IMPACTS OF SHORELINE CHANGE ON THE NEARSHORE MARINE ENVIRONMENT AT GAZI BAY, KENYA; BETWEEN 1989 AND 2020

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A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Award of the Degree of Master of Science in Environmental Science of Chuka University

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DECLARATION AND RECOMMENDATIONS

Declaration

This thesis is my original work and has not been submitted for an award of diploma or conferment of degree in any institution.

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Recommendations

This thesis has been examined, passed and submitted with our approval as University supervisors

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DEDICATION

I dedicate this work to my father Mr. James Mwangi, my grandparents Mr. Naftaly Mwathi and Mrs. Pauline Mwathi who could see potential in me.

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ABSTRACT

Coastal zones are dynamic environments influenced by both human and natural processes. In the current study, the objectives were to estimate change in shoreline at Gazi bay between 1989 and 2020, to identify the spatial-temporal changes of the nearshore marine environment; particularly on mangrove forests and to establish hotspot areas of shoreline change. The study applied both longitudinal and ecological research design. Digital Shoreline Analysis System (DSAS 5.0), a software within ArcGIS Platform computed change statistics along the study area over the study period. Kalman filter model was used to project future shoreline positions. Supervised, and unsupervised classification methods were used in detecting vegetational change. The relationship between shoreline change and mangrove cover change was examined using the Pearson Correlation coefficient. The average End Point Rate (EPR) of shoreline change at Gazi bay was estimated at -1.38 m/y, with the northerner sections of the western creek showing an accretion rate of 2.38 m/y. At least 88.62 hectares of the mangroves had been affected by the sedimentation processes, representing 55% of mangroves in the study site. A hotspot area exhibiting a change of -4.99m/y was observed at the opening of the Mkurumudzi River, where sandspits and sandbars had formed. Other hotspots areas were at the site with introduced artificial rocks to serve as gabions, fish landing sites, and at the northern side of western creek that had enhanced sediment accretions killing mangroves. A negative correlation between shoreline change and mangrove cover loss was observed, though not statistically significant ($r=-0.536$, $p=0.273$, $\alpha=0.05$). Assessing the dynamics and vulnerabilities of the coastal zones is very crucial in understanding sustainable coastal development and management. These findings provide valuable insights on shoreline changes that could contribute towards integrated coastal zone management strategies for the area.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ACRONYMS AND ABBREVIATIONS

CDA	Coast Development Authority
COED	Cost of Environmental Degradation
DSAS	Digital Shoreline Analysis System
EMCA	Environmental Management and Coordination Act
EPR	End Point Rate
ESRI	Environmental System Research Institute
GIS	Geographical Information Science
ICM	Integrated Coastal Management
ICZM	Integrated Coastal Zone Management
KFS	Kenya Forest Service
KMFRI	Kenya Marine and Fisheries Research Institute
KWS	Kenya Wildlife Service
LMS	Least Median of Squares
LRR	Linear Regression Rate
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NSM	Net Shoreline Movement
RMS	Root Mean Square
SR	Remote Sensing
SDGs	Sustainable Development Goals
UNEP	United Nations Environment Programme
WIO	Western Indian Ocean
WLR	Weighted Linear Regression
WWF	Worldwide Fund
FLAASH	Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Coastal shorelines are transitional areas between land and the ocean; that are highly influenced by human and natural processes (Carter *et al.,* 1998; Khomsin *et al.,* 2021). Shoreline changes impacts on coastal zones in terms of sediment erosion and accretion which results to habitat loss, flooding, saltwater intrusion, and a vast range of socio-economic vulnerability (Nicholls et al., 2007). It is projected that 20–90% of the global coastal wetlands will be lost by 2100 due to human and climate related effects (Sheng *et al.,* 2022; Jevrejeva *et al.,* 2023).

Mangrove forests are a common feature in protected bays, creeks, and deltas of major rivers across tropical and subtropical coasts (Spalding & Parrett, 2019). The area of mangroves around the world is estimated to range from 138,000–152,000 km^2; distributed in 120 countries (Giri *et al.,* 2011 Giri, 2016). These forests provide a wide range of goods and services, including fisheries production, coastal protection, climate regulation and provision of harvestable wood and non-wood resources (Barbier, 2017). However, across the world, mangroves and associated ecosystems have been lost and degraded due to human and other causes (Luijendijk *et al.,* 2018). Losses of mangroves have undesirable effects to fisheries, shoreline protection, and resource sustainability (Mentaschi *et al.,* 2018).

The 600km Kenyan coastline is endowed with diverse coastal and marine ecosystems (NEMA, 2017). The nearshore environment such as mangroves, seagrasses and coral reefs provide favourable environment for fish and other wildlife, protect shoreline from erosion, and support livelihood (Brooks *et al.,* 2012). However, land-based activities are impacting this nearshore environment through deforestation, abstraction of freshwater, poor farming activities, mining, and infrastructure development (GoK, 2017).

At Gazi bay, changes in shoreline due to natural processes and land-based activities has led to erosion of agricultural lands; with the fringing coconut palms being washed and uprooted. Shoreline change has also increased mangrove sedimentation, leading to their death (Dahdouh-Guebas et al., 2004; Ndirangu, 2017) The current study aimed to assess the status and extent of shoreline change in Gazi bay and quantify its impacts on the nearshore marine environment.

1.2 Statement of the Problem

Coastal zones are highly dynamic. They are influenced by a combination of human and natural processes. Loss of natural capital, such as mangroves, is accelerating shoreline change along the coast. Natural processes ranging from low frequency to high intensity have contributed to approximately 70% of mangrove mortality globally since the 1960. Climate change is predicted to impact the remaining mangrove areas through increased aridity, sedimentation and accelerated sea level rise. On the other hand, land-based activities are the dominant cause of shoreline change ranging from activities within the coastline and the unforeseen impacts of upstream activities and disturbance of water catchments. Gazi bay consists of various blue carbon ecosystems which supports the local fishing community. Its shoreline has been changing gradually, with part of it experiencing erosion and another part experiencing sediment deposition. The impacts of these changes are causing death to the near-shore mangroves, seagrass beds, and negative impacts on corals hence reducing their cover and their ability to protect the shoreline from wave energy. To assess how shoreline changes affects the nearshore marine environment, the current study analysed shoreline change in Gazi bay from 1989 to 2020 and identified the influence of shoreline change on the cover extent of the nearshore marine environment.

1.3 Objectives of the Study

1.3.1 Broad Objective

The broad objective of the study was to assess the impacts of shoreline change on the nearshore marine environment at Gazi Bay, Kenya

1.3.2 Specific Objectives

i. To estimate changes in shoreline in Gazi Bay between 1989 and 2020.
ii. To identify the spatial-temporal changes of the nearshore marine environment in the Bay.
iii. To establish hotspot areas of change.

1.4 Research Questions

i. To what extent has the Gazi Bay shoreline changed between 1989 and 2020?
ii. What are the spatial-temporal changes of the nearshore marine environment in the Bay?
iii. Which are the hotspot areas of shoreline change?

1.5 Justification of the Study

The nearshore coastal areas of Gazi bay contain mangroves, seagrass beds and coral reef (Juma *et al.,* 2020; Kairu *et al.,* 2021). However, there has been observed changes in shoreline and degradation of the nearshore marine environment which is affecting the productivity of the bay (Dahdouh-Guebas *et al.,* 2004). Shoreline change is threatening current infrastructures, ecological services, and economic activities within and adjacent of the bay. The study clarifies on general changes in patterns of sediment erosion and deposition that is helpful in decision-making for future developments. Findings from the study on shoreline change and changes in nearshore marine environment can spark interest in land-based activities that could be responsible for the changes which could influence policy formulation and enforcement towards protecting the marine resources. Additionally, the study contributes towards achieving the 17 sustainable development goals (SDGs) which includes SDG Goal 14 "Life below water" focusing on conservation of oceans and related marine resources. The study could also help in accomplishing the Agenda 2030 on Sustainable Development and the Vision 2030 development blueprint through informing, engaging and creating awareness to all stakeholders, including coastal communities. Moreover, the Updated National Determined Contribution (NDC) and the national development strategy, Kenya aims to reduce its GHG emissions by 32% by 2030 hence this study encourage mangrove conservation in order to achieve the target.

1.6 Scope of the Study

The study focused on assessing shoreline changes and the impacts on the nearshore marine environment at Gazi bay of Kwale County. Using remotely sensed data and GIS, rates of shoreline change and trends were analysed in terms of sediment accretion and erosion. With increasing population, land-sea interactions have increased adjacent to Gazi Bay. For this study, the focus was for the period between 1989 and 2020. This is the period in which major land use changes such as plantation agriculture of sugar cane and mining occurred in areas adjacent to Gazi bay.

1.7 Limitations of the Study

One of the limitations of the study was availability of cloud free satellite images. To minimize this, Landsat images were assessed before downloading and only cloudless images were downloaded. The images were then imported to ENVI software for pre-processing to ensure radiometric, atmospheric, and geometric corrections. Generalizability of the study findings might be a limitation since each shoreline change and its impacts are unique depending on geographical area and temporal variations. To overcome this, data acquisition, processing, and ground truthing was done systematically in an orderly manner which ensured quality work, reduction of errors and proper satellite image interpretations. Tide variations could hinder data corrections and ground truthing at a specific time of the day, the researcher ensured use of published Tide Tables for the Kenya Coast.

1.8 Definition of Terms

Blue carbon- Carbon captured by coastal ecosystems particularly, mangroves, seagrass, and salt marshes.

Coastal shoreline- A transition area between land and the ocean

Hotspot areas- Areas with significant changes in shoreline either due to sediment accretion or erosion.

Land-based activities- Human mediated activities on-land influencing marine environment. These include agricultural activities, mining, fishing, transportation, among others.

Natural capital- The world's stock of natural assets, including geology, air, and all living things where humans derive a wide range of ecosystem services.

Nearshore Marine Environment-The area along a coastline where the sea meets the shore. It extends from the highest water mark to a depth of around 200 feet seaward side characterised by mangroves, seagrass and corals and diverse marine life.

Sediment accretion- The process of depositing sediment in a new site, because of fluid movement or ocean currents.

Sediment erosion- Wearing a way of soil or rock particles by the influence of hydrodynamic processes.

Shoreline change- Landward or seaward movement of marine edge or change of the coastline landscape.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background information on Shoreline Change

Over 40% global population lives about 100 km from the ocean and depends on coastal marine resources for their livelihood (Roebeling *et al.,* 2013; Merkens *et al.,* 2016). A significant feature of tropical and subtropical coastline are the mangroves. They are critical habitats providing wood and non-wood forest products, habitat for fish and other wildlife, protecting shoreline from erosion. As per Roebeling *et al.*, (2013) and Kummu *et al.,* (2016) coastal population directly depend on coastal wetlands. With the impacts of sea level rise vertical expansion of these wetlands is facing inadequate sediment supply and Physical Alterations and Destruction of Habitats (PADH) by human related activities (Mwaipopo, 2016; Pörtner *et al.,* 2019). Land-sea interactions cause shoreline change through sediment accretion and erosion; leading to loss of mangroves and associated ecosystem. These in turn impact on community livelihood and wellbeing through shortages of wood products, reduction in fisheries and increased shoreline erosion. In Tanzania coastal zones host significant habitats, including mangroves, seagrass beds, lagoons, coastal forests, beaches and dunes, sand flats, and mudflats. These habitats are essential sources of resources, including food, building materials, and tourism-related resources (Shaghude *et al.*, 2003). Due to the overall active state of the ocean water body and excessive siltation, mangroves are affected causing habitat degradation and the shorelines are constantly changing (Alemayehu, 2016). These changes impact the social systems and economic dynamics of coastal people. An example, shoreline changes may reduce the extent of recreational areas and threaten the development of coastal infrastructure (Bagdanavičiūtė *et al.,* 2012; Parthasarathy & Deka, 2021). The coastal processes mostly associated with these shoreline changes includes the alteration in sedimentation regimes, storm water discharge, water and nutrient nourishment, surface and underground water inflows, which lowers the integrity of coastal zones (Lee *et al.,* 2006; Zhu *et al.,* 2021). Subsequently, these processes are being exacerbated by anthropogenic pressures from urbanization, marine traffic-related pollution, coastal agriculture-related run-off, fishing activities, and coastal tourism, all of which further strain the shorelines (Shaghude *et al.,* 2003; Görmüş *et al.,* 2021).

Sediments eroded by rivers move to the beach floor or add to the landmass, while sand from the coral reef area is brought ashore to form the sandy beaches. In tropical regions mangroves protect shoreline from waves and control coastal flooding (Nicholls *et al.,* 2010; Paterson *et al.,* 2010).. Blue carbon ecosystems, river watersheds, and river basins interacts with ocean currents and tides in regulating estuarine and coastal processes (Tian *et al.,* 2020). However, both land-based activities and ocean processes have significant impacts on the shoreline and nearshore environment. Global shoreline assessment by Mentaschi *et al.,* (2018) found that the eroded land along coastline almost doubles the gained land and mainly contributed by human activities. Unsustainable land-based activities within and outside coastal zones cause discharge of large amounts of sediments or deficit that affects blue carbon ecosystems and associated biodiversity. Additionally, they affects the flow of nutrients and freshwater discharge into the same ecosystems (Fan *et al.,* 2018). Variations in sediments input either very low or very high volumes causes negative impacts on mangroves and seagrass as they are either uprooted by wave energy due to sediment deficit or they are covered by excessive sediment (Okello *et al.,* 2020). These changes affects the whole ecosystem processes, its species present, cover extent or causes presence of new species and formation of new landform (Robinet *et al.,* 2020). Shoreline change between 1953-2017 has led to major environmental problems along Yeşilirmak Delta in Turkey especially due to erosion processes that had led to a change in shape and location of the delta (Kale *et al.,* 2019).

In Africa most of the studies have recorded negative impacts associated with landward movement of the shoreline. For instance, a study carried out in Red Sea, Egypt there was a decrease in beach width in some areas causing changes in mangrove colonies. Between the year 1990-2007 some areas in Egypt coastline experienced accretion with rate of upto 5 m/yr. with erosion rate higher than –3.7 m/yr (Sea, 2011). A study estimating the Cost of Environmental Degradation (COED) in the coastal zones of Côte d'Ivoire, Benin, Senegal, and Togo found that about 60% of US$3.8 billion was spent on erosion and flooding issues. In addition, coastal pollution, floods, and degradation in the same regions contributed to over 13,000 deaths in a year. These countries are undergoing alarming coastal degradation with about 56 percent of the coastline subject to an average erosion of 1.8 meters per year leading to deaths, losses of human assets and damages to critical ecosystems such as mangroves and marine habitats (Croitoru *et al.,* 2019).

Western Indian Ocean (WIO) region's shoreline has suffered from long-term, and short-term shoreline dynamics (Bosire *et al.,* 2015). In Madagascar shoreline erosion and accretion has been observed in most parts in the western and eastern shores resulting to coastal flooding and loss of land with shoreline erosion of approximately 5 m/y. The highest rate of erosion was experienced between 2004 and 2011 (Rahobwasoa *et al.,* 2014). In Mauritius, the period between 2009 and 2018 the land extended 62.5± near Villa Caroline with an 8049.7 ± 5% m^2 net shoreline erosion and a net shoreline accretion of 6571.3 ± 5% m^2 (Doorga *et al.,* 2021). In addition, erosion processes have been also documented Mauritius by Joottun *et al.,* (1994) and Chacowry, (2023). In Zambezi delta in Mozambique, sediment accretion had been occurring at a rate of 1m/y (Kairu & Nyandwi, 2000). Coastal erosion in Seychelles had been occurring in most parts of the islands (Shah, 1994; Etongo *et al.,* 2021). Additionally, Coastal erosion and accretion challenges had been experienced in most parts of coastal areas in Tanzania and in Unguja island (Shaghude *et al.,* 1994; Ngowo *et al.,* 2021). Shoreline change caused by coastal erosion and sediment accretion are some of the main problems faced in the coastal region with great losses (Payet, 2005). Population pressures and dependence on shoreline resources for housing materials, tourism, trade, and fisheries have caused unsustainable marine resource extraction (Cinner *et al.,* 2009). According to Kairu & Nyandwi, (2000) construction of structures to control shoreline change has occurred in Mtwapa, Kenya, some parts of Mauritius coastal zones, in Tanzania and island of Praslin in the Seychelles contributing to coastal management through human interventions.

In Kenya, coastal accretion and erosion have been experienced in Mombasa, Malindi, Kanamai, some parts of Shanzu, Nyali, Likoni, and Tiwi (Abuodha, 2003). The coastline has a diverse nearshore environment and serve a critical role in shaping the shoreline geomorphology (Ndirangu, 2017). The nearshore environment also supports marine habitats by providing shallow sand flats and snags undercut banks that gives a favourable environment for fish breeding and hiding from predators. These ecosystems underpin human well-being by providing harvestable products, protecting the shoreline, fishing ground, and other wildlife services (Brooks *et al.,* 2012). However, mass manipulation of rivers draining into the ocean and wetland zones along marine nearshore through the construction of dams, poor farming activities, mining activities, and urbanization have led to a shift of coastline's morphology, thereby influencing the natural marine ecosystems (Mentaschi *et al.,* 2018). Freshwater input along the coastline ensures sediment balance and salt concentration variations that offers a favourable habitats for nearshore marine species (Huxham *et al.,* 2013). Threats arising due to change in shoreline position include loss of habitats, loss of fishing sites and beaches, unfavourable nesting areas for turtles, loss habitats for birds and other marine species, and consequent damage of properties (Alemayehu *et al.,* 2016).

In Kwale County, Kenya, there are both large-scale and small-scale land-based activities which include agricultural activities, mining activities, and damming along River Mkurumudzi (Ouédraogo *et al.,* 2018). The abstraction of water from this river was hypothesized to have caused changes in hydrological patterns downstream, consequently impacting the mangrove and seagrass meadow negatively (Katuva, 2014). Mikoko Pamoja is a community-based organization involved with mangrove co-managed area for a carbon-offsetting scheme. The project started back in 2013 and has a target of conserving 107 hectares of natural mangrove forest, 10 hectares of planted forest and restoring 0.4 hectares in the degraded areas up to 2033. Through the project activities, approximately 3,000 metric tons CO_2-equivalent are annually sequestered earning at least US$12,000 annually that is used for developments in the nearby communities (Huff & Tonui, 2017). However, the project was also unable to meet mangrove restoration targets of 0.4 hectares per year due to the increasing sedimentations especially along the south western creek of Gazi Bay as mangroves are very sensitive and vulnerable to slight changes in freshwater intake and physical conditions (Murungi, 2017). Sediment erosion has been observed in some parts of the bay with coconut palms along the shoreline being washed and uprooted out to the sea, and flooding frequency has increased in inland areas.

2.2 Factors that Contribute to Coastal Shoreline Change

Coastal shoreline change is influenced by natural and land-based activities. In Vietnam, for instance, high population along the coastal zone increases the risks of the coastal resources to the impacts of climate change and sea level rise. Along the Vietnam coastline, there are numerous inlets from the rivers, especially around the northern side of the river delta. Estuaries in this sector attract massive populations that increase overexploitation of resources that in turn cause coastal land cover change and loss of barriers of waves and tides (Tuong, 2001). In Mekong delta sand mining activities has severely contributed to sediment erosion at an average rate of 25-30m/year. According to Quang *et al.,* (2021) it was revealed that the construction of a dam in 1977 accelerated the rate of shoreline change in Cua Dai estuary, Vietnam. This is in addition to flooding, winds, the action of waves and tides as the natural processes. Construction of seawalls, jetties, groins, and hydropower plants. Vietnam people's adapting mechanisms along the coastal areas include building houses on stilts, early warnings, and high storm infrastructures (Nguyen *et al.,* 2023; Quang *et al.,* 2023).

According to Mwasra *et al.*, (2015), an assessment of shoreline change in South Gujarat it was observed that coastline processes were the cause of accretion/erosion dynamics along the coastline. Further, it was noted that a vast range of anthropogenic activities impacted the shoreline stability and change trends including the construction of sea walls, groins, breakwaters, and jetties that altered the sediment transport dynamics of the region. Such human intervention activities are a threat to coastal protection as the soils are characterised by the clay or silt which is eroded easily by the water. In a similar study that assessed shoreline changes in the Karnataka coast, India, general changes in the coastlines were found to result from coastal processes such as waves and tides movements and riverine inputs. In addition, the contribution of river mouth morphology variations was found to be significant. Overall, the study revealed changes in shorelines was mainly due to variations in coastal processes and land run-off (ChenthamilSelvan *et al.*, 2014). Similar factors of shoreline change were identified in a land-use assessment and shoreline change in Branganca coast, Northern Brazil (Souza-Filho & Paradella, 2003). The shoreline in Branganca coast, Northern Brazil was exposed to a retreat of about $32km^2$ and $20km^2$ accretion with a mangrove cover loss of about $12km^2$. As per the study, sedimentary dynamics and tidal current effects were pertinent in controlling the coastal changes (Souza-Filho *et al.*, 2003). On the other hand, shoreline advancement has been reported by Dede *et al.*, (2023) whereby coastal infrastructure developments, hydrological patterns, impacts of river input and estuarine processes were identified as the main drivers of shoreline accretion.

Human mitigation measures on the other hand have highly contributed to continuous shoreline erosion and sediment deposition in some parts of the world (Pörtner *et al.,* 2019). In Mauritania harbour constructed structures to mitigate impacts of erosion blocked the unidirectional sediment transport by ocean currents accelerating beach erosion. Since the time the harbour was constructed the erosion negative impact had increased to ten times by inducing erosion to over 10km to a zone where the sediment could be deposited if the harbour was not constructed (Ould *et al.,* 2007). In Australia Various attempts to improve the functionality at the Tweed River accelerated the rate of shoreline erosion to the north of the constructed jetties while the southern side sediment was been accreted. To solve the problem sand bypassing method was applied which is a sustainable method (Dyson *et al.*, 2001).

2.3 Marine Geomorphology

Shoreline consists of rocky shores, sandy beaches, muddy shores, estuaries, mangroves and other blue carbon ecosystems. Natural processes and sediment erosion less affect rocky shores (Purkwas *et al.,* 2016). Mostly rocky shores consist of rock pools, boulder fields, rocky vertical that acts as important coastal habitats to plants, animals and birds adapted to this harsh environment. Most of these rocky shores are shaped by the action of waves, tides and the characteristics of the rock. The rocks shores support diverse fish species, molluscs and gastropods that are adapted to strong oceanic winds and exposure to water and sunlight. Cape Verde and Gulf of Guinea, mainly consists of rocky beaches mainly from volcanic processes (Ankrah *et al.,* 2023). On the other hand, sandy beaches are found along the shorelines, lagoons, bays, coastal estuaries and sand spits (Cooper *et al.,* 2020). Beaches offer a crucial bleeding habitat for fish, birds and other marine species. Sand coasts occupy about 20% of the coastline globally (Vos *et al.,* 2019). In Dundrum Bay, which is found in Northern side of Ireland, it consists of coastal dunes and sandy beaches. Over the last two centuries its shoreline has experienced drastic changes especially at the river mouth near Ballykinler with formation of a sandpit. Despite the construction of hard infrastructures such as seawalls in 1910 to 2007 shoreline erosion has increased at a higher rate (Grottoli *et al.,* 2023). In South Africa

80% of the coastline consists of sandy beaches which are at risk of shoreline erosion mainly with influence from human activities. Since 1937-2020 the shoreline of southwestern beaches of South Africa has a net loss of land by 38m perpendicularly to the ocean with higher rates of erosion occurring between 2015 and 2020 (Murray *et al.,* 2023). West Africa covers almost 6000km comprising sandy beaches, rocky coastline, muddy beaches, estuaries, sand spits mainly at river mouth of River Senegal, Nigeria and Gambia. Mangrove forest can be found in most part of west Africa coastline which supports the local communities (Ankrah *et al.,* 2023).

The coastline is also characterized by muddy shores mostly within or near estuaries and mangrove ecosystems. They are important feeding grounds for shorebirds and support various invertebrates. Freshwater intake and sedimentations influence the functioning of this nearshore muddy environment (Wensink & Tiegs, 2016). The coastline of Guinea-Bissau and Sierra Leone consists of mainly muddy shores mainly influenced by the waves and storms for south and north of Antlantic ocean (Ankrah *et al.,* 2023). In addition, the Sea cliffs are part of nearshore marine environment that are steep coastal cliffs formed by erosion. They may host nesting seabirds and provide important vantage points for coastal ecosystems. Disko Island which is found in Greenland consists of sea cliffs from erosional processes. The nearshore marine environment sometimes suffers from accumulation of pollutants from the freshwater river flow that lowers their productivity. Most of the sediment delivered to the nearshore environment is retained in coastal estuaries and river deltas (Filipponi *et al.*, 2015). An estuary develops by the action of the energy of the tides and waves as the marine forces acting on energy of the river discharge (Nassar *et al.,* 2019). Both energy forces seldom reach equilibrium due to the continuous change across spatial and temporal scales. Coastline erosion, longshore turbid plume transport and normal actions of tides and waves are usually locally important as they ensure the mix of ocean and freshwater (Fagherazzi *et al.,* 2015). In deltaic coasts the nearshore marine environment is highly susceptible to shoreline recession and sediment imbalance, inundation and subsidence accelerated by groundwater withdrawal and upstream damming.

Most of the sediment delivered nearshore environment is retained in coastal estuaries. Sand dunes along the Namibian coastline play a significant role in the context of shoreline change. The most prominent sand dune area in Namibia is the Namib Sand Sea, a UNESCO World Heritage Site known for its vast dune fields. While dunes themselves do not directly impact shoreline change, they are integral components of a dynamic coastal system influenced by various factors, including climate, oceanography, and human activities. The formation and movement of sand dunes are closely linked to prevailing winds and tides, and their position and stability can indirectly affect the shoreline (Sabour *et al.*, 2020). The south eastern coastal region of Bangladesh presents a multifaceted tapestry of distinct geomorphological units and subunits, each possessing unique characteristics and attributes. These encompass swamps, lagoons, estuaries. mud and sand flats and tidal marshes. Within this mosaic, the sediments prevailing in this dynamic coastal milieu predominantly consist of active channel deposits, flood plain deposits, and tidal deposits, with a noticeable abundance of sand, complemented by a minor fraction of silt. This comprehensive geomorphic classification provides an intricate and holistic framework that allows for a profound comprehension of the intricate interplay between coastal dynamics and sedimentary processes characterizing this particular geographical domain (Hossain *et al.,* 2021). Additionally, blue carbon ecosystems in particular coastal marshes, mangroves and seagrass, store large amounts of carbon in sediments, leaves, and other forms of biomass reducing carbon amounts from the atmosphere (Duarte *et al.,* 2013; Kairo *et al.,* 2021) Seagrass meadows control sediment erosion and acts as primary producers, which in turn supports secondary production of marine invertebrates and fish (Paul, 2018). Most of fishery organisms find a refuge in seagrass beds. The diverse seagrass beds canopy reduces wave and tide energy and controls ocean currents that help in trapping sediment (Mchenry *et al.,* 2021).

2.4 Nearshore Marine Environment

Nearshore marine environment refers to the transition area between sub tidal marine ecosystems to the upland shallow sub-tidal marine waters (Cocquempot *et al.,* 2019). It consists of the marine ecosystems and habitats within the shoreline or the land-sea interface. There is strong relationships and interactions between the marine processes and land-based habitats along the coastline (Görmüş *et al.,* 2021; Hamza & Esteves, 2022; Howard *et al.,* 2023). Mangroves and other nearshore upland habitats stabilize banks, provide shades to the upper intertidal zone and its woody debris acts as a source of food and shelter to the fish (Macreadie *et al.,* 2019). Nearshore marine environments are diverse including rocky shorelines, beaches muddy flats, coastline ecosystems and coral reefs. Most of these nearshore habitat's distributions are highly influenced by climatic conditions, coastal land use and geomorphology (Njiru *et al.,* 2022). Marine resources represent some of the most heavily exploited ecosystems globally. This ecosystems transfer substances, nutrients and energy among themselves and thereby their connectivity sustains and stabilizes coastal zone's productivity and biodiversity (Lson *et al.,* 2019). According to Huxham *et al.,* (2018) mangroves, coral reefs and seagrass beds breaks the wave energy and acts as bio shield which prevents shoreline erosion and promotes coastline stability as demonstrated in Figure 1.

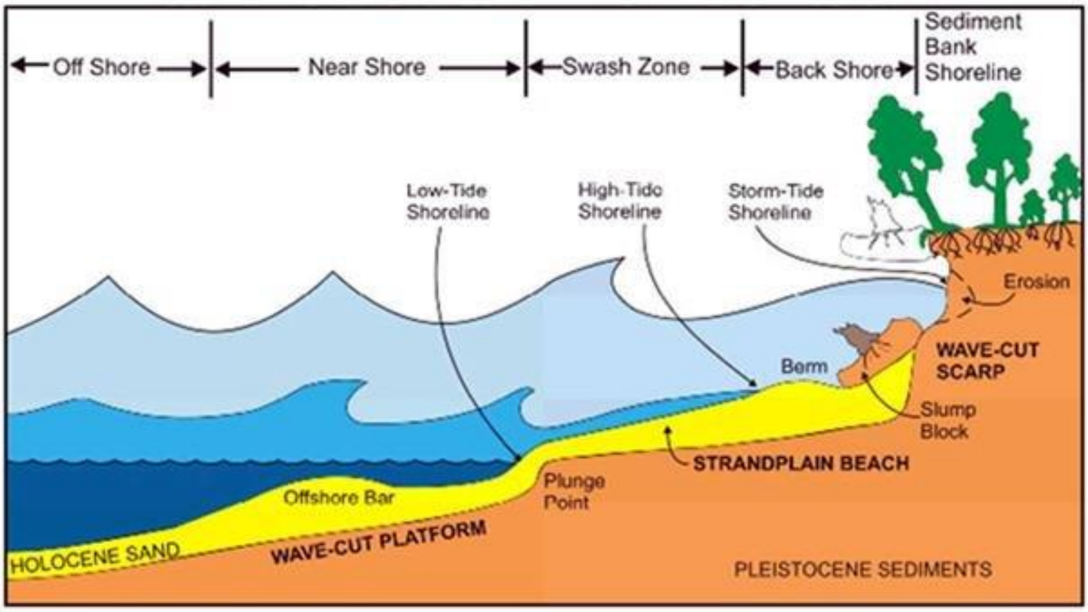

Figure 1: http://www.deepmapscork.ie/environmental-priorities/climate-change/weather-and- coastal-erosion/

On the other hands it improves the functioning and productivity of the mangrove and the adjacent ecosystems (Kabir *et al.,* 2020). Mangrove ecosystem in turn enhances abundance of fisheries on coral reefs as it serves as nursery habitat for juveniles (Serafy *et al.,* 2015). Additionally, the rooting system of mangroves traps sediment and excess nutrients from the land and freshwater intake hence stabilizing shoreline geomorphology (Okello *et al.,* 2020).

Most of the land-based activities affects nearshore marine environment by increasing the rate of runoff, sediment imbalance, eutrophication and excessive harvesting of coastal resources (Waslam, 2004). This process decreases fish population and other marine species that rely on coral on nearshore marine environment for survival and as a habitat (Fondo *et al.,* 2015).

The nearshore marine environment are threatened by resource exploitation, sedimentation coastal developments, marine transport, climate change and sea level rise (Lau, 2012). In Gulf St Vincent, commercial fishing, tourism, aquaculture, sand mining, transport, waste and storm water disposal, urbanization and alteration of water catchments has reduced the productivity of coastal ecosystems (Bryars, 2013). River discharge with polluted water and increased sedimentation increases nutrient levels that cause a shift of nearshore productivity as it increases eutrophication and negative impacts to the nearshore environment (Brook *et al.,* 2020).

Jakarta bay is one of the coastal regions suffering from excessive human influence such as increased population growth, coastal developments, unsustainable economic activities and massive utilization of resources. Most of its nearshore marine environment such as mangroves are overharvested for economic purposes and land conversion for settlements (Sudirman *et al.,* 2019). The bay is affected by sediment imbalance and environmental degradation resulting to land subsidence. The heavy metal pollution from the 13 river mouths has led to excessive growth of phytoplankton. In a study in North Karawang found that there was significant change on mangrove cover mostly as a result of human influence, coastal abrasion, wild catch, shrimp and milkfish aquaculture, rice plantations, salt ponds and impacts of tourism. Most areas have the greatest seagrass losses especially from coastal developments and water quality reduction (Dunic *et al.,* 2021). A quarter of tidal marshes and salt marshes have been lost globally with an estimate of 1-2% annually mainly due to human interference and resource overexploitation (Crooks *et al.,* 2011). Coral reefs on the other are vital ecosystems that acts as the nursery habitat of ecological and commercial marine species and source of compound used in medicines. In Caribbean coastline, the coral reefs that also control flooding in the region protect about 21% of the shoreline environment. Increased pollution and increasing demand of coastal resources has become a threat to coral reefs (Chollett *et al.,* 2012).

In Kenya total mangrove area declined throughout the 20-year period, from 54,990 ha in 1996 to 53,852 ha in 2016. This is a net loss of 1,139 hectares. Mangrove cover increased significantly (578 hectares) between 2016 and 2020, mostly as a result of natural expansion brought about by sedimentation and restoration work at different locations. Following significant losses in the 1970s and 1980s, estimated losses to the nation's mangroves between 1985 and 2010 were as high as 18% of the original mangrove cover (Erftemeijer *et al.,* 2022). In an effort to preserve water towers, stop environmental degradation, and lessen the consequences of the nationwide drought, the government outlawed mangrove logging in 2018. But the restriction was repealed in Lamu County in January 2019. Following an appeal to the government by the local inhabitants, who depended on mangroves for their livelihoods. The presidential restriction on the export of mangrove poles in 1982 was followed by a ban on mangrove logging in 1997, which was repealed in 2003 (Mbatha *et al.,* 2023, Bosire *et al.*, 2014).

Besides to the direct anthropogenic impacts on mangrove ecosystems, their vitality is profoundly linked to the inflow of freshwater. The discharge patterns of rivers, both seasonal and perennial, into the Indian Ocean are fundamental to the coastal hydrology of the region. Notably, the Tana River and the Sabaki River, both perennial rivers, represent critical contributors to this hydrological system as they flow into the Indian Ocean (Njiru *et al.,* 2022). However, it's important to recognize the highly seasonal nature of these river outflows. The Tana River, for instance, enters the Indian Ocean near Kipini on the north coast of Kenya, releasing approximately 4 billion cubic meters of freshwater annually and transporting 6.8 million tonnes of sediment. The river diverges into a complex deltaic system at the Kipini and Mto Tana sites, which ultimately connect with the Indian Ocean. It is worth noting that the flow and sediment dynamics of the Tana River have experienced alterations due to the construction of various dams, primarily for hydroelectric power generation (Amin *et al.,* 2015). Additionally, several seasonal rivers, including the Mwatate, Mwache, and Manjera rivers, originating from the Mwatate Basin in the Taita Hills, empty into Port Reitz in Mombasa. Moreover, the Kombeni and Tsalu rivers discharge into Port Tudor at the Mombasa site. Other intermittent streams like the Rare River (a tributary of the Voi River) and the Ndzovuni River also contribute to the hydrology as they drain into Kilifi Creek. The Ramisi River, characterized by an intermittent discharge, flows into the

Ramisi/Funzi area in Kwale County. Furthermore, the Umba River, originating in the Pare and Usambara mountains in Tanzania, exhibits intermittent discharge as it drains into Vanga with the Mwena River, a minor tributary of the Umba River, also making its contribution to the region's hydrological dynamics. River mkurumudzi is a seasonal river which drains into Gazi bay originating from Shimba hills (Kitheka *et al.*, 1996).

In Kenya, the institutions responsible and mandated for the protection and management of mangrove forest and the associated blue carbon ecosystems, marine species, including the Marine Park and Reserve in Kenya includes; Kenya Wildlife Service (KWS), Coast Development Authority (CDA), Kenya Forest Service (KFS), Fisheries Department and Kenya Marine and Fisheries Research Institute (KMFRI). The Kenyan government has instituted a decentralized approach to forest management in compliance with the Forest Act of 2016. This approach empowers local communities by establishing a co-management framework, effectively serving as a bridge between the central government and community-based associations. The primary objective is to transfer the authority for forest management and decision-making to these local community associations, thereby facilitating the sustainable utilization of mangrove forests under the Kenya Forest Service (KFS) and ensuring the long-term benefits for the community.

According to Alemayehu, (2016), there is no enough manpower to patrol the Marine Park and Reserve and there are increased unplanned development along the coastline, beachfront, and in mangrove adjacent areas that encourage encroachment and illegal cutting of the mangroves and harvesting of the marine resources. These institutions face challenges in the enforcements of the riparian zone regulations within the designated area of 30 meters from the Highest Water Mark (HWM) (Carter, 2013). The process of obtaining a license for mangrove harvesting takes a lot of time resulting to illegal harvesting of mangroves (Dahdouh *et al.*, 2000). In terms of regulatory framework other than the Constitution of Kenya 2010, Kwale County has a number of laws, acts and policies that apply to all the sub-counties and wards respectively. For example, the Kwale County Forest Conservation and Management Act, 2017 that ensures the conservation of forests within the county. In addition, there are national laws that are domesticated by the county for example, Fisheries (BMU) Regulations, 2021, The

Wildlife Conservation and Management Act, 2013, Environmental Management and Coordination Act (EMCA), 2015 among others (Kairu *et al.,* 2021, Ahmed *et al.,* 2022).

2.5 Impacts of Shoreline Change on the Nearshore Marine Environment

Effects of shoreline change include the increase of flood risk, submergence, salinization of surface and underground water, morphological changes such as sediment erosion and accretion, and loss of wetlands (Kaliraj *et al.,* 2014). Sediment's fluctuations, especially at the river mouth of rivers draining into oceans, may lead to positive or negative impacts on marine ecosystems. The accretion process is usually brought by the anthropogenic influence such as land vegetation clearance, sand mining or by natural processes such as sea-level rise and sediment deposition. Change of river mouth morphology accelerates salinity intrusion upstream, which affects biodiversity that cannot withstand brackish water or excessive salts. A study on Pangani River in Tanzania observed that crocodiles were migrating upstream due to changes in salinity levels. Changes occurring along the river mouths results to a loss of estuaries, aquatic habitats degradation and increasing vulnerability to coastal sources of livelihood (Anthony *et al.,* 2014). Texel inlet, the Netherlands River mouth has suffered from damming activities and flooding. Mitigation actions taken by government include sand nourishment for coastline stabilization and flood control (Taljaard et al., 2022a). Impacts of sea level rise and river flow changes largely affects the functionality of river estuary which is a source of income to fishermen, sand mining activities and tourism sector (Duong *et al.,* 2016). In addition, the agricultural activities, construction of dams, sand mining, artificial bleaching and unsustainable fishing activities resulted to the degradation of the river mouth (Van Niekerk *et al.,* 2020). A Bigi pan, Suriname, a wetland lake connected to a sea has exhibited decline in fish catch and water quality due to shoreline changes of the estuarine. (Taljaard et al., 2022b). On the other hand, the Mississippi River Delta region exemplifies the complex interactions between shoreline change and the nearshore marine environment, with far-reaching ecological and socioeconomic repercussions (Turner, 2017). In Southern coast of Bangladesh, it experiences extensive erosion, partly due to rising sea levels, which disrupts the coastal landscape and submerges large areas of mangroves. This impacts the diverse flora and fauna of the Sundarbans, including the Bengal tiger and several endangered species.

Additionