolved government.

2.7 Mangrove Management and Restoration

The trans-boundary area of Bangladesh and India with the largest mangrove system in the world occupying approximately 600,000ha has been identified as best global example of mangrove restoration initiative and the place where the restoration process began (Gravez *et al.,* 2013; Lewis and Brown 2014). Presently mangrove restoration and conservation initiative have increased globally (Lewis and Brown, 2014). The increase could be attributed to the widespread awareness to the communities living adjacent the systems understanding value of the critical mangrove ecosystem as well as the and the rapid global decline of the mangrove cover (Gravez *et al.,* 2013). Examples of the mangrove restoration initiatives are the Western Indian Ocean Mangrove Network, Mangrove Watch, Mangrove Action Project not forgetting the domestic organizations such as Mangrove Forest Conservation Society in Nigeria, Mobore in Kenya and Hoko in Madagascar (Gravez *et al.*, 2013; Lugo *et al.*, 2014).

It is of essence to note that management and restoration of mangrove forest currently recognize the critical ecosystem services played by mangroves including carbon sequestration (Lewis and Brown, 2014). An example of this is the large mangrove plantations established in China and India to enhance the process of carbon sequestration (Giri *et al.*, 2008). Erosion control, fish production, experiments to analyze mangrove biology and eco-tourism are some of the other reasons for mangrove restoration. The mangrove restoration process has succeeded in some regions but failed in other regions. Poor site and species selection for restoration programmes and ignoring recent mangrove scientific discoveries are among the reasons for failed restoration programmes (Kairo *et al.*, 2008; Lewis and Brown, 2014).

Along the Kenyan coast mangrove restoration and rehabilitation have taken place at Gazi in Kenya. About 10 hectares of mangroves were successfully planted at Gazi bay mangrove system in 1993 and about five hectares were planted after the 1997/1998 El Niño that affected the Gazi mangrove system (Kairo *et al.*, 2008). In Tanzanian, efforts of restoration have been carried out in Muhenza district but with no much success (Wang *et al.*, 2005).

2.8 Summary of the Knowledge Gaps

The rate of loss and degradation of mangroves is still high all over the world with major losses reported in the developing regions of the world. This is despite the fact that the ecosystem providing many benefits ranging from social-cultural, economic and ecological goods and services. In addition, recently mangrove cover has been found to have a 5-10 times higher capability of sequestering and storing carbon as compared to equivalent area of terrestrial forests, thus a critical ecosystem in this error of climate change. Information on forest cover as well as cover changes of a particular forested area is critical for ventures such as Payment of Ecosystem Services (PES). Mangrove forest cover/cover change assessment provides crucial information required to understand the status and condition of a given mangrove forest that determine among other benefits, its carbon sequestration potential.

Mangrove cover/cover change assessments at both global as well as at local scale, have shown some inconsistence that has been attributed to different methodologies, data sources, time and what is considered to be mangrove. There is limited consistent data and information on mangrove status and condition for the identified transboundary conservation area between Kenya and Tanzania. Rapidly increasing population and unsustainable use as well as illegal mangroves harvesting in both Kenya and Tanzania has been feared to impact not only mangroves but also the associated ecosystems. Use of mangrove in the trans-boundary area could be affected by lack of a common binding rules and regulations. To formulate rules and regulations to guide management and use of the critical transboundary mangrove resources, information of status, condition and changes taking place in the system is needed. This coupled with existence of limited consistent empirical works on the mangrove of the trans-boundary area, there was necessary to investigate conditions, trends and status of TBCA mangroves, which is a core ecosystem in the area.

2.9 Conceptual Framework

The study adopted DPSIR (Driver, Pressure, State, Impacts and Responses) model a causal framework for describing the interactions between the environment and society (Svarstad *et al.,* 2008). In the same way, the human activities and natural factors influence the functionality as well as the spatial-temporal occurrences within mangrove forest systems. In this case the study investigated how the forest adjacent communities (society) along the transboundary area influence and bring about change on mangrove forest cover (environment) through their day to day activities. Hence, the driver being construction poles and wood from mangroves, pressure being the rapidly increasing population along the coast that bring about increased demand for construction materials and wood for energy, state being the forest condition, impact being degradation through loss of cover while the response is the management policies and restoration programs. As a guide the study variables were generated from the objectives of the study (Figure 1).

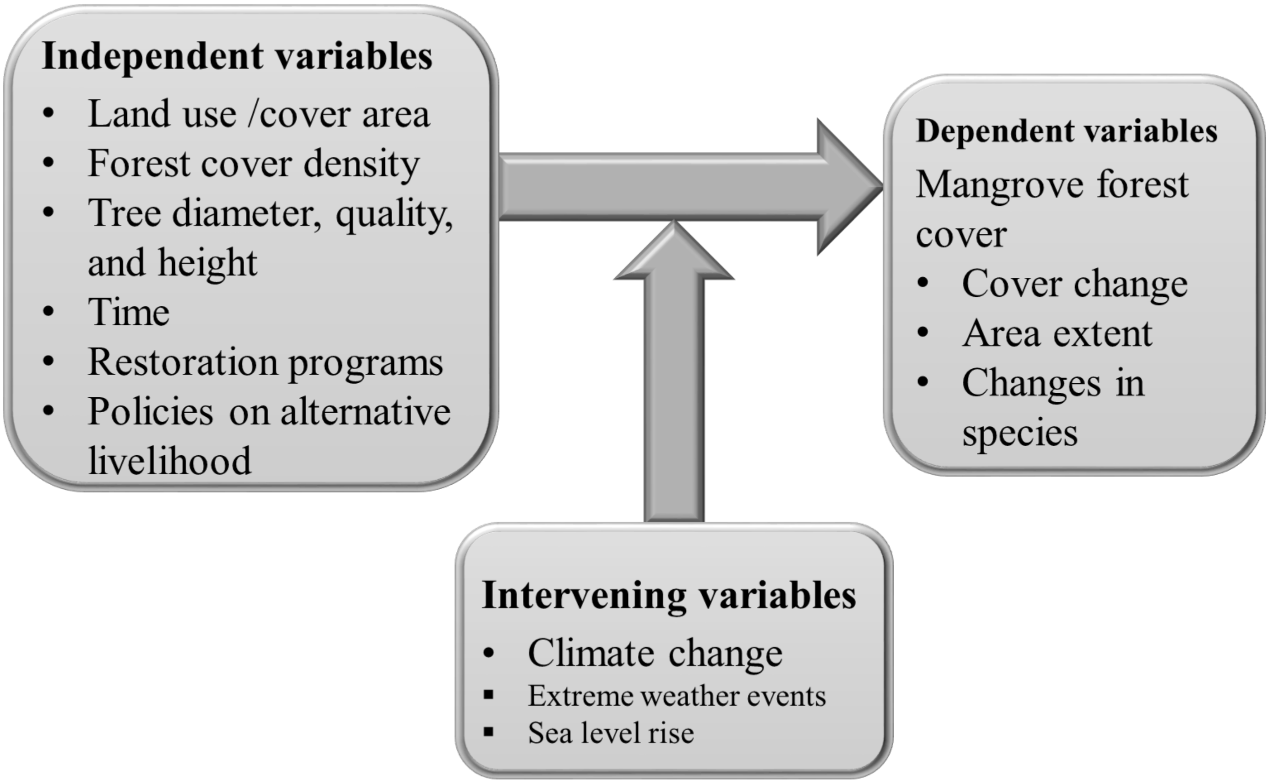


Figure 1: Conceptual framework used in the study

Source: Synthesis of literature

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This section describes and shows the location of the trans-boundary area. The research design as well as sampling techniques used in the study are expounded on. Sources and approaches used acquiring data, methodologies used in analyzing these data, tools used as well as the obtained information is presentation are all elaborated in detail in the chapter. Finally, procedures and processes of classification accuracy assessment used in study have also been particularized.

3.2 Research Design

The study adopted a correlational research approach which aided in image analysis and in acquisition of the mangrove forest structure data. GIS and Remote Sensing techniques were utilized to carry out an analysis of the acquired remotely sensed and structural data to meet the study objectives. A field survey was conducted to facilitate ground truthing as well as accuracy assessment processes. Analysis of field data was carried out using Minitab statistical program version 17.0 and Microsoft Excel, while the image processing and analysis was carried out using ArcGIS and ENVI software applications.

3.3 Study Area

The study is located within the proposed TBCA between Kenya and Tanzania that extends from Diani in Kenya ($39^{0}0^{1}0^{11}$ E, $4^{0}25^{1}0^{11}$ S) to the north, to Tanga in Tanzania in the South ($39^{0}40^{1}0^{11}$E, $5^{0}10^{1}0^{11}$S), a Euclidean distance of 101.9 km (Figure 2). The TBCA present a narrow strip along the coast, with an estimated area of 2,440.7 km^2. This area falls within Kwale County in Kenya and Mkinga district in Tanzania along the coast with the Diani- Tanga road forming the boundary landward while ocean ward, a depth of 200m forms the boundary.

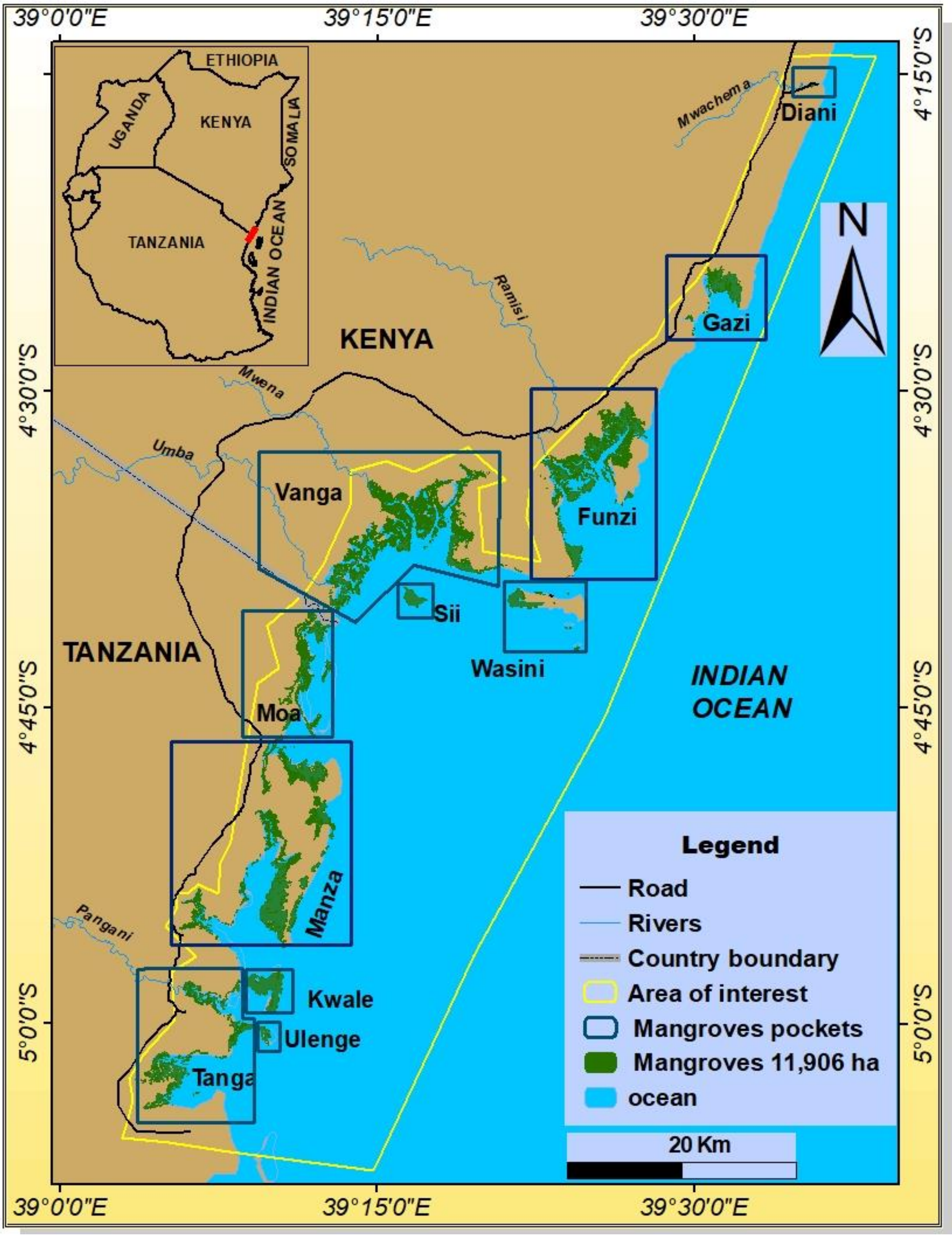


Figure 2: Map of the study area: proposed transboundary conservation area (TBCA) between Kenya and Tanzania

Source: KMFRI, Study Data, (2018)

3.3.1 Climatic Conditions

The study area lies on the tropical region, where the weather and climatic conditions are highly influenced and determined by the southeast and northeast monsoon winds as well as the inter-tropical convergence zone (ITCZ) (MPRU & KWS, 2015; Bosire *et al.*, 2016). According to Koppen climate classification system, the TBCA falls under tropical savanna/tropical wet and dry category supporting mixed woodland and grassland vegetation (Anderson, and Samoilys, 2015). Minimum and maximum annual rainfall ranges from 1000 - 1200 mm. Rainfall is bimodal with two distinct periods; the long rains between March and May, and the short rains usually between October and December (Figure 3). Minimum and maximum temperatures ranges between 18 and 26^{o}C respectively. The area experiences high mean annual relative humidity of 74-78%/year (Bosire *et al.*, 2016).

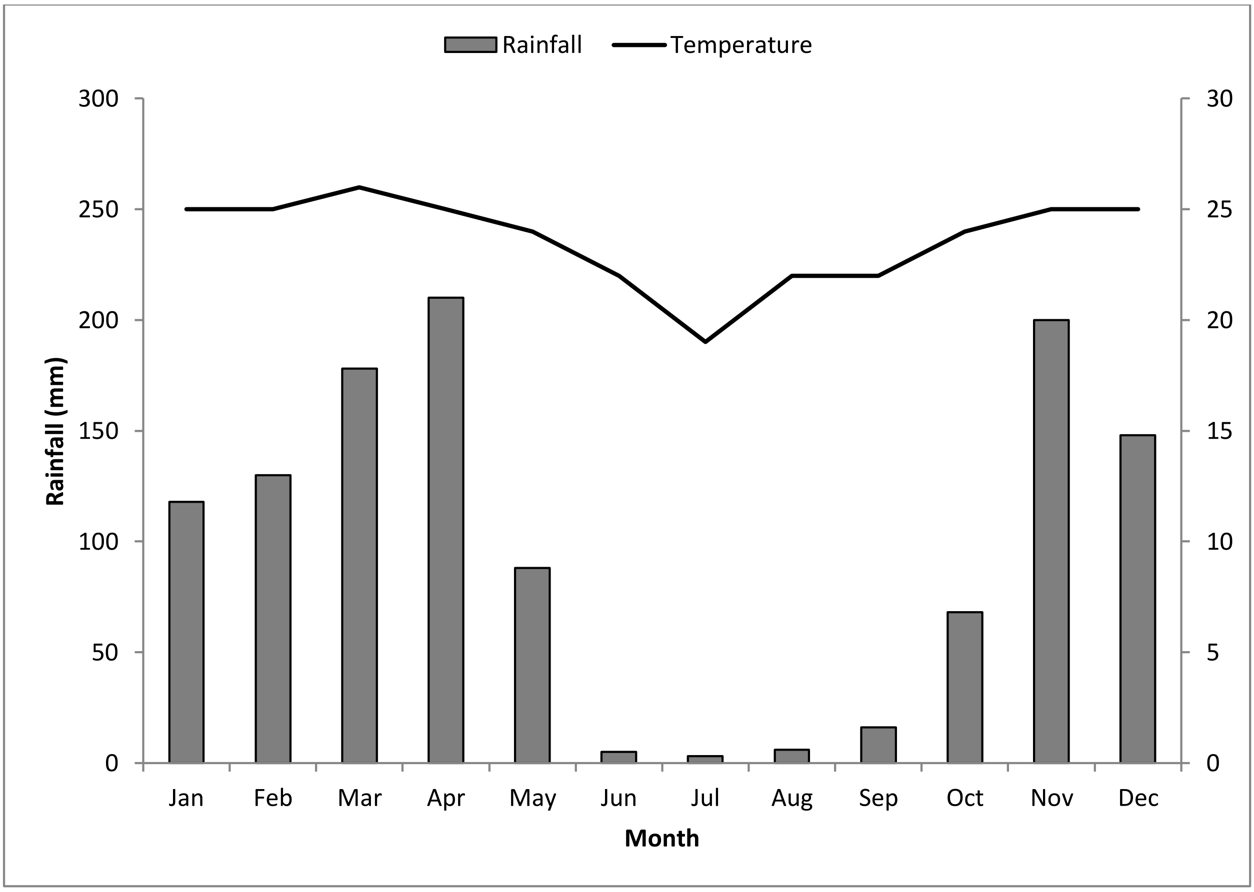


Figure 3: Climatic patterns (annual rainfall and temperature) along the transboundary area

Source: MPRU & KWS, (2015)

3.3.2 Bio-Physical Conditions

Mangroves of the Kenya –Tanzania TBCA

All nine mangrove species described in the WIO region occur in the TBCA. The key species are *Rhizophora mucronata, Ceriops tagal* and *Avicennia marina* which occupy 70% of the mangrove forest formation in the area (Bosire *et al.,* 2016). Similar to most mangrove areas in the region, different species in the TBCA exhibit horizontal distribution patterns (Bosire *et al.,* 2016). The seaward side is occupied by *Sonneratia alba* and tall *Avicennia marina*. This is followed by *Ceriops tagal*, *Rhizophora mucronata*, *Bruguiera gymnorrhiza* and *Xylocarpus granatum* mosaics in the middle zone; while the landward side is occupied by dwarf *Avicennia marina, Heritiera littoralis* and *Lumnitzera racemosa* (Bosire *et al.,* 2016). Mangroves within TBCA are exploited for wood and non-wood resources. Trees are harvested for wood and energy, whereas forest adjacent communities frequent mangrove areas for fishing. The major drivers of losses and degradation of mangroves in the transboundary area have been identified as overharvesting of wood products, conversion of mangrove areas for other land uses such as solar salt works, human settlement, and rice farming, pollution effects, and climate change (Bosire *et al.,* 2016).

In addition to the mangrove cover that is the most dominant habitat and resource, the trans-boundary area also harbors coral reefs, seagrasses, sandy beaches, coastal forests and rivers including Pangani, Ramisi, Mkurumudzi and Umba (which is trans-boundary in nature) that provide the transboundary area with important estuarine habitant (Bosire *et al.,* 2016). There are nine mangrove species occurring along the study area, which includes *Sonneratia alba, Rhizophora mucronata, Xylocarpus granatum, Lumnitzera racemosa, Heritiera littoralis, Xylocarpus moluccensis, Bulguiera gymnorrhiza, Avicennia marina,* and *Ceriops tagal* (Semesi, 1992; Bosire *et al.,* 2016; GoK, 2017).

Geology along TBCA

Geologically the principal rock along the trans-boundary region is of sedimentary origin giving rise to soil of low fertility. Nevertheless, patches of fertile alluvial soil exist along the region. The principal soil type is a narrow strip of sand, bi-alternate bands of loam soil away from which grumosils are permeated by a copious layer of pumice soils and ash (Lovett & Wasser, 2008). There are intertidal mudflats and sand flats distributed all along the transboundary area. These mudflats and sand flats are predominantly associated with mangroves and seagrass meadows.

Sea surface temperatures and Salinity

Sea surface temperatures and to a lesser extend the salinity of ocean waters of the transboundary area are influenced by the monsoons and tides. The temperature ranges from 25^0 C between June-September as the lowest which raises to 28^0 C -30^0 C in November to March but generally the average temperature is approximately 27^0 C. The salinity is lowest along the creeks and during the rainy season though the average is 34ppm.

Oceanography along the TBCA

On oceanography the transboundary area waters are mainly influenced by the east African coastal currents that flows along the coast of the two countries almost throughout the year. During the north eastern monsoons, the east African current flows up to Malindi in Kenya where it joins the Somali current. On the other hand, during the south eastern monsoons, the current is enhanced and joins the Somali current north of Malindi flowing up to horn of Africa. The transboundary area experiences a semi-diurnal type of tide that is predominant along the East African coast. The semi-diurnal tide has two tidal cycles in 24.5 hours whereby the tidal range averages between 2m during neap tide and raises up to 4m during spring tides.

3.3.3 Social Economic Activities of the Study Area

Communities within the study area largely depend on readily available coastal and marine resources to meet their livelihood demands. The main economic activities associated with these resources include forestry, fishing, tourism, mining and plantation agriculture (UNEP, 2009; Bosire *et al.,* 2016). These economic activities within the transboundary area in one way or the other may influence of bring about change in land use of the area. Mining (Base Titanium limited) and plantation agriculture (Kenya International Sugar Company Limited) along the transboundary area demands a lot of water for processing and irrigation respectively. Mangroves on the other hand, requires inflow fresh water without which the system is changed in area extent and formations distribution (Bosire *et al.,* 2016).

Generally, the population along the coast of east Africa has rapidly increased. This majorly attributed to the rural urban migration of the young people seeking employment in town (Cleland & Machiyama, 2016). For instance, on the Tanzanian side the coastal population stood at 379,000 in 1994 and rose to over 500,000 by 2005 with a proportion of 242,640 and 220,000 in Tanga City, Pangani Town and in the villages respectively (López-Carr *et al.,* 2014). On the other hand, Kwale county in Kenya has a rapid growing population projected to rise to 0.9 million increasing at a rate of 3.1%/annum by 2017 from the 2009 population census result.

Msambweni constituency along which the study area lies along recorded the highest population density and rate of increase of 4%/annum (CGK, 2013).

3.4 Sampling Procedures

Systematic random sampling approach was adopted for each of the three sites in Kenya and Tanzania. Three study sites were randomly selected from both sides of the boundary giving a total of 6 sites along transboundary area. At each study site, 4 transect lines were laid perpendicular to the shoreline/creeks along which 5 plots of 10mx10m were systematically established at 15-50 m interval depending on forest formation and extend of mangroves. A total number of 120 plots that is 20 plots at each study site were sampled (Figure 4). From the plots structural data that is tree height, diameter at breast height (DBH), regeneration, number of stumps per plot, forest cover, forest type and tree quality data were obtained.

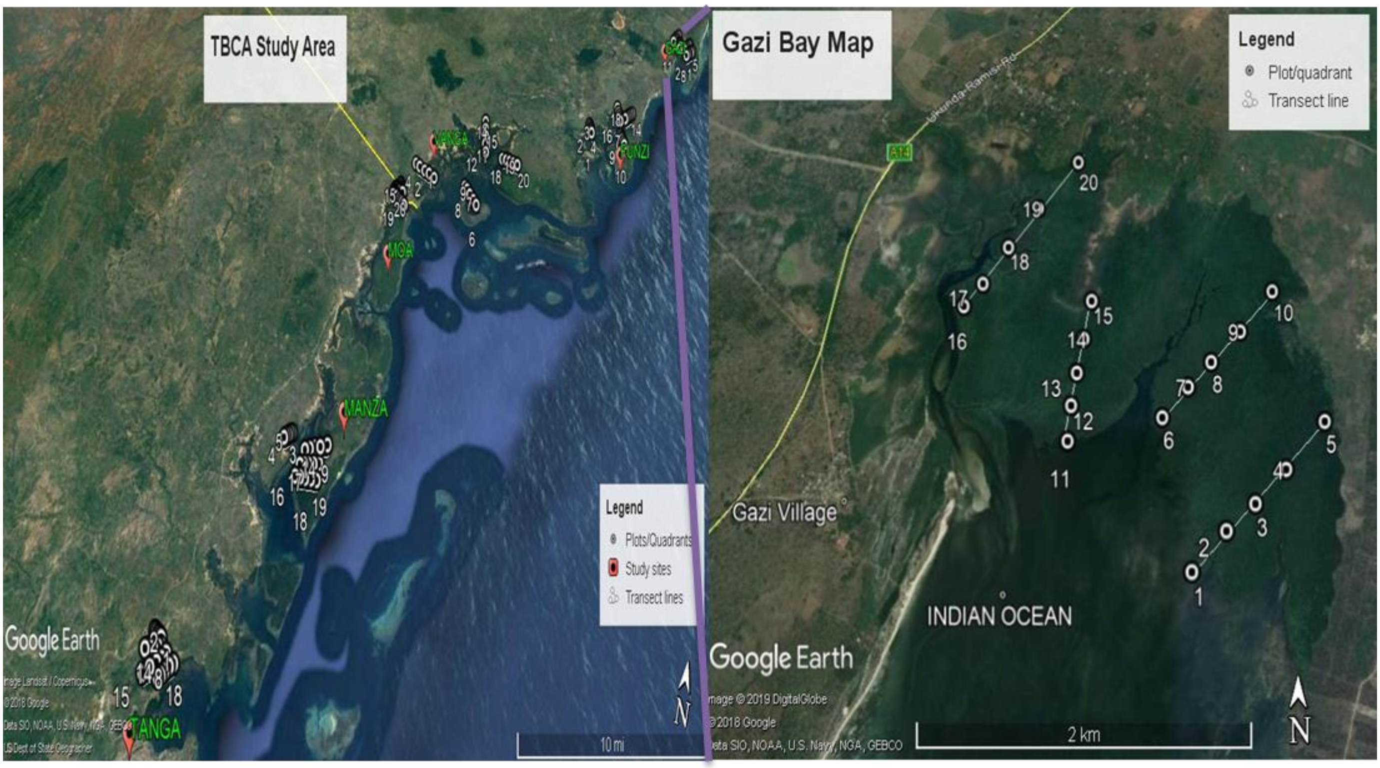


Figure 4: Google Earth image showing the study sites and the transect lines along which the plots/quadrants were laid

Source: Google Earth Pro image (2018)

3.5 Instrumentation

The study utilized mainly secondary data that was validated by collected primary data collected during field campaigns. Secondary data were the Landsat and Sentinel images collected by sensors mounted on satellites. The primary spatial data and its associated attribute information were collected using hand held GPS devices. Additional information was collected using mangrove structural data sheet.

3.5.1 Satellite Data Acquisition

The study used Global Land Survey data (GLS) supplemented by Landsat imagery freely acquired from the United States Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS) website (www.glovis.usgs.gov). Landsat images since 1980's were reviewed for quality, and cloud-free scenes selected for analysis at different epochs as specified in (Table 4). Additional information of the study area was obtained from the national mangrove database archived at Kenya Marine and Research Institute (KMFRI) in Kenya and Forest and Beekeeping Division (FBD) in Tanzania; Africover data, technical reports, Google Earth pro, and land cover/use reference maps. Other data sets included the World mangrove Atlas accessed from URL:http//data.unep-wcmc.org/datasets/6 and the 2011 mangrove map from ocean data viewer website. The Ground Control Points (GCP) were sourced from the GPS coordinates collected during fieldwork exercise.

Table 4: Details of Imagery Used in Analysis and Mapping of Mangroves of the TBCA.

Sensor	Resolution (meters)	Raw and column	Epoch	No. of images obtained
Thematic Mapper	30	166/063	1986	2
Thematic Mapper	30	166/063	1991	2
Enhanced Thematic Mapper plus	30	166/063	2003	2
Observation Land Imager	30	166/063	2016	2
Sentinel 2A	10	006/510 & 014/775	2018	2

Source: Study Data, (1986-2018)

3.5.2 Initial Ground Truthing

During the ground truthing (GT) campaigns, the initial classified 2016 Landsat and 2018 Sentinel imagery were used to guide collection of information required. The data was collected at the identified study sites all along the transboundary area. Garmin GPS 64s devises were used to record the spatial data and descriptive information of the 120 sites visited. Google earth pro was critical in preparation for the field campaigns as well as providing any extra required information that may not have been acquired during the exercise.

3.6 Data Collection Procedures

On getting data collection approval from Egerton University Graduate School, the researcher acquired a research permit both from the National Commission of Science, Technology and Innovation (NACOSTI). Being a transboundary area I had to have another permit for the Tanzanian side from Kenya Marine and Fisheries Research Institute previously acquired for the Transcoast project that my work was part of.

3.7 Data Management and Analysis

Data analysis for the study entailed getting meaningful information from the data collected. ArcGIS and ENVI was used in image preprocessing analysis, classification and post classification analysis. Microsoft Excel and Minitab were used in organizing and analyzing the primary data that helped in obtaining information on the condition/status of transboundary mangroves. The presentation of the findings was done in form of maps, graphs and figures. Detailed procedures followed are elaborated below.

3.7.1 Image Processing

Geo-referencing of acquired spatial data (Landsat imageries, Ground Control Points (GCP)) to a common global geo-referencing system that is World Geodetic System (WGS) 1984 was performed. The data was then registered to the local area coordinate system of Universal Transverse Mercator (UTM) Zone 37S with first-degree polynomial adjustment using ArcGIS geo-referencing tools. Normalization process was performed on all imageries to eliminate variation brought about by solar angle and the Sun-Earth distance.

The normalization process entailed conversion of Digital Numbers (DN) to top of atmosphere reflectance in two steps: First, the DN was returned to values that can be compared between scenes. Secondly, the values obtained in step one were converted to account for difference in solar irradiance due to earth/sun geometry (orbital distance and tilt). The conversion was carried out in ArcMap using a raster calculator tool while the scene variables were sourced from metadata files acquired together with the imagery. To improve clarity and quality of the outputs, image enhancement was performed in the image analysis window in ArcMap.

Geometric correction was executed to improve the geo-location to a Root Mean Square (RMS) of 0.5 of a pixel. The area of interest thus included mangrove cover and the adjacent land uses/cover along the transboundary area. The corrected imageries were then subset and clipped out to include only areas within and adjacent to where mangroves are likely to occur. This process is imperative; as it improves overall image classification accuracy by reducing image spectral variations as well as the total number of land cover types (Dan *et al.,* 2016; Ghosh *et al.,* 2016).

3.7.2 Image Classification and Change Detection

A hybrid Supervised Maximum Likelihood Classifier (SMLC) and Iso cluster Unsupervised Classification (IUC) algorithm was used in the image analysis. First, IUC was performed on the 2016 Landsat and 2018 Sentinel clipped image to guide the initial ground truthing and fieldwork campaigns for land cover and mangrove species mapping processes. The initial GT entailed verification of the land use/cover generated from the unsupervised classification process and collection of spatial and associated attribute data. These data were critical during generation of training samples for SMLC and accuracy assessment processes. After initial GT process, SMLC was performed on all the clipped out images of the TBCA. The use of a hybrid method of both IUC and SMLC helped in overcoming the challenge posed when a single method is used as well as make use of the advantage provided by each (Giri *et al.,* 2008; Dan *et al.,* 2016; Ghosh *et al.,* 2016).

Training samples were generated to obtain mangrove and adjacent land use/cover from 1986, 1991, 2003 and 2016 imagery and species cover from 2018 image. Mangrove species identification and mapping was carried out using the obtained spectral signatures (Figure 5). In addition, supplementary information obtained from various sources and authors' prior knowledge were used to document different characteristics of mangrove species formations based on previously published work (Semesi, 1992; Bosire *et al.,* 2016; GoK, 2017). To detect change in mangrove cover, from the four epochs of classified images (1986, 1991, 2003 and 2016), a post classification technique was employed. This approach provided a "from–to" change information and has been considered the most common change detection method (FAO, 1994; Giri *et al.,* 2008, 2016). Changes in mangrove cover was carried out by comparing data of the four periods: 1986–1991, 1991–2003, 2003–2016 and 1986–2016.

The change in cover and the rate at which the change occurred were analyzed using the formulas:

Change area = C2-C1 where C1 & C2 are the area of the target land cover type at the beginning 1986 and at the end 2016 of the study respectively (1)

% change = (change area/B) x100, where B is the total area (2)

Annual rate of change (ha/year) = change area/T, where T is the number of years between the beginning and the end of the study period (3)

% annual rate of change (%/year) = change area/ (C1xT) (4)

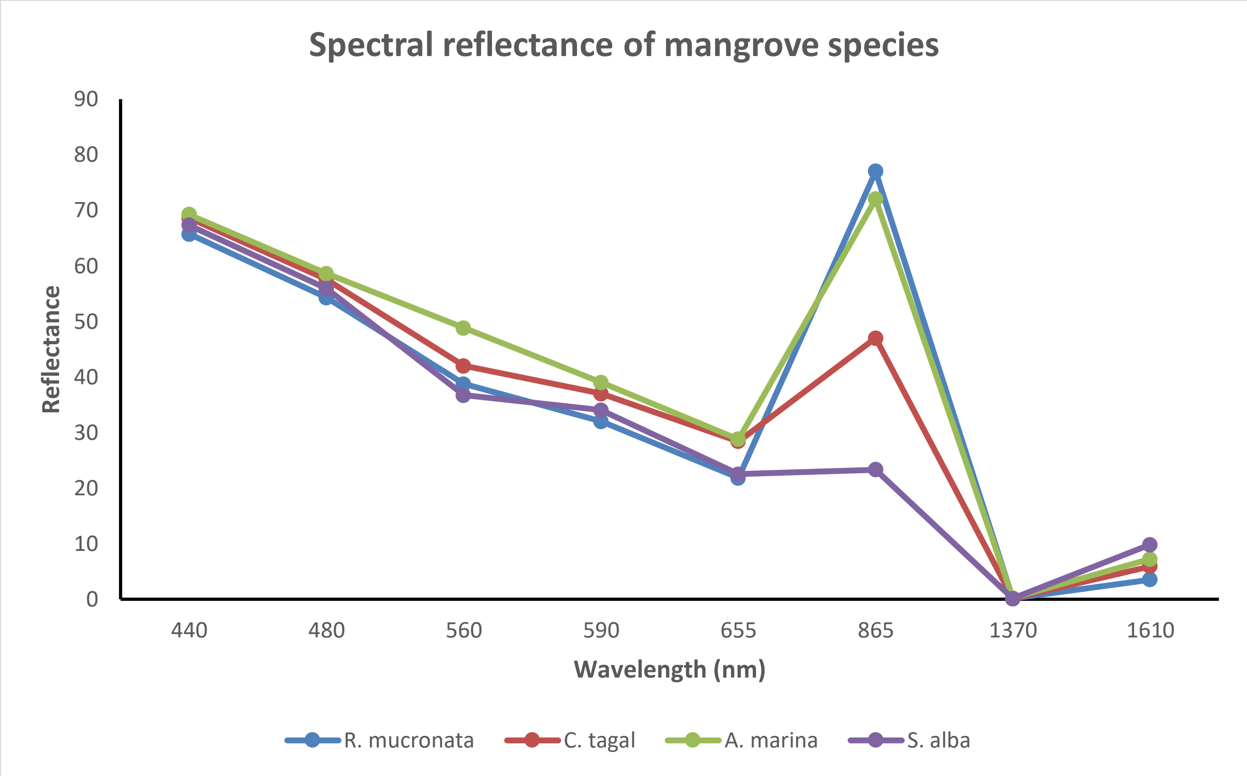


Figure 5: Mangrove species spectral reflectance at different wavelength along the electromagnetic spectrum

Source: Field data (2018)

3.7.3 Hot Spots Analysis

Hot spots are locations where observed patterns are not likely the result of random processes or of subjective cartographic design decisions; they represent places where there are underlying spatial processes at work (Getis and Ord 1996). For this study hot spots of mangrove cover/change were analyzed using spatial statistics tools: integrate; collect events; incremental spatial out correction and hotspot analysis tools within ArcGIS environment. High resolution imagery from Google Earth were used to validate the observed changes and the identified likely drivers.

3.7.4 Analysis of Mangrove Forest Structural Data

The structural data generated from the field was used to derive importance value index (%), stand density (stems/ha), basal area (m^2 /ha) and stand volume (m^3/ha) using the following equations:

Importance value (%) = Relative dominance% + relative frequency% + relative density%(5)

Stand density (stems/ha) = (number of stems in plots x 10000)/area of the plot (6)

Basal area=$\pi/4dbh^2=0.00007854D_{130}^2$ (7)

3.7.5 Normalized Difference Vegetation Index (NDVI) Calculation

NDVI is calculated from the red and the near infrared spectral bands. Studies have used NDVI to assess the conditions/status/health of mangrove forests and how these have changed over time (Wachid *et al.*, 2017; Muhsoni, *et al.*, 2018). Plant (including mangroves) leaves through chlorophyll pigments absorbs the visible light that is ranging from 0.4-0.7mm of the electromagnetic spectrum EMS, and reflects the near infrared light ranging from 0.7-1.1mm as a result of the plant leave inner structure (Wachid *et al.*, 2017). The study used NDVI to assess mangrove density and its spatial-temporal changes along the transboundary area of Kenya and Tanzania. NDVI was calculated using the relation of the near infrared and the red band where:

NDVI= (NIR-Red) / (NIR+Red) (8)

An NDVI output varies between -1 to +1. The higher/positive NDVI values closer to +1 means a healthy ecosystem in this case high mangrove density, while on the other hand the lower NDVI value close to -1 means poor condition of the vegetation in this case least mangrove density and/or absence of vegetation. The NDVI values were calculated and classified into the dense vegetation (healthy mangroves) and the sparse vegetation (unhealthy mangroves) using raster calculator tool in ArcMap.

3.8 Assessment and Validation of Classification Accuracy

It is of paramount importance that after any image classification, an accuracy assessment is performed to assess the representativeness of the classified phenomenal to the real world (FAO, 1994; Dos Santos, & da Silva, 2013; Giri, 2016). For this study ArcGIS 10.5, google earth pro and part of the data obtained during the fieldwork campaigns were used in assessing the accuracy of all the generated land use/cover maps of the TBCA. Thus, error matrix was generated to derive Producer's Accuracy (PA), User's Accuracy (UA), Overall Accuracy (OA) and Kappa co-efficient statistics using the following equation (Kamal and Johansen, 2017).

$$K^{\wedge} = \frac{\sum_{i=1}^{r} xii - \sum_{i=1}^{r}(Xi + *X + i)}{N^2 - \sum_{i=1}^{r}(Xi + *X + i)}$$

Where, K^ =Kappa Coefficient

r = Number of rows in the matrix

xii = Number of rows in row i and column i

xi+ and x+i = Marginal totals of row i and column i

N= Total number of observations

3.8.1 Accuracy Assessment Result

The classification accuracy result for both mangroves cover and species formation was satisfactory, thus warranting output interpretation. Majority of the randomly generated points on classification outputs were correctly classified. The overall accuracies and Kappa co-efficient of all classes were above 80% and 0.75 respectively hence warranting further interpretation of the results (Table 5). Table 6 demonstrate an error matrix tables generated in calculation of producer accuracy, user accuracy and overall accuracy hence Kappa co-efficient.

Table 5: Summary of Classification Accuracy Assessment Results

Year	Expected	Overall Accuracy	Kappa Co-efficient
1986	0.24	82%	0.76
1991	0.24	87%	0.83
2003	0.24	92%	0.89
2016	0.24	91%	0.88
2018	0.13	89%	0.87

Source: Study Data, (1986-2018)

Table 6: Mangrove Species Formation Error Matrix of the 2018 Sentinel Classified Image

Classified	*Rhizophora mix Stands*	*Avicennia mix Stands*	*Avicennia pure stands*	*Ceriops mixed*	*Sonneratia pure stands*	*Rhizophora pure stands*	*Rhizophora-Sonneratia*	*Ceriops pure stands*	*Mixed stand of Ceriops and*	**Raw Total**	**Producer Accuracy**	**User Accuracy**
Rhizophora mix Stands	**49**	2	0	0	0	0	0	1	0	**52**	85.96	94.23
Avicennia mix Stands	3	**53**	1	3	0	0	0	0	1	**61**	84.13	86.89
Avicennia pure stands	1	4	**123**	7	1	1	8	1	0	**146**	93.89	84.25
Ceriops mixed stands	3	0	6	**115**	0	0	0	10	0	**134**	82.14	85.82
Sonneratia pure stands	0	2	0	4	**87**	0	0	0	1	**94**	96.67	92.55
Rhizophora pure stands	0	0	0	0	2	**96**	0	1	0	**99**	95.05	96.97
Rhizophora-Sonneratia	0	0	1	11	0	4	**105**	1	2	**124**	89.74	84.68
Ceriops pure stands	0	2	0	0	0	0	3	**48**	1	**54**	76.19	88.89
Mixed stand of *Ceriops* and *Rhizophora*	1	0	0	0	0	0	1	1	**43**	**46**	89.58	93.48
Column total	**57**	**63**	**131**	**140**	**90**	**101**	**117**	**63**	**48**	**719**		

Overall Accuracy = 0.89 Kappa = 0.87

Source: KMFRI, Study Data, (2018)

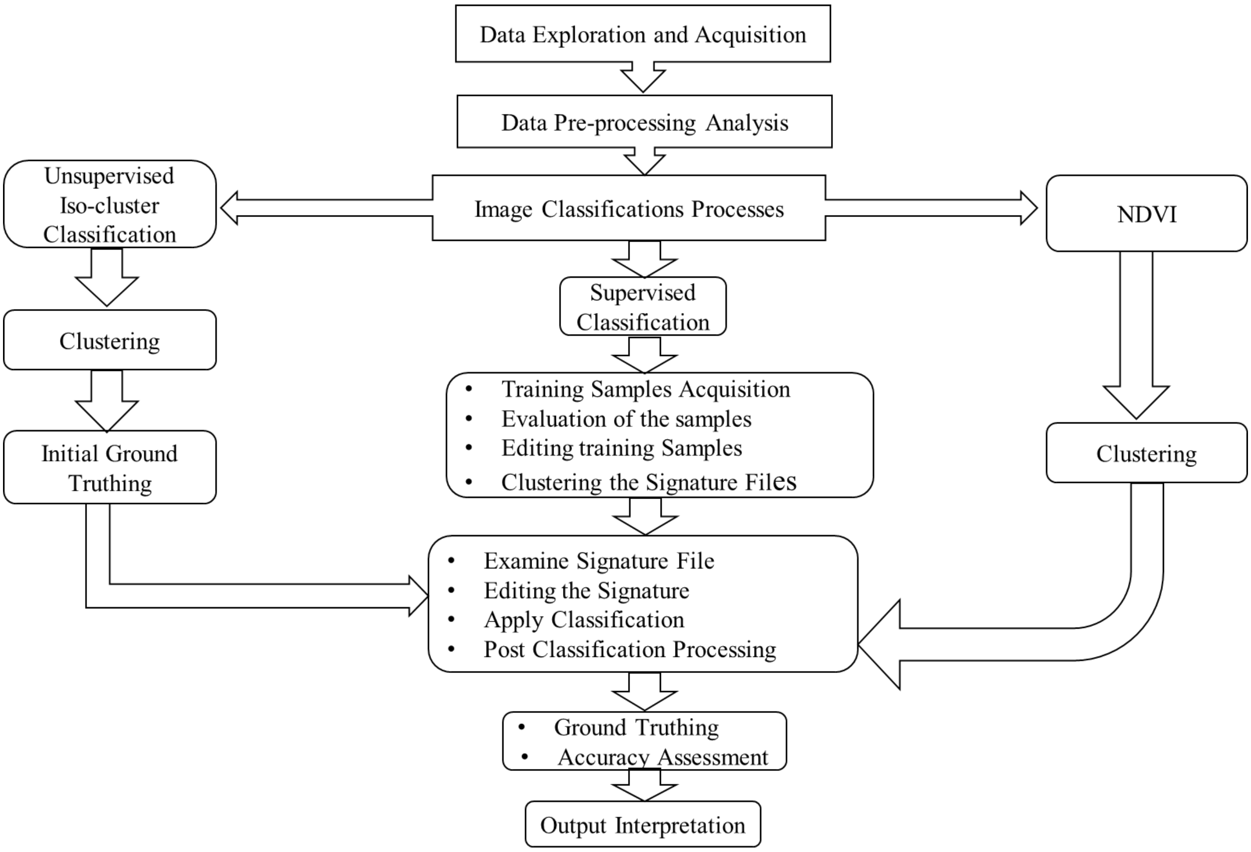


Figure 6: A Summary of Methodology used in the Study

Source: Authors Own Conceptualization

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This section will cover the status/condition and trends of mangrove forest cover along the TBCA which include: mangrove forest cover along the TBCA; mangrove cover change in the TBCA; structural attributes of mangroves in TBCA; mangrove species composition; forest type classification used in the survey; comparison of area occupied by mangrove species formation in different periods; variation in (NDVI value) mangrove density; land use/cover change and mangroves cover change regression against land cover changes. The similarities and difference of mangrove cover/ cover change has been pointed out within the above mentioned subsections.

4.2 Status, Condition and Trends of Mangrove Cover

4.2.1 Mangrove Forest Cover along the TBCA

Analysis of satellite images indicated the area of mangroves in the proposed TBCA as 11,906 ha. These forests are distributed in twelve major distinct 'pockets' in creeks, bays, lagoons, small islands, river opening and estuarine of main rivers all along the 175km coastline on both sides of the transboundary area (Figure 3.1).

About 6,195ha (or 55%) mangroves occur in the Kenyan side of TBCA, with the balance (45%) occurring in Tanzania. Vanga block in Kenya constitutes the largest single extent of mangroves in the TBCA with 25% of the forest coverage, while the smallest area (of about 8ha) occur in the opening of Mwachema river in Diani. Overall, the mangrove cover along the TBCA, occupy about 80% of the 175km coastline (Figure 3.1). Other significant mangrove areas (pockets) in the TBCA are Manza 2863ha, Funzi 2226 ha, and Tanga 1212 ha (Table 4.3). Only 18% of the mangroves in the TBCA falls under the protected area that is under Kenya wildlife service (KWS) in Kenya and Marine Park Reserve Unit (MPRU) in Tanzania.

GIS and Remote Sensing technology plus readily available voluminous remotely sensed data provide an accurate and effective way of estimating spatial extent of mangrove forest cover at different scales which has been used all over the globe (Polidoro *et al.*, 2010; Spalding *et al.*, 2010, Giri *et al.*, 2011; Kirui *et al.*, 2013; Hamilton, & Casey, 2016; Thomas *et al.*, 2017). The high overall (82%, 87%, 92%, 91%, and 89%) and kappa (0.76, 0.83, 0.89, 0.88 and 0.87) classification accuracy attained for this study shows the level of reliability of the information provided. In this study, mangroves of Kenya-Tanzania transboundary area were mapped using combination of Landsat and Sentinel imageries; supplemented with detailed ground-truthing.

Table 7: Major Mangrove Areas (Pockets) Along the Proposed Marine TBCA between Kenya and Tanzania

Forest Block	Country	Area(Ha	Main Characteristics
Mwachema estuarine Diani	Kenya	8	Dwarf mangrove forest that falls within Diani-Chale Marine Protected Area The principle species is *Avicennia marina* and *Ceriops tagal* Area is hampered by sediment deposition at the river mouth. Main driver of mangrove cover change is illegal harvesting and sedimentation.
Gazi bay	Kenya	515	Fringing forest with good participation of community in conservation and rehabilitation activities. The principal species are *Rhizophora mucronata, Ceriops tagal, Sonneratia alba* and *Avicennia marina*. Partly falls under Diani-Chale Marine reserve. Main driver of mangrove cover change is illegal harvesting and sedimentation.
Funzi	Kenya	2226	Fringe mangrove forests. Includes mangroves of Ramisi, Bodo and Shirazi. The principal species are *Rhizophora mucronata, Avicennia marina and Ceriops tagal*. Main driver of mangrove cover change is illegal harvesting
Wasini	Kenya	252	Island fringe mangrove forests. Falls under Kisite Mpunguti Marine National Reserve. The principal species are *Rhizophora mucronata* and *Sonneratia alba*.
Vanga	Kenya	3035	Fringe mangrove forests. Includes the VAJIKI (Vanga, Jimbo and Kiwegu) and Majoreni mangroves. The principal species are *Rhizophora mucronata* and *Ceriops tagal.* Main driver of mangrove cover change is illegal harvesting
Sii	Kenya	199	Island fringe mangrove forests. Constitute one of the pristine mangroves in Kenyan south coast. Falls under Kisite Mpunguti Marine National Reserve. The principal species are *Rhizophora mucronata* and *Sonneratia alba.*
Moa	Tanzania	991	Fringe mangroves with approximately more than half of the system falling under MPA (Kirui Island Marine reserve). The principal species are *Rhizophora mucronata* and *Ceriops tagal.* Main driver of mangrove cover change is illegal harvesting and conversion to other land use.

Forest Block	Country	Area(Ha	Main Characteristics
Manza	Tanzania	2863	Majorly riverine mangroves although in some area they occur as fringe mangroves. Less than 5% of the system falls under MPA (Mwewe Island Marine reserve). The principal species are *Rhizophora mucronata, Heritiera littoralis* and *Ceriops tagal.* Main driver of mangrove cover change is illegal harvesting and conversion to other land use.
Kwale	Tanzania	517	Island fringe mangrove forests. Constitute one of pristine mangroves in north coast of Tanzanian. This block falls entirely under Kwale Island Marine reserve. The principal species are *Rhizophora mucronata, Avicennia marina* and *Sonneratia alba.*
Ulenge	Tanzania	88	Over washed mangrove forest. Falls entirely under Ulenge Island Marine reserve. The principal species are *Rhizophora mucronata* and *Sonneratia alba.*
Tanga	Tanzania	1212	Fringe mangrove forest The principal species are *Ceriops tagal, Avicennia marina* and *Rhizophora mucronata.* Majorly dominated by dwarfed mangroves due to lack of nutrients, high salinity, and rocky soils Main driver of mangrove cover change is illegal harvesting.

Source: Study Data, (2016; 2018)

4.2.2 Mangrove Cover Change in the TBCA

Both losses and gains of mangrove cover were observed over the study period. Although the mean mangrove cover change was higher on the Kenyan side of the TBCA, no significant difference was noted between the two sides of the transboundary area ($t=1.01$ $p<0.05$ $DF=5$). Over the last three decades, mangrove in TBCA declined from 15,015ha in 1986 to 11,906ha in 2016; translating to a loss of 0.69% per annum. Generally, mangrove cover change along the TBCA was observed to be on a declining trend over the study period. This was the same for the Kenyan side of the TBCA but different for the Tanzanian side where some gain in mangrove cover was observed (Figure 4.1). The loss of mangrove cover along the TBCA was particularly higher between 1986-1991 (13%) compared to 6.5% and 1.1% losses recorded between 1991-2003 and 2003-2016, respectively.

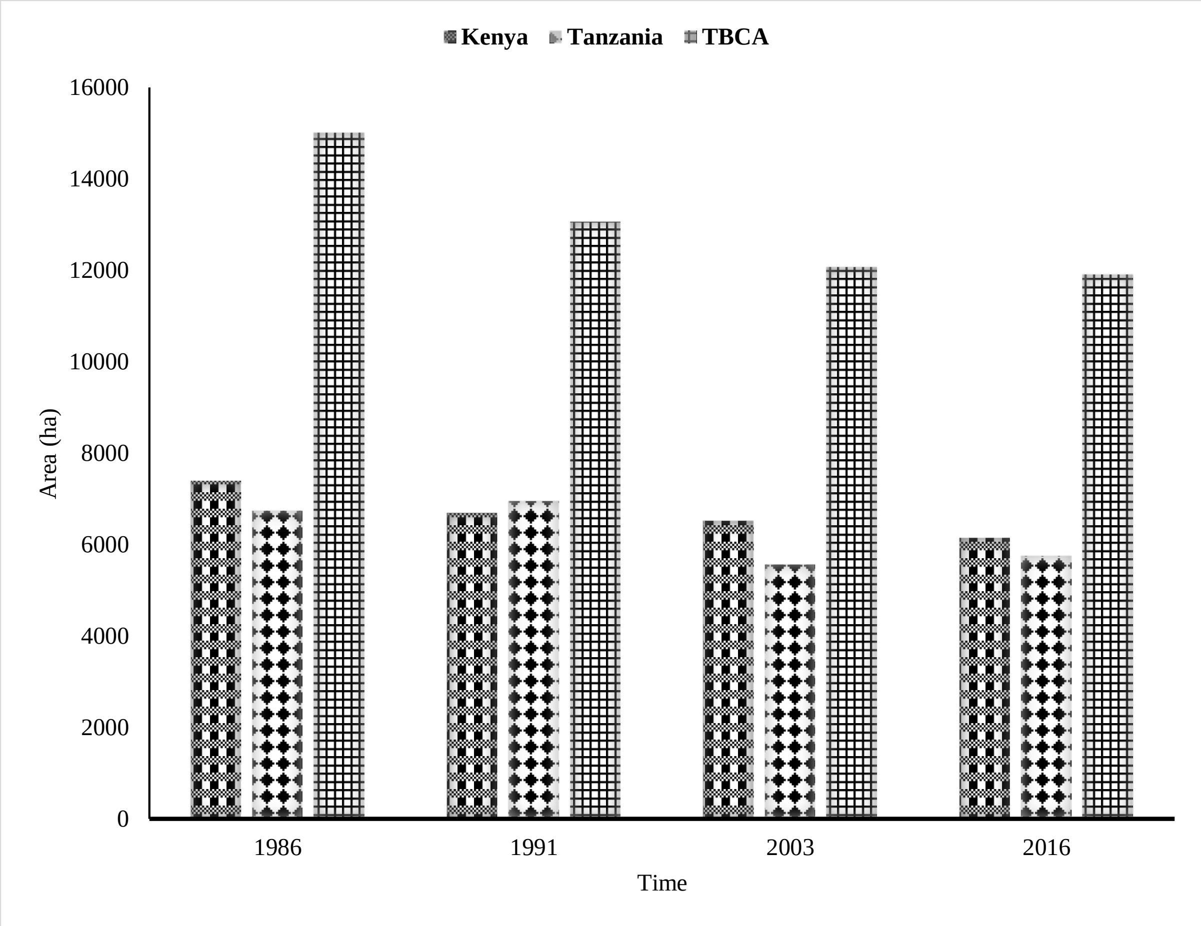


Figure 7: Comparison of trends of mangrove cover along the TBCA that is the Kenyan and Tanzanian side.

Source: Study Data, (1986-2016)

Further analysis of trend at block level indicated a variation of cover change on both sides of the TBCA although the Kenyan side indicated a continuous decline, some gain in mangrove cover was noted at Funzi and Gazi blocks over 1991-2003 epoch (Figure 4.2). Vanga and Tanga blocks showed a continuous decline of cover all along the study period.

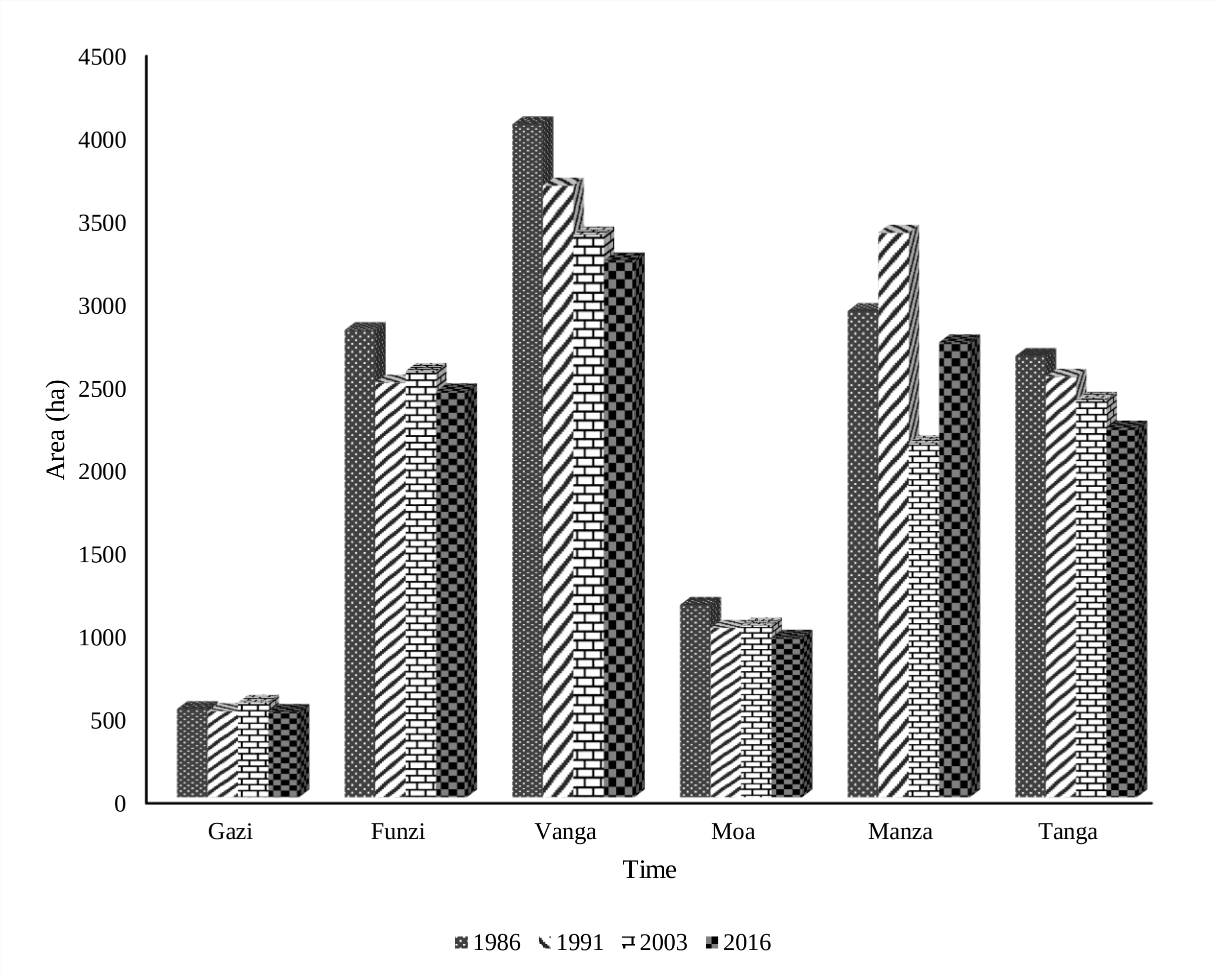


Figure 8: Mangrove cover change trends at different pockets along the TBCA

Source: Study Data, (1986-2016)

The total area of mangroves in TBCA is estimated at 11,906. This forest is in different state of degradation. Major loss of mangroves has occurred in the Kenya side of the proposed TBCA. This loss and degradation of mangroves in the region has been associated to over-harvesting of mangrove wood products, conversion of mangrove area to other land uses such as pond aquaculture and rice farming; and the impacts of climate change (Semesi, 1992; Bosire *et al.*, 2016; GoK, 2017). The Tanzanian side of the TBCA experienced an increase of mangrove coverage during the 1986-1991 epoch that coincided with a national ban of mangrove harvesting in 1987 (Wang *et al.*, 2003).

Overall, rate of mangroves loss in the TBCA during the 2003-2016 epoch reduced to 0.12%/annum. The reduced rate could be attributed to ban on domestic harvesting of mangroves, restoration effort at different sites within the TBCA as well as increased awareness of mangroves goods and services among the community (Bosire *et al.*, 2016). A good example is at Gazi bay (Kenya) and Moa (Tanzania) where community participation in mangrove restoration has significantly contributed to rehabilitation, conservation and sustainable utilization of mangroves in the area (Kairo *et al.,* 2001; Bosire *et al.,* 2003,2016). The decline in rate of loss of mangrove cover observed along the transboundary area in the post 2000 period agrees with other studies in the region and other parts of the world (Kirui *et al.,* 2013; Lang'at *et al.,* 2014; Lovelock *et al.,* 2015; Hamilton, & Casey, 2016).

The expansion of mangrove cover along the channels and upstream may be attributed to salinity regimes as a result of sea level rise and altered fresh water discharge through increased upstream dams, new *Avicennia marina* were observed along the channels and mudflats at the mouth of river Umba, Mkurumudzi and Pangani during the fieldwork. Although most studies have indicated continues loss of mangrove cover specifically within the two countries of the study and WIO region at large increase in mangrove cover have been observed in Sri Lanka, Kenya and Mozambique (Dahdouh-Guebas *et al.,* 2004; 2005; Okello *et al.,* 2014; Shapiro *et al.,* 2014).

For effective resource management, a resource management plan is paramount which has not been the case for the two countries. In Kenya for instance it was not until 2017 when the national mangrove management plan for the entire country's mangrove ecosystem was developed (GoK, 2017). This is expected to provide guidance in utilization patterns and in overall improve management and conservation of this critical ecosystem in the country. On the other hand, the republic of Tanzania is yet to review its 1991 national mangrove management plan (Semesi, 1992; Bosire *et al.,* 2016).

Although the pattern of degradation can largely be attributed to anthropogenic causes, natural causes have also contributed to the observed changes. Climate related events including increased sea level rise, extended drought periods, flooding and shoreline change have contributed to loss and degradation of mangroves in Kenya (Kitheka *et al.,* 2002; Bosire *et al.,* 2014) and specifically on both sides of the transboundary area within Mkinga district on the Tanzanian side and Kwale County on the Kenyan side (Dahdouh-Guebas *et al.,* 2004; Bosire *et al.,* 2006; Wells *et al.,* 2007). Observed shoreline change in 2003-2016 has resulted to loss of mangroves along the TBCA through increased sedimentation of the forest. Similar observations were made at Gazi bay whereby increased sedimentation led to loss and degradation of mangroves.

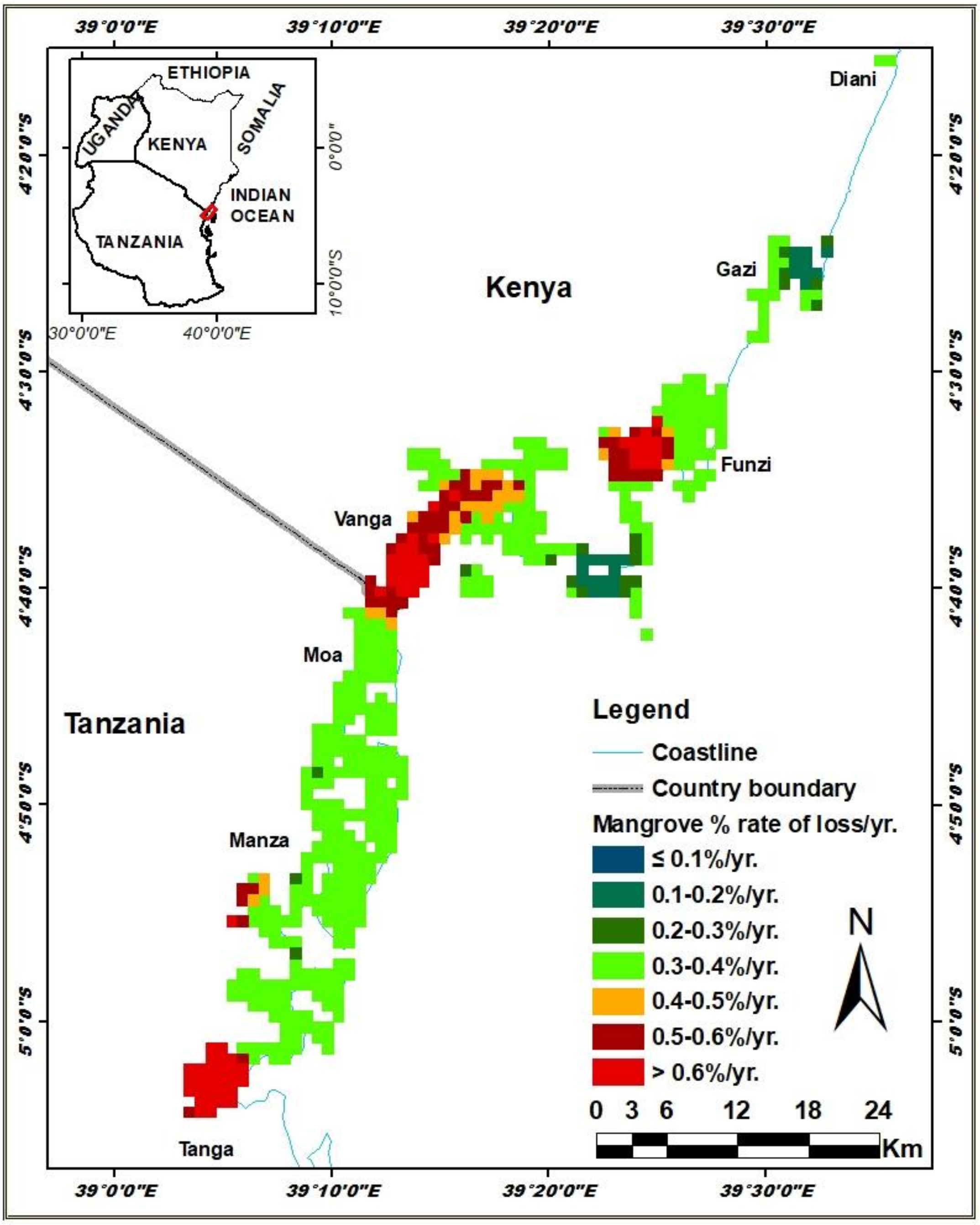


Figure 9: Mangrove cover change within the proposed TBCA in Kenya and Tanzania showing hotspot areas.

Source: Study Data, (1986-2016)

Loss and degradation of mangroves was disproportionately higher closer to human settlements in both Kenya (Jasini, Jimbo, Kiwegu, Majoreni, Mwazaro, Ramisi, and at the mouth of Mkurumudzi & Mwachema rivers) and Tanzania (Mafurikoni, Mabokweni, Boda, Mwaboza, and close to Mhandakini). Over the study period (1986-2016), the highest loss of mangroves was recorded in the Kenyan side of TBCA (1248 ha) as compared to the Tanzanian (992 ha). The hotspots of mangrove loss were observed at Vanga in Kenya (27 ha/yr.), Tanga, Tanzania (14.5 ha/yr.) and Funzi, Kenya (12.3 ha/yr.) as shown in (Figure 4.3).

FAO (2005), the WIO region have been estimated to loose more than 50% of the current mangrove forest cover that has largely been attributed to anthropogenic causes. Areas with high human settlement in the region adjacent to mangrove areas has not only recorded continous decline but the rate of loss are also high. Although not along the tranboundary area peri urban cities (Mombasa and Dar es salam) mangrove areas have recorded high rates of loss (Semesi, 1992; Wang *et al.,* 2003; Bosire *et al.,* 2014) explplaining the observed high rates of loss in mangrove areas next to high populated areas at Vanga, Tanga and Funzi.

In addition, UNEP, (2009) indicate the two main mangrove forest transboundary issues within the WIO region as; loss of mangrove forest cover and illigal trade across the Tanzania-Kenya and Kenya-Somalia borders triggering coastal erosion and sediment transpot with negative implications on fisheries in the area (Semesi, 1999; UNEP, 2009). Further, the root causes to the observed drivers of mangrove loss in the region being the value attached to mangrove as extractable resource hence overexploitation of mangroves. Secondly, is the multiple use potential of mangrove environments that brings about catchment degradation and land use change for muliculture and solar salt production that has occurred on both sides of the border along the TBCA.

4.2.3 Structural Attributes of Mangroves in TBCA

At least eight mangrove species were encountered during the field campaigns along the transboundary area on the Kenyan side. These species exist in either single or mixed stands. Based on importance value (IV) index, the most dominant species of mangroves along the transboundary area are *Rhizophora mucronata, Ceriops tagal* and *Avicennia marina* that occupy 81.3% of forest formation (Table 4.2). *R. mucronata* recorded the highest importance value of 82% closely followed by *Ceriops tagal* and *Avicennia marina* with 81% and 41% respectively.

Table 7: The importance value of mangroves along the TBCA

Species	R/Density %	R/dominance %	R/frequency %	IV[1]
Rhizophora mucronata	36.56	15.59	29.89	82.04
Ceriops tagal	43.76	15.58	21.84	81.19
Avicennia marina	10.46	14.82	16.09	41.37
Sonneratia alba	1.82	13.68	9.20	24.69
Bruguiera gymnorrhiza	5.39	15.55	11.49	32.44
Xylocarpus granatum	1.63	15.09	5.17	21.88
Heritiera littoralis	0.14	0.51	5.17	5.83
Lumnitzera racemosa	0.23	9.17	1.15	10.55
Total	**100.00**	**100.00**	**100.00**	

[1] Importance Value of a given species is the sum of relative (R) density, dominance and frequency.

Source: Field Data, (2018)

To understand the characteristic of a given forest structural attributes such as species composition, tree density, tree height and basal area have been used in the region to characterize forest community (Kairo *et al.*, 2002; 2008; Nicolau *et al.*, 2017). For this study the data collected from sampled quadrants indicated occurrence of eight mangrove species along the transboundary area that is *Sonneratia alba, Avicennia marina, Rhizophora mucronata, Ceriops tagal, Bulguiera gymnorrhiza, Xylocarpus granatum, Lumnitzera racemose* and *Heritiera littoralis*. Although *Xylocarpus moluccensis* species did not appear in the table it was observed during the fieldwork campaign in small patches that may not have fallen within the sampling plots. *Rhizophora mucronata, Ceriops tagal,* and *Avicennia marina,* are the principal species are within the transboundary area as have been observed and documented for the two countries (Semesi, 1992; GoK, 2017).

4.2.4 Mangrove Species Composition

The mangrove species as is in the region display horizontal distribution (zonation) along the intertidal area of the TBCA. In most cases the seaward side is occupied by *Sonneratia alba* although maybe replaced by large and tall *Avicennia marina* and *Rhizophora mucronata* along the creeks, followed by *Ceriops tagal, Rhizophora mucronata, Bulguiera gymnorrhiza* and *Xylocarpus granatum,* mosaics at the middle belt. and Almost pure stands of *Avicennia marina,* or mixed with *Lumnitzera racemose* occupy landward belt of the forest formation (Figure 4.4). *Heritiera littoralis* grows along the fresh water channels with a surface with harder substrate as compared to the other species. Among the nine mangrove species *Xylocarpus moluccensis* is the rarest mangrove species on both sides of TBCA.

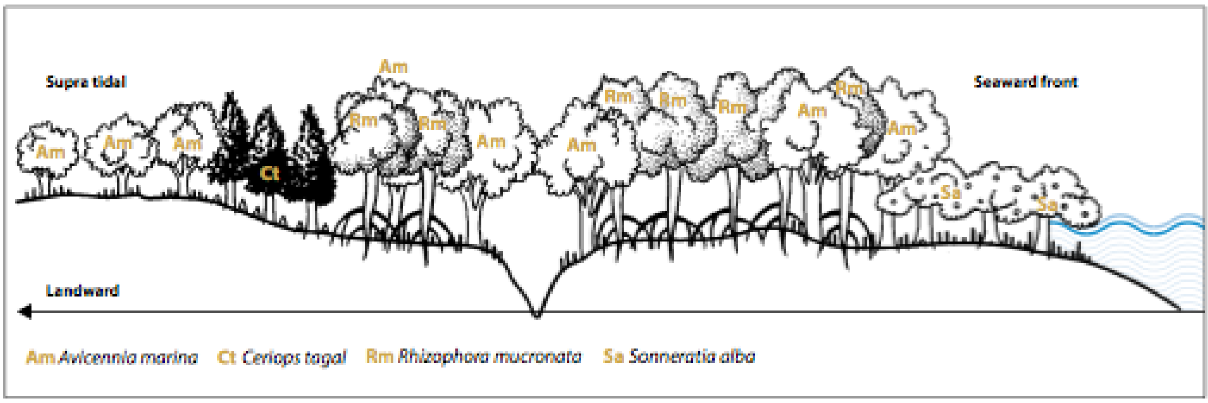


Figure 10: Distribution of mangrove vegetation across the intertidal area typical of the transboundary mangrove forests

Source: GoK, (2017)

The TBCA vegetation map from the 2018 sentinel imagery obtained is as shown (Figure 4.5). The most widely spread mangrove species formation is *Ceriops tagal* that occupy 18% of total TBCA forest formation. A detailed area and percentage representation of each mangrove formation along the transboundary area is provided below:

Rhizophora mixed stands

This formation consists of *Rhizophora* as the dominant species with occurrence of *Ceriops, Avicennia, Sonneratia* and *Bulguiera.* This is the most extensive formation occupying 979ha (or 10%) of the mangroves in the TBCA. The forest is exploited for building poles and firewood; with localized over-harvesting experienced close to human settlement.

Avicennia mixed Stands

In this formation, *Avicennia marina* is the dominant species mixed with *Ceriops, Lumnitzera* and *Xylocarpus.* The formation is distributed in both seaward and landward side of the intertidal complex. Across the TBCA, mixed stands of *Avicennia* occupied about 1450ha (or 15%) of the mangrove coverage.

Avicennia pure stands

An almost pure stand of *Avicennia* was observed majorly to occur on the landward side of the mangroves of the study area. On the seaward, *Avicennia marina* occurs as large trees of up to 20m tall; whereas on the landward side the species exist as scrub forest with truncated trees of less than 2.0m tall. Pure *Avicennia* stands occupy some 10% (956ha) of mangroves in the TBCA.

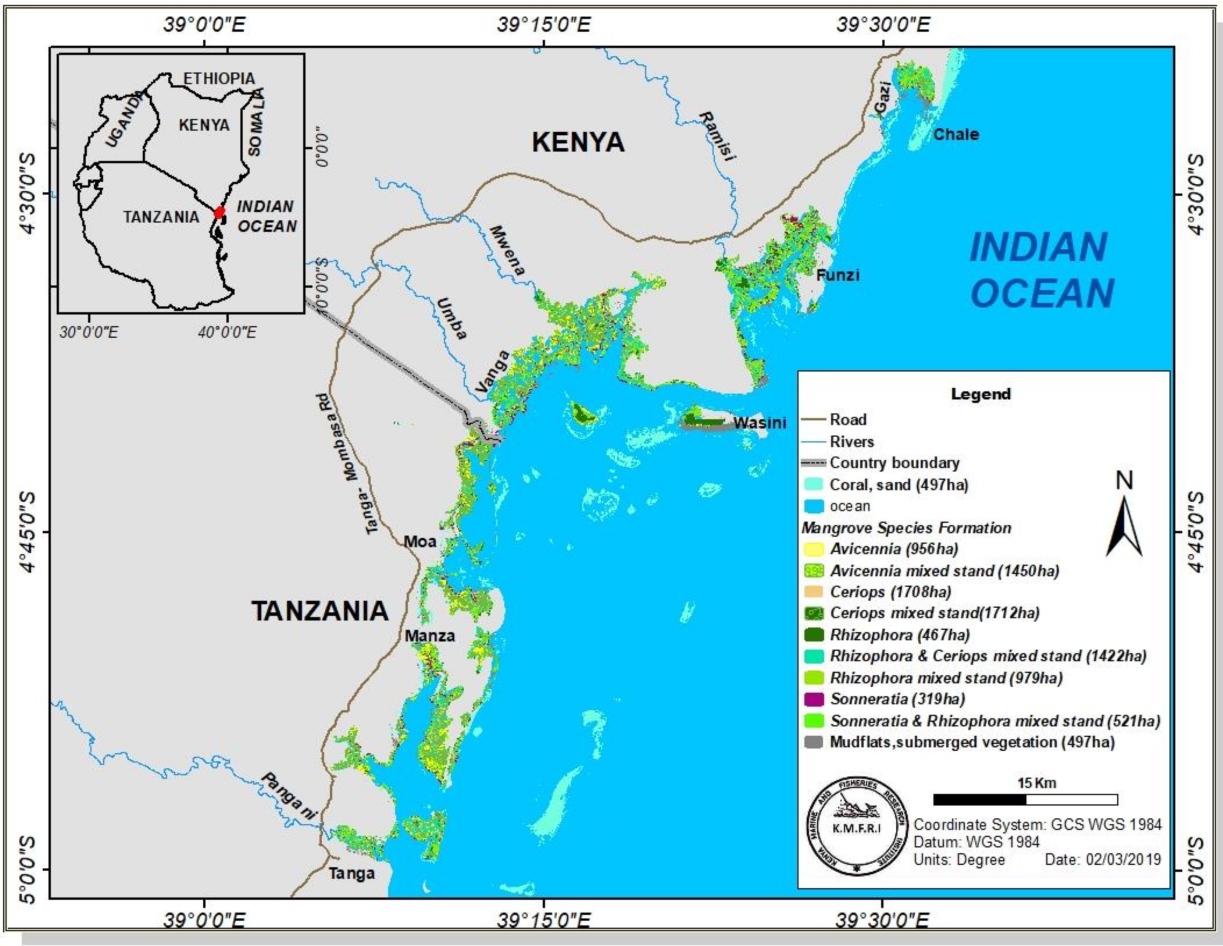


Figure 11: Mangrove species formation along the transboundary area from 2018 sentinel imagery.

Source: KMFRI, Study Data, (2018)

Ceriops mixed stands

The formation occupies 18% (1712ha) of the mangroves in TBCA. The trees in this formation ranges from 2-10 m tall. As observed by Kairo *et al.,* (2002) *Ceriops* has a higher potential to regenerate as compared to the associated species within the formation. Where *Rhizophora mucronata* were harvested for wood products (such as in Vanga, Funzi and Mafuriko (Tanga)) *Ceriops tagal* were observed to recolonize the sites.

Sonneratia pure stands

Along the transboundary area pure stands of *Sonneratia alba* are common feature on the seaward side of the mangrove forests. The trees with characteristic upright pneumatophores occupy the Inundation Class 1 of Watson (1928) where they receive daily tides. Pure stands of *Sonneratia alba* occupy about 3% (319ha) of the total mangrove forests in the TBCA. Trees of *Sonneratia* are exploited for boat building as well as for house construction.

Rhizophora pure stands

Pure stands of *Rhizophora mucronata* occupy only 5% (467ha) of the mangroves in the TBCA. *Rhizophora mucronata* is the most exploited mangrove species in Kenya. This is because it produces quality poles that are straight and resistance to termites (GoK, 2017). Selective logging of the *Rhizophora* has contributed to localized over-exploitation of the species in most parts of the TBCA. To counter this, local communities within the TBCA has promoted reforestation of *Rhizophora mucronata* among other mangroves species. For instance, at Gazi bay small-scale mangrove reforestation dating since 1990's has successfully returned the lost *Rhizophora* forests in the degraded sites. Similar initiatives have been carried out in Moa (Tanzania) and Vanga (Kenya)

Sonneratia -Rhizophora stands

This formation appears to occur immediately after the pure stand of *Sonneratia* from the seaward side. Trees of *Sonneratia* in the mixed zone appear less productive and with inadequate natural regeneration compared to the same species in pure stands. Total area occupied by *Sonneratia-Rhizophora* stands is estimated at 6% (521ha) of mangroves in the TBCA.

Ceriops pure stands

Pure stands of *Ceriops tagal* are observed in patches across the entire TBCA. They occur in the middle zone of mangrove formation as well as in the outer zone close to the land. The species is exploited for building and energy. Where sediment is suitable for the species, such as in Sii Island in Kenya, the trees grow to a height of 27m tall. In drier parts landward, however, *Ceriops* stands exist as thickets of scrub forests that are difficult to penetrate. The total coverage of pure stands of *Ceriops tagal* in the TBCA is about 1708 ha (18%). Good stands of *Ceriops tagal* occur in Vanga-Funzi system, Gazi and Mafuriko (near Tanga).

Mixed stand of Ceriops and Rhizophora

This formation occurs on slightly raised ground along the transboundary area within inundation class 3 & 4 (Watson, 1928). The total coverage of this formation is 15% (1422ha) of the total mangroves in TBCA. Selective logging of market superior *Rhizophora* trees is promoting recolonization by less desirable *Ceriops tagal* (Kairo *et al.,* 2002).

4.3 Similarities and Differences in Mangrove Forest Condition

4.3.1 Comparison of Area Occupied by Mangrove Species Formation in Different Periods

A comparison of mangrove species was done for Gazi mangrove system between 2018 Sentinel data (this study) and the 1992 aerial imagery data. Over this period, significant change in mangrove species assemblage was noted. Generally, pure stands of *Ceriops tagal* declined by 26% while *Rhizophora-Ceriops* stand recorded an increase of 25.7%. Least change (1%) was noted in *Rhizophora-Sonneratia* mixed stand (Figure 4.6).

The observed changes, although not conclusively substantiated due to different sources of data the observation could still be attributed to utilization patterns and natural causes. The reduction in *Sonneratia alba* and *Rhizophora-Sonneratia* could be attributed to pest infestation and desiccation as well as sea level rise that lead to raised number of dieback trees. Most diebacks trees were observed and recorded on the seaward side (a zone where Sonneratia mangrove species occur) of the forest formations all along the transboundary area (GoK, 2017).

On one hand, mixed stands of *Rhizophora* and *Ceriops* reduced the area occupied, while on the other hand pure stand of *Ceriops* and *Rhizophora-Ceriops* mixed stand recorded an increase in area. The change could be attributed to selective harvesting of the form one poles of the two most preferred species (GoK, 2017) giving room for pure stands of *Ceriops* to colonize the harvested area as unlike the other species of mangrove in the region that flowers twice in a year, *Ceriops* flowers all the year round (Kairo *et al.,* 2002; Bosire *et al.,* 2003).

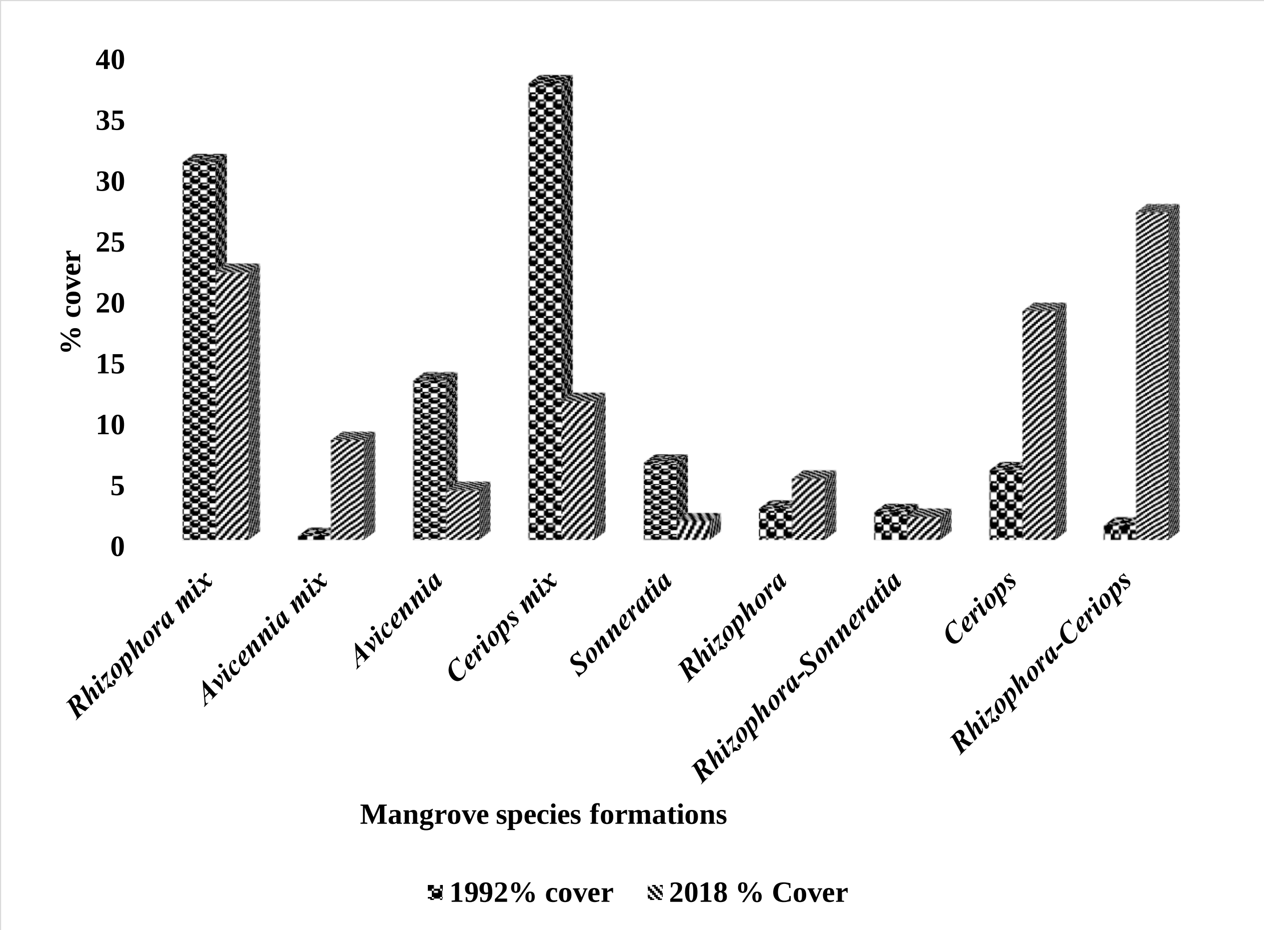


Figure 12: Percentage change coverage of mangrove forest formation along the TBCA area at Gazi

Source: KMFRI, (1992) and Study Data, (2018)

4.3.2 Change in Density of Mangrove

Both spatial as well as temporal change in density of mangrove cover was observed along the transboundary area over the study period. A continuous decline in dense mangrove was noted while a continuous increase was observed in mangrove cover along the transboundary area in 1986 to 2016 (Table 8).

Table 8: Class Covers Distribution Classified by Threshold.

Class cover	Thresholds (NDVI values)				1986		1991		2003		2016	
	1986	1991	2003	2016	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Dense mangroves	0.21-0.67	0.21-0.69	0.21-0.49	0.21-0.46	13812	91.99	11468	89.18	10517	87.10	8216	69.01
Sparse mangroves	0.3-0.2	0.38-0.2	0.46-0.2	0.14-0.2	1203	8.01	1391	10.82	1557	12.90	3690	30.99
	Total area(ha)				**15015**	**100**	**12859**	**100**	**12074**	**100**	**11906**	**100**

Source: Study Data, (1986-2016)

The dense mangroves recorded a higher percentage area of the total TBCA as compared to the sparse mangrove though the trend for dense mangroves indicated a continuous decline reducing from 92% (13,812ha) to 69% (8,216ha) from 1986 and 2016 respectively (Fig. 11). On the other hand, the percentage of sparse mangrove showed an increasing trend from 8% (1203ha) to 31% (3,690ha) over the same period. Over the last three decades, mangrove density within the TBCA reduced at a rate of 187ha/annum (1.4%/annum), whereas sparse mangroves increased at a higher rate of 83.0ha/annum (6.9%/annum). The spatial-temporal change observed over this period was as displayed (Figure 4.7).

The observed reduction in mangroves density and increase in sparse mangroves may be attributed to the uncontrolled selective logging of mangroves poles for construction poles (Kairo *et al.,* 2002; GoK, 2017). The reduced density in the transboundary area is further justified by the high percentage (50%) of form threes trees as compared to least percentage (17%) of the form ones of the total encountered trees. The increased sparse mangroves along the channels could be attributed to pest attack on Sonneratia alba mangrove species (GoK, 2017) leading to increased dieback that was evident along the TBCA during fieldwork campaigns.

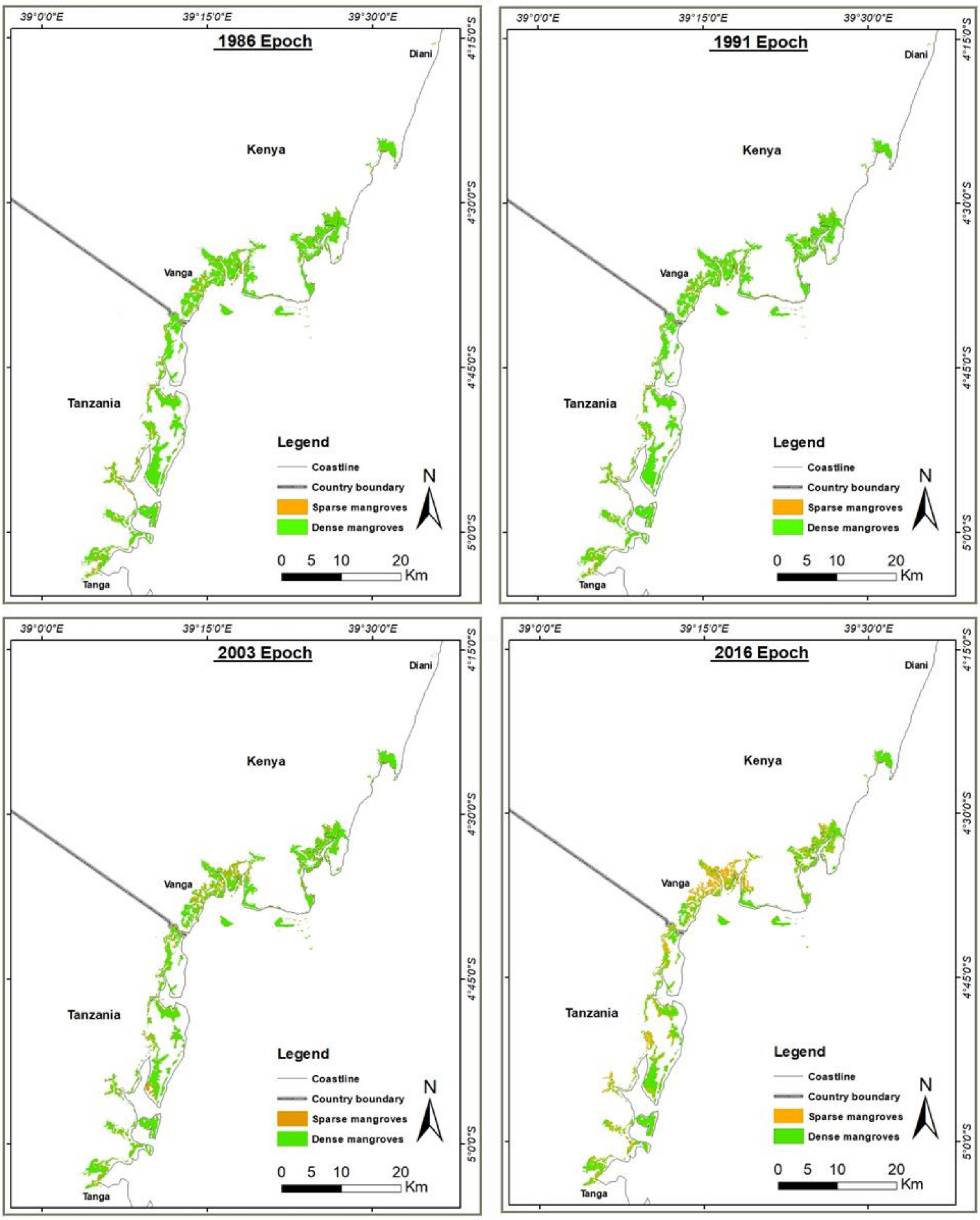


Figure 13: Spatial-Temporal variation in the density of mangrove along the TBCA over the study period (1986-2016)

Source: Study Data, (1986-2016)

Natural events including El Nino of 1997/98 caused increased flooding that led to death of and degradation of different mangrove species (Kitheka *et al.,* 2002; Bosire *et al.,* 2006; Wells *et al.,* 2007). Excessive sand deposition along the channel was also observed to contribute to the dieback of mangroves in the transboundary area an example being at Manza, Vanga, Gazi and Diani mangrove system.

4.4 Effect of Land Use Practices on Mangrove Cover Change

4.4.1 Land Use/Cover Change

A relationship exists between land use changes and integrity of mangrove ecosystem downstream in transboundary area. Mangrove cover change is subject to a number of land use activities within and without the forest. Figure (4.8) displays the observable change recorded for land use/cover within the TBCA over the study period.

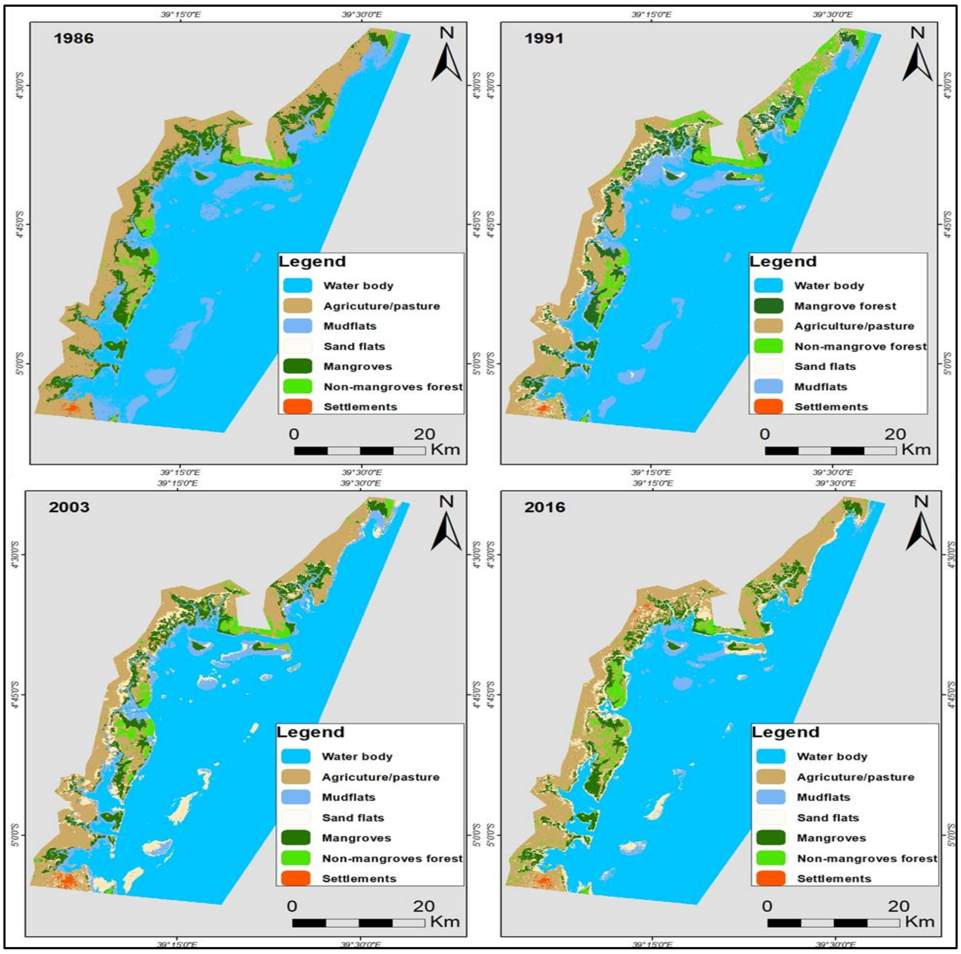


Figure 14: Land use/cover change along the TBCA, 1986 to 2016

Source: Study Data, (1986-2016)

Agricultural land use was observed to have increased from 1986-1991 and 2003-2016 by 6% and 27% respectively although there was a slight decline between 1991-2003 when rise in coverage of non-mangrove forest, sand flats and settlement was recorded (Table 4.5).

Table 9. The Land Use/Cover Area and % Change along the TBCA 1986 to 2016

LULCC	1986-1991	% change	1991-2003	% change	2003-2016	% change	1986-2016	Net % change	Comment
Mangrove forest	-1955	-13.0	-986	-6.6	-168	-1.1	-3109	-20.7	Decreased
Agriculture/ pasture	1609	6.1	-2236	-8.5	7094	26.9	6467	24.5	Increased
Non mangrove forest	-4779	-44.4	821	7.6	-3676	-34.1	-7634	-70.9	Decreased
Settlement	664	37.9	782	44.7	78	4.5	1524	87.1	Increased
Sand flats	4570	33.3	2837	20.6	-1720	-12.5	5687	41.4	Increased
Water body	195	0.4	-2579	-5.2	-1410	-2.8	-3794	-7.6	Decreased

Source: Study Data, (1986-2016)

As for the non-mangrove forest area coverage was observed to continuously decline with the exception of the period, 1991-2003 when a slight increase was observed, the non-mangrove area was then observed to decline by (50%). Over the study period settlements category of land use recorded a continuous increase averaging to 87%. In general, a continuous rise of the area under sand flats category was noted although a slight decline was recorded in 2003-2016.

4.4.2 Mangroves Cover Change Regression against Land Cover Changes

Simple linear regression analysis of land cover/use change against mangrove cover change indicated existence of a relationship between Land cover/use changes. The changes in mangrove cover was not statistically significant ($p<0.05$), apart from the settlements land use (Table 4.6).

Table 10: Regression Results of Mangrove Cover Change against Other Land Cover Changes within the Study Area

Mangrove VS LULC Type	Linear Equations	Correlation coefficient	P-Value	Coefficient of determination
MF:ST	y = 18705 - 2.202X	r = -0.0977	p = 0.023	$r^2 = 0.954$
MF:AG	y = 21546 - 0.3078X	r = -0.609	p = 0.391	$r^2 = 0.371$
MF:NMF	y = 9648 + 0.4795X	r = 0.931	p = 0.069	$r^2 = 0.867$
MF:SF	y = 21227 - 0.4614X	r = -0.901	p = 0.099	$r^2 = 0.812$

MF-mangrove forest, NMF-none mangrove forest, AG-agriculture, SF-sand flats, ST-settlement

Source: Study Data, (2018)

The land use activities adjacent and upstream were observed to impact on mangrove cover directly and indirectly as indicated by UNEP, (2009). There are many villages located along the transboundary area where majority of dwellers practice subsistent type of agriculture in areas adjacent to the mangrove cover of the TBCA area. The coastal area has experienced continued rapid increase in population lead to increased demand for wood products for construction and energy (UNEP, 2014). An estimated 120 million people currently live within a 10km of significant mangrove area, mostly in developing countries in Africa and Asia and are heavily reliant on mangrove for livelihood (UNEP, 2014). It is estimated that 70% of the wood requirement by the local communities adjacent to the forest is met by mangroves in Kenya (GoK, 2017).

A net increase of 24% and was recorded over the study period for agriculture land use class. This may have been brought about by increased demand for cultivable land due to increased demand of food (resulting from increased population) thus conversion of other land use/cover to agricultural land use. The result agrees with the result of land use land cover change in Kenya carried out by FAO (2015) where cropland increased by 1,080,000ha during the (1990-2015) period study. Although the change in mangrove cover in relation to agricultural land use did not show statistical significance, unsustainable land use activities adjacent to mangrove area have shown both direct and indirect impacts to mangrove cover as well as cover change (Appendix B).

Along the coast of the WIO countries both subsistence and plantation farming is practiced. Precisely, plantation of coconuts, sugarcane, sisal, cashew nuts fruits trees and rice paddies is practiced. WIO coastal areas are dominated by loose sand, high poverty status of the traditional coastal communities, as well as growing pressure, tend to decrease the length of fallow periods thus same piece of land is cultivated over and over again resulting to soil degradation and soil impoverishment (UNEP, 2009; Bosire *et al.*, 2016). The sand and mudflats along the TBCA was observed to have increased by 41.4% over the study period. Directly the discharge of sediments from degraded lands leads to an increased turbidity of coastal waters with consequent impact on productivity of the critical coastal ecosystems including mangroves. These impacts results to drying of rivers reduced marine and coastal biodiversity, salt-water intrusion, lowering of water table (UNEP, 2009). Indirectly, vulnerability to natural calamities including floods and droughts impacts are increased. These leads to loss of livelihood and cultural values associated with forest further increasing poverty. Deforestation especially along the shores leads to shoreline erosion and change.

Non-mangrove forest reduced by 70.9% during the study period. The recorded loss is similar to the high loss recorded for East African coastal forest at 60% whereby this forests were found to have been converted to human settlement and other land uses (Burgess, 2000). Furthermore, 75% of the remaining forests have been flagged to be highly fragmented. Land use and land cover change assessment in Kenyan during 1990-2015 indicated forest cover decreased by 31,100ha that is 25% (FAO, 2015). Similar reduction was recorded during the 1991-2016 epoch where a loss of 26.5% was recorded. The drastic change could be attributed to increased demand for wood, which is the main source of energy, clearing field for settlement and for agricultural activities brought abought by increased population along the Kenyan and Tanzanian (Bosire *et al.,* 2016). Indirectly tourism development causes coastal forest deforestation and degradation through increased demand for non-wood and wood material used for construction of tourist hotels, curies and through increased demand for agricultural products.

Further, over 80% of the Kenyan domestic energy is met from fuel wood. Where 90% of the rural household use firewood for cooking, while 80% of the urban household depends on charcoal as primary source of fuel for cooking (MENR, 2016). The loss and degradation of coastal forest and mangroves could be attributed to the rapidly increasing population along the coast. According to WWF (2006) major threats to the coastal forests includes expanding agriculture, illegal logging, destructive mining, unplanned settlements, uncontrolled wildfire, firewood collection and charcoal burning. Wang *et al.,* (2005) and UNEP (2009) indicates that the loss of forests will continue if nothing is done especially in improving agricultural practices and land use management to prevent the consequences of the forest loss. These includes desertification, sedimentation, loss of marine life and corals and soil erosion.

Human habitation increased by 87.1% that conforms to the consistent rise in population along the coastal region in both countries. Between the 1980-2000 epochs the population along the Tanzanian coast urban area increased by about 80% (GoT, 2003). Kenyan coastal region has been observed to experience a rapid population growth rate of 2.02%/ annum, increasing from 1.3 million in 1979 to 3.3million in 2009 (KNBS, 2010). This could explain the reduction of both mangrove and non-mangrove forest as the community sourced wood for energy and construction materials. The increasing population and development along the coastal area could have brought about increased demand for shelter.

The water body remained more or less the same. The little change observed could have been due to the effect of tides in the different periods of acquisition of the imageries used in the study.

CHAPTER FIVE

SUMMARY OF THE FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The chapter provides a summary of the overall finding of the study, which is the overview of answers to the research questions. Contribution of the work towards a better understanding of status and condition of the transboundary mangrove is highlighted. Recommendations based on the results of this study are also presented.

5.2 Summary of the Key Findings

The key findings of the study are summarized based on the specific objectives answering the related research questions as highlighted below:

(i) *To identify and map out trends and areas of mangrove cover change within the trans-boundary area between Gazi (Kenya) and Tanga (Tanzania) from 1986-2016.*

The transboundary of Kenya and Tanzania has a total of 11,906ha of mangrove cover that has reduced from 15,015ha in 1986. The analysis of cover change shows that these mangroves are not pristine as the trends show a continuous decline over the study period. The rate of mangrove cover loss was observed to decline from 2.6%/annum to 0.1%/annum.

(ii) *To determine the effect of land use practices on mangrove cover change within the trans-boundary area between Gazi (Kenya) and Tanga (Tanzania) from 1986-2016.*

The land use/cover adjacent to mangrove cover that is agricultural, settlement, non-mangrove forest and sand flats/mudflats have had influence on mangrove cover changes within the transboundary area of Kenya and Tanzania.

(iii) *To characterize the similarities and differences in mangrove cover and cover change across the Kenya-Tanzania boundary.*

Mangroves along the transboundary area occurs in 12 distinct ‘pockets’ in creeks, bays, lagoons, small islands, river opening and estuarine of main rivers in both Kenyan and Tanzanian side displaying similar structural characteristics.

The mangrove cover within the designated TBCA are more on the Kenyan side (55%) as compared to 45% on the Tanzania side of the transboundary area.

Over the study period more mangrove losses occurred on the Kenyan side of the TBCA with Vanga block in Kenya indicating the highest loss of mangrove cover.

5.3 Conclusion

From the image analysis it is evident that the transboundary mangroves are not pristine as loss and degradation was noted on both sides of the boundary. It is also of importance to note that although there is a slight decline in rate of mangrove loss within the TBCA, without management interventions, removal of mangrove wood products is likely to increase. Secondly, the land use/cover adjacent to mangrove forests in the TBCA have influenced the changes occurring on mangrove cover both directly and indirectly. Thirdly, mangroves along the transboundary area were found to display similar forest formation characteristics on both side of the boundary that is the Kenyan and Tanzanian sides, thus this could allow similar measure in management and utilization of the resource.

The rates of mangrove loss and degradation however are higher on the Kenyan side of TBCA as compared to the Tanzanian side thus it is important that future measures directed into management of the transboundary mangrove resource puts that into consideration. Results of this study have applications in promoting work entailing carbon incentive schemes in the mangrove of Vanga (Kenya) that falls within the transboundary area. These results could also provide a good baseline for initiating other similar incentive schemes involving communities in the transboundary area. It is anticipated that further the results of this study will be used to strengthen capacity of the institutions mandated to manage mangroves in the two countries, as well as proving baselines for improved management of mangroves in the transboundary area.

5.4 Recommendations

Based on the findings of the study the researcher recommends an integrated approach which combines sustainable agricultural practices upstream and mangrove conservation ensure sustainable management and utilization of mangrove resources that will help achieve ecosystem integrity along Kenya-Tanzania transboundary area. Precisely, this study recommends the following:

- The loss and degradation of mangrove along the transboundary area, having been observed to occur even within the protected areas, measures in place should be revised by all stakeholders that is Tanzania Forest Service (TFS), Marine Park Reserve Unit (MPRU) of Tanzania and Kenya Forest Service (KFS), and Kenya Wildlife Service

(KWS). This is mainly because as observed from the study, change in mangrove cover was observed in

- Secondly, restoration of critically degraded (identified hotspots area of mangrove cover loss) areas should be initiated by TFS, KFS, KWS, and MPRU in collaboration with the forest adjacent communities.
- To overcome negative impacts on mangrove ecosystem along the transboundary area arising from adjacent land use practices and change, the researcher recommends harmonization of the different adjacent land uses as a paramount decision. To start with a buffer against coastal erosion from up-stream activities should be established in the most affected areas to act as protective zone of mangroves of the TBCA.
- As a long term strategy of reducing loss of mangrove cover along the transboundary area of Kenya and Tanzania initiatives such as Mikoko Pamoja should be promoted as this will aid in management of natural resources. The initiative once started, it brings along other benefits including awareness of other non-wood benefits from the forests, provision of alternative sources of energy and materials for construction being the precedence issues aimed at protecting and conserving mangrove.
- Finally, the management decisions along the transboundary area of Kenya and Tanzania specifically on mangroves, should take into consideration that the rate of mangrove loss are higher on the Kenyan side as compared to the Tanzanian side of the border.

5.5 Areas for Further Research

This study identified the following as areas for further research

- Need for further assessment on sediment dynamics at the mouth of Mkurumudzi River and the direct implication on the critical ecosystem at the bay so that a permanent solution to the increasing problem may be found.
- Further research is needed to quantify the impacts per the identified drivers of mangrove cover loss at different sites along the TBCA and further along the coast of the Kenya and Tanzania.
- Using the advanced GIS and RS technology, a study should be carried out along the Kenyan and Tanzanian coast to assess the above ground biomass that will be compared with the results of current conventional method and make a recommendation of the best method.

- Need for enhanced mapping capabilities that will help in development of harvest plan to guide removal of mangrove products.
- Need to investigate aquaculture can be sustainably integrated into mangrove

REFERENCES

Adger, W. N., Arnell, N. W., & Tompkins, E. L. (2005). Successful adaptation to climate change across scales. *Global environmental change*, 15(2), 77-86.

Alongi, D. M. (2012). Carbon sequestration in mangrove forests. *Carbon management*, *3*(3), 313-322.

Altchenko, Y., & Villholth, K. G. (2013). Transboundary aquifer mapping and management in Africa: a harmonised approach. *Hydrogeology Journal*, *21*(7), 1497-1517.

Anderson, J., & Samoilys, M. (2015). Case Studies on the Impacts of Climate Change of Fisheries in Africa–Small Pelagic Fisheries in Tanzania. *FAO Circular. In prep*.

Bandeira, S. O., Macamo, C. C. F., Kairo, J. G., Amade, F., Jiddawi, N., & Paula, J. (2009). Evaluation of mangrove structure and condition in two trans-boundary areas in the Western Indian Ocean. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 19(S1).

Bosire, J. O., Dahdouh-Guebas, F., Kairo, J. G., & Koedam, N. (2003). Colonization of non-planted mangrove species into restored mangrove stands in Gazi Bay, Kenya. *Aquatic Botany*, 76(4), 267-279.

Bosire, J. O., Dahdouh-Guebas, F., Kairo, J. G., Wartel, S., Kazungu, J., & Koedam, N. (2006). Success rates of recruited tree species and their contribution to the structural development of reforested mangrove stands. *Marine Ecology Progress Series*, *325*, 85-91.

Bosire, J. O., Kaino, J. J., Olagoke, A. O., Mwihaki, L. M., Ogendi, G. M., Kairo, J. G., & Macharia, D. (2014). Mangroves in peril: unprecedented degradation rates of peri-urban mangroves in Kenya. *Biogeosciences,* 11(10), 2623-2634.

Bosire, J., Mangora, M., Bandeira, S., Rajkaran, A., Ratsimbazafy, R., Appadoo, C., & Kairo, J. (2016). *Mangroves of the Western Indian Ocean: status and management*. WIOMSA, Zanzibar Town.

Burgess, N. D., & Clarke, G. P. (2000). *Coastal forests of eastern Africa*. IUCN-The World Conservation Union, Publications Services Unit.

Cleland, J., & Machiyama, K. (2016). The challenges posed by demographic change in sub-Saharan Africa: a concise overview. *Population and Development Review*, n-an.

County Government of Kwale, (2013). *First County Integrated Development Plan.* County Government of Kwale.

Dahdouh-Guebas, F., De Bondt, R., Abeysinghe, P. D., Kairo, J. G., Cannicci, S., Triest, L., & Koedam, N. (2004). Comparative study of the disjunct zonation pattern of the grey mangrove Avicennia marina (Forsk.) Vierh. in Gazi Bay (Kenya). *Bulletin of Marine Science*, *74*(2), 237-252.

Dahdouh-Guebas, F., Hettiarachchi, S., Seen, D. L., Batelaan, O., Sooriyarachchi, S., Jayatissa, L. P., & Koedam, N. (2005). Transitions in ancient inland freshwater resource management in Sri Lanka affect biota and human populations in and around coastal lagoons. *Current Biology*, *15*(6), 579-586.

Dahdouh-Guebas, F., Mathenge, C., Kairo, J.G., & Koedam, N., (2000). Utilization of mangrove wood products around Mida Creek (Kenya) amongst subsistence and commercial. *Marine and Freshwater Research,* 53, 255-310

Dallen, J. T. (2009). Cross border partnership in Tourism resource management: International parks along the US-Canada border. *Journal of Sustainable tourism*. 7(182-205).

Dan, T. T., Chen, C. F., Chiang, S. H., & Ogawa, S. (2016). Mapping and change analysis in mangrove forest by using Landsat imagery. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *3*, 109.

Donato, D.C., Kauffman, J.B., Murdiyarso, D., Kurnianto, S., Stidham, M., Kanninen, M., 2011. Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience* 4, 293-297.

Dos Santos, J. A., & da Silva, T. R. (2013). Remote Sensing Image Segmentation and Representation through Multiscale Analysis. In *Graphics, Patterns and Images Tutorials (SIBGRAPI-T), 2013 26th Conference on* (pp. 23-30). IEEE.

Duke, N.C., Meynecke, J., Dittmann, S., Ellison, A., Anger, K.U., Berger, U., Cannicci, S., (2007). A world without mangroves. *Science* 317: 41-42.

FAO, (1994). *Mangrove forest management guidelines* (Vol. 117), 319 pp. Rome.

FAO, (2005) *Status and trends in mangrove area extend worldwide*. Working paper No. 64. Forest Resource Division. FAO, Rome. 64(4), 367-379

FAO, (2007). The World's Mangroves 1980-2005. *FAO Forestry Paper*, No. 153. Rome.

FAO, (2015). Global forest resources assessment 2015. Kenya County Report. Accessed March 2018 http://www.fao.org/documents/card/en/c/8017d9cc-dcba4488-a053-7851ab3c2ccd/

Feka, N. Z., & Ajonina, G. N. (2011). Drivers causing decline of mangrove in West-Central Africa: a review. *International Journal of Biodiversity Science, Ecosystem Services & Management*, 7(3), 217-230.

Foote, K. A., Hill, K. H., & Martin, L. G. (Eds.). (1993). *Demographic change in sub-Saharan Africa*. National Academies. Forest Resources Division, FAO, Rome pp. 77.

Friess, D. A. (2016). Mangrove forests. *Current Biology*, 26(16), 746-748.

Getis, A., & Ord, J. K. (1996). Local spatial statistics: an overview. *Spatial analysis: modelling in a GIS environment*, *374*, 261-277.

Ghosh M. K., Kumar L. & Roy C. Roy (2016). Mapping Long-Term Changes in Mangrove Species Composition and Distribution in the Sundarbans. *Forests*, 7, 305

Gibbs, H. K., Ruesch, A. S., Achard, F., Clayton, M. K., Holmgren, P., Ramankutty, N., & Foley, J. A. (2010). Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proceedings of the National Academy of Sciences*, *107*(38), 16732-16737.

Giri, (2016). Observation and Monitoring of Mangrove Forests Using Remote Sensing: Opportunities and Challenges. *Remote Sens*. 2016, 8, 783.

Giri, C., Long, J., Abbas, S., Murali, R. M., Qamer, F. M., Pengra, B., & Thau, D. (2015). Distribution and dynamics of mangrove forests of South Asia. Journal of environmental management, 148, 101-111.

Giri, C., Ochieng, E., Tieszen, L. L., Zhu, Z., Singh, A., Loveland, T., & Duke, N. (2011). Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecology and Biogeography*, 20(1), 154-159.

Giri, C., Zhu, Z., Tieszen, L.L., Singh, A., Gillette, S. & Kelmelis, J.A. (2008) Mangrove forest distributions and dynamics (1975–2005) of the tsunami-affected region of Asia. *Journal of Biogeography*, 35, 519–528.

GoK (2017), *National Mangrove Ecosystem Management Plan*. Kenya Forest Service,

Government of Tanzania. (2003). *Population and housing census, National Bureau of Statistics, Government of Tanzania*. (http://www.tanzania.go.tz, accessed July 17, 2017).

Gravez, V., Bensted-Smith R, Heylings, P., and Gregoire-Wright, T. (2013). Governance systems for marine protected areas in Ecuador. In. Moksness, E., Dahl, E., Stottrup, J., Eds. *Global challenges in integrated coastal zone management.* John Wiley & Sons, Ltd., Oxford, UK, 145-158.

Hamilton, S. E., & Casey, D. (2016). Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). *Global Ecology and Biogeography*, *25*(6), 729-738.

Hanson, K., D'Alessandro, C., & Owusu, F. (Eds.). (2014). *Managing Africa's natural resources: capacities for development*. Springer.

Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M., & Troxler, T. G. (2014). 2013 supplement to the 2006 IPCC guidelines for national greenhouse gas inventories: Wetlands. *IPCC, Switzerland*. 84(6), 167-275

Huxham, M., Emerton, L., Kairo, J., Munyi, F., Abdirizak, H., Muriuki, T., & Briers, R. A. (2015). Applying climate compatible development and economic valuation to coastal management: a case study of Kenya's mangrove forests. *Journal of environmental management*, *157*, 168-181.

Kairo J.G., Kivyatu B. and Koedam N. (2002) Application of Remote Sensing and GIS in the management of mangrove forests within and adjacent to Kiunga marine protected area, Lamu, Kenya. *Environment, Development and Sustainability* 4: 153–166.

Kairo, J. G., Dahdouh-Guebas, F Bosire, J and Koedam, N (2001). Restoration and management of mangrove systems — a lesson for and from the East African region. *South African Journal of Botany*, 67: 383–389.

Kairo, J. G., Lang'at, J. K., Dahdouh-Guebas, F., Bosire, J., & Karachi, M. (2008). Structural development and productivity of replanted mangrove plantations in Kenya. *Forest ecology and management*, 255(7), 2670-2677.

Kamal, M., & Johansen, K. (2017). Explicit area-based accuracy assessment for mangrove tree crown delineation using Geographic Object-Based Image Analysis (GEOBIA). In *Earth Resources and Environmental Remote Sensing/GIS Applications VIII* (Vol. 10428, p. 104280I). International Society for Optics and Photonics.

Kennedy, M. D. (2013). Introducing geographic information systems with ArcGIS*: a workbook approach to learning GIS*. John Wiley & Sons.

Khorram, S., van der Wiele, C. F., Koch, F. H., Nelson, S. A., & Potts, M. D. (2016). Remote sensing: past and present. In *Principles of Applied Remote Sensing* (pp. 1-20). Springer, Cham.

Kihia C. M. (2014). Impact of Human Physical Disturbance on Mangrove Forest Structure at the Gazi Bay, Kenya. *Egerton J. Sci. & Technol.* Volume 14: 31-47

Kirui, K.B., Kairo, J.G., Bosire, J., Viergever, K.M., Rudra, S., Huxham M. and Briers, R.A. (2012) Mapping of mangrove forestland cover change along the Kenya coastline using Landsat imagery. *Ocean & Coastal Management* 6(4), 26-54.

Kitheka U.J., Ongwenyi S.G., Mavuti M.K. (2002). Dynamics of suspended sediment exchange and transport in a degraded mangrove creek in Kenya. *Ambio*31: 580-587.

KNBS, (2010), *Kenya Population Census, 2009*. Ministry of State for Planning, National Development and Vision 2030, Nairobi. Government Print Press.

Kwok, R. (2018). Ecology's remote-sensing revolution. *Nature*, *556*(7700), 137-139.

Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual review of environment and resources*, 28(1), 205-241.

Lang'at, J. K. S., Kairo, J. G., Mencuccini, M., Bouillon, S., Skov, M. W., Waldron, S., & Huxham, M. (2014). Rapid losses of surface elevation following tree girdling and cutting in tropical mangroves. *PLoS One*, *9*(9), e107868.

Lewis, R.R and Brown, B. (2014). Ecological mangrove rehabilitation: a field manual for practitioners. Version 3. Mangrove Action Project Indonesia, *Blue Forests*, Canadian International Development Agency, and OXFAM. 275 p.

Linell, A., Sjöstedt, M., & Sundström, A. (2019). Governing transboundary commons in Africa: the emergence and challenges of the Kavango–Zambezi Treaty. *International Environmental Agreements: Politics, Law and Economics*, *19*(1), 53-68.

Liu, Y., Peng, J., & Yu, Z. (2018, August). Big Data Platform Architecture under The Background of Financial Technology: In The Insurance Industry As An Example. In *Proceedings of the 2018 International Conference on Big Data Engineering and Technology* (pp. 31-35). ACM.

López-Carr, D., Pricope, N. G., Aukema, J. E., Jankowska, M. M., Funk, C., Husak, G., & Michaelsen, J. (2014). A spatial analysis of population dynamics and climate change in Africa: potential vulnerability hot spots emerge where precipitation declines and demographic pressures coincide. *Population and Environment*, *35*(3), 323-339.

Lovelock, C. E., Cahoon, D. R., Friess, D. A., Guntenspergen, G. R., Krauss, K. W., Reef, R., ... & Saintilan, N. (2015). The vulnerability of Indo-Pacific mangrove forests to sea-level rise. *Nature*, *526*(7574), 559.

Lovett, J. C., & Wasser, S. K. (2008). *Biogeography and ecology of the rain forests of eastern Africa*. Cambridge University Press.

Lugo, A. E., Medina, E., & McGinley, K. (2014). Issues and challenges of mangrove conservation in the Anthropocene. *Madera y Bosques*, *20*(1), 11-38.

Marchant, R., Richer, S., Boles, O., Capitani, C., Courtney-Mustaphi, C. J., Lane, P., ... & Phelps, L. (2018). Drivers and trajectories of land cover change in East Africa: Human and environmental interactions from 6000 years ago to present. *Earth-Science Reviews*, *178*, 322-378.

Marine Parks and Reserves Unit, and Kenya Wildlife Service, (2015). *A proposed marine transboundary conservation area between Kenya and Tanzania*. With technical and financial support from The Nairobi Convention., Pp3-63.

MENR. (2016). *National Forest Programme of Kenya*. Ministry of Environment and Natural Resource Nairobi, Kenya.

Muhsoni, F. F., Sambah34, A. B., Mahmudi, M., & Wiadnya, D. G. R. (2018). Comparison of Different Vegetation Indices for Assessing Mangrove Density Using Sentinel-2 Imagery. *International Journal*, *14*(45), 42-51.

Nicolau, D., Macamo, C. C., Mabilana, H. A., Taju, A., & Bandeira, S. O. (2017). Mangrove change detection, structure and condition in a protected area of eastern Africa: the case of Quirimbas National Park, Mozambique. *Western Indian Ocean Journal of Marine Science*, *16*(1), 47-60.

Notti, D., Giordan, D., Caló, F., Pepe, A., Zucca, F., & Galve, J. (2018). Potential and limitations of open satellite data for flood mapping. *Remote Sensing*, *10*(11), 1673.

Obade, P.T., Koedam, N., Soetaert, K. Neukermans, G. Bogaert, J. Nyssen, E. VanNedervelde, F. BergerU. & Dahdouh-Guebas, F. (2009). *Impact of Anthropogenic Disturbance on a Mangrove Forest.* Assessed by a 1d Cellular Automaton Model Using Lotka–Volterra-Type Competition. *8*(4), 237-269.

Obura, D., Smits, M., Chaudhry, T., McPhillips, J., Beal, D., & Astier, C. (2017). Reviving the Western Indian Ocean economy: Actions for a sustainable future. *World Wide Fund for Nature (Formerly World Wildlife Fund), Gland, Switzerland Google Scholar*.

Okello, J. A., Robert, E. M., Beeckman, H., Kairo, J. G., Dahdouh-Guebas, F., & Koedam, N. (2014). Effects of experimental sedimentation on the phenological dynamics and leaf traits of replanted mangroves at Gazi bay, Kenya. *Ecology and evolution*, *4*(16), 3187-3200.

Okumu, W. (2010). Resources and border disputes in Eastern Africa. *Journal of Eastern African Studies*, *4*(2), 279-297.

Pettorelli, N., Laurance, W. F., O'Brien, T. G., Wegmann, M., Nagendra, H., & Turner, W. (2014). Satellite remote sensing for applied ecologists: opportunities and challenges. *Journal of Applied Ecology*, *51*(4), 839-848.

Pimm, S. L., Alibhai, S., Bergl, R., Dehgan, A., Giri, C., Jewell, Z., ... & Loarie, S. (2015). Emerging technologies to conserve biodiversity. *Trends in ecology & evolution*, *30*(11), 685-696.

Polidoro, B.A., Carpenter, K.E., Collins, L., Duke, N.C., Ellison, A.M., Ellison, J.C., Farnsworth, E.J., Fernando, E.S., Kathiresan, K., Koedam, N.E., Livingstone, S.R., Miyagi, T., Moore, G.E., Nam, V.N., Ong, J.E., Primavera, J.H., Salmo, S.G., Sanciangco, J.C., Sukardjo, S., Wang, Y., and Yong, J.W.H. (2010). The Loss of Species: Mangrove Extinction Risk and Geographic Areas of Global Concern. *PLoS ONE* 5, 1 – 10.

Primavera, J. H. (2000). Development and conservation of Philippine mangroves: institutional issues. *Ecological Economics*, *35*(1), 91-106.

Richards, D. R., & Friess, D. A. (2016). Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. In *Proceedings of the National Academy of Sciences USA*, *113*, 344–349.

Roberts, R. W., and W. W. Ruara. 1967. *Lamu Mangrove Inventory*. Forest Department, Nairobi, Kenya

Semesi, A. K. (1992). Developing management plans for the mangrove forest reserves of mainland Tanzania. In *The Ecology of Mangrove and Related Ecosystems* (pp. 1-10). Springer, Dordrecht.

Semesi, A. K., Muruke, M. H. S., & Mgaya, Y. D. (1999). Mangroves of Ruvu river and Kaole, Bagamoyo District. *Coastal resources of Bagamoyo District, Tanzania.*, 17-25.

Shapiro, A.C, C.C. Trettin, H. Küchly, S. Alavinapanah, and S. Bandiera. 2015. The mangroves of the Zambezi Delta from 1995 to 2013 increase in extent observed via satellite 1994 to 2014. Remote Sens. 7:16504-16518.

Simon F. F., & Gregory N. T., (2014). Using satellite data to monitor land-use land-cover change in North-eastern Latvia. *Springerplus*, 3 (1), 61.

Spalding, M. D., Ruffo, S., Lacambra, C., Meliane, I., Hale, L. Z., Shepard, C. C., & Beck, M. W. (2014). The role of ecosystems in coastal protection: adapting to climate change and coastal hazards. *Ocean & Coastal Management*, 90, 50-57.

Spalding, M., Kainuma, M. and Collins, L. (2010). *World Atlas of Mangroves*. ITTO, ISME, FAO, UNEP-WCMC, UNESCO-MAB and UNU-INWEH. Earthscan Publishers Ltd. London.

Svarstad, H., Petersen, L. K., Rothman, D., Siepel, H., & Wätzold, F. (2008). Discursive biases of the environmental research framework DPSIR. *Land Use Policy*, *25*(1), 116-125.

Tabor, K., Burgess, N. D., Mbilinyi, B. P., Kashaigili, J. J., & Steininger, M. K. (2010). Forest and woodland cover and change in coastal Tanzania and Kenya, 1990 to 2000. *Journal of East African Natural History*, *99*(1), 19-46.

Thomas, N., Lucas, R., Bunting, P., Hardy, A., Rosenqvist, A., & Simard, M. (2017). Distribution and drivers of global mangrove forest change, 1996–2010. *PLoS One*, *12*, e0179302.

Turner, W., Rondinini, C., Pettorelli, N., Mora, B., Leidner, A. K., Szantoi, Z., ... & Koh, L. P. (2015). Free and open-access satellite data are key to biodiversity conservation. *Biological Conservation*, *182*, 173-176.

UNEP (2007) Mangroves of Western and Central Africa. UNEP-Regional Seas Programme/UNEP-WCMC.

UNEP, (2007). *Mangroves of Western and Central Africa*. UNEP-Regional Seas Programme/UNEP-WCMC. http://www.unep-wcmc.org/resources/publications/

UNEP, (2009). *Transboundary Diagnostic Analysis of Land-based Sources and Activities Affecting the Western Indian Ocean Coastal and Marine environment*. UNEP, Nairobi, Kenya, 378, 3-355 pp.

UNEP, (2014). The importance of Mangroves to people: A call to action. In J. Van Bochove, E. Sullivan, & T. Nakamura (Eds.), *United Nations Environment Programme* (128 pp.). Cambridge: World Conservation Monitoring Centre.

USGS, (2000). Global Land Survey, 1986-2016, Landsat TM, ETM+, OLI and SA imagery, USGS, Sioux Falls, South Dakota. www.glovis.usgs.gov

USGS, (2013). Land Cover Applications and Global Change. *West Africa Land Use and Land Cover Trends Project.* United States Geological Survey. 36(4), 267-279

Utton, A. (2019). *Transboundary resources law*. Routledge.

Wachid, M. N., Hapsara, R. P., Cahyo, R. D., Wahyu, G. N., Syarif, A. M., Umarhadi, D. A., ... & Widyatmanti, W. (2017, June). Mangrove canopy density analysis using Sentinel-2A imagery satellite data. In *IOP Conference Series: Earth and Environmental Science* (Vol. 70, No. 1, p. 012020). IOP Publishing.

Wang Y, Bonynge G, Nugranad J, Traber M, Ngusaru A, & Tobey J, (2003) Remote Sensing of mangrove change along the Tanzania coast. *Marine Geodesy*, 26:35–48

Wang Y., Tobey G, Bonynge J., Nugranad A., Ngusaru V. M. & Michael T. (2005). Involving Geospatial Information in the Analysis of Land-Cover Change along the Tanzania Coast. *Conservation Biology* 16, 26-27.

Watson, J.G. 1928. *Mangrove Forests of the Malay Peninsula*. (Malayan Forest. Ree. No. 6) Fraser and Neave, Ltd., Singapore.

Wells, S., Makoloweka, S., & Samoilys, M. (2007). Putting adaptive management into practice: Collaborative coastal management in Tanga. *Northern Tanzania*.

Wulder, M. A., White, J. C., Loveland, T. R., Woodcock, C. E., Belward, A. S., Cohen, W. B., ... & Roy, D. P. (2016). The global Landsat archive: Status, consolidation, and direction. *Remote Sensing of Environment*, *185*, 271-283.

Yaw A. T. & Edmund C. M, (2006). GIS and Remote Sensing Applications in the Assessment of Change within a Coastal Environment in the Niger Delta Region of Nigeria. *Environmental Science* 26(4), 26-27.

APPENDICES

APPENDIX A: Mangrove Vegetation Data Sheet

OBSERVERS…………………………………………………………………………………….

AREA……………………………………………. SITE…………DATE…………………

Forest Type………………………. Plot No……………… Plot Size……Photo No…………

Inundation class………………………. Cover (percentage)…................No. of stumps………..

GPS No………… Waypoint……………. Easting…………………………. Southing.............

					Regeneration (Plot Size……….……)			
No	Species	DBH(cm)	HT (m)	Quality classes(1, 2, 3)	Species	RCI	RCII	RCIII

General observations
……………………………………………………………………………………………
………………………………………

APPENDIX B: Plate

Increased erosion of agricultural fields due to deforestation of fringing mangroves, Gazi bay, Kenya (Photo: Author, Courtesy of KMFRI. 4/2/2017).

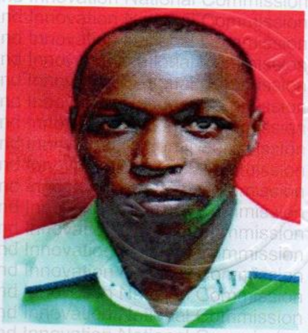
APPENDIX C: Research Permit

THIS IS TO CERTIFY THAT:
MR. FREDRICK MUNGAI MBURU
of EGERTON UNIVERSITY, 81561-80100
MOMBASA,has been permitted to
conduct research in *Kwale County*

on the topic: *MANGROVE COVER/COVER CHANGE ASSESSMENT IN THE TRANS-BOUNDARY AREAS OF KENYA AND TANZANIA OVER THE 1986-2016 PERIOD*

for the period ending:
14th March,2019

Permit No : NACOSTI/P/18/88897/21465
Date Of Issue : 14th March,2018
Fee Recieved :Ksh 1000



....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation

CONDITIONS

1. The License is valid for the proposed research, research site specified period.
2. Both the Licence and any rights thereunder are non-transferable.
3. Upon request of the Commission, the Licensee shall submit a progress report.
4. The Licensee shall report to the County Director of Education and County Governor in the area of research before commencement of the research.
5. Excavation, filming and collection of specimens are subject to further permissions from relevant Government agencies.
6. This Licence does not give authority to transfer research materials.
7. The Licensee shall submit two (2) hard copies and upload a soft copy of their final report.
8. The Commission reserves the right to modify the conditions of this Licence including its cancellation without prior notice.

HARAMBEE

REPUBLIC OF KENYA

NACOSTI

National Commission for Science, Technology and Innovation

RESEARCH CLEARANCE PERMIT

Serial No.A 17893

CONDITIONS: see back page

APPENDIX D: Publication Abstract

JOURNAL OF THE INDIAN OCEAN REGION
https://doi.org/10.1080/19480881.2019.1613868

Routledge
Taylor & Francis Group

Check for updates

Mangrove cover and cover change analysis in the transboundary area of Kenya and Tanzania during 1986–2016

Fredrick Mungai[a], James Kairo[c], John Mironga[a], Bernard Kirui[b], Mwita Mangora[d] and Nico Koedam[e]

[a]Department of Geography, Egerton University, Njoro, Kenya; [b]Department of Natural Resource, Egerton University, Njoro, Kenya; [c]Kenya Marine & Fisheries Research Institute, Mombasa, Kenya; [d]Institute of Marine Sciences, University of Dar es Salaam, Dar es Salaam, Tanzania; [e]Laboratory of Plant Biology and Nature Management, Ecology and Biodiversity, Vrije Universiteit Brussel – VUB, Brussels, Belgium

ABSTRACT

Mangrove forests are among the most threatened ecosystems on earth. Some of these forests traverse national boundaries complicating their management due to differences in governance structures between countries. To improve the management of transboundary species regular monitoring is essential. Remotely sensed data were used to estimate forest cover and analyze conditions of mangroves in the proposed transboundary conservation area (TBCA) between Kenya and Tanzania. Image analysis was performed using unsupervised and supervised classification methods. The transboundary mangroves cover an estimated 11,906 ha; 55% being in Kenya, 45% in Tanzania. *Ceriops tagal, Avicennia marina*, and *Rhizophora mucronata* species co-dominate the mangroves of the transboundary area. The hotspot for loss and degradation of mangrove in the TBCA is Vanga in Kenya with a loss of 27 ha/yr. Harvesting of mangrove wood products have contributed to the loss of mangroves in the transboundary area. TBCA formation could play a critical role in ensuring sustainable mangrove resources utilization.

ARTICLE HISTORY
Received 21 October 2018
Accepted 23 April 2019

KEYWORDS
Mangroves; transboundary conservation area; remote sensing; Kenya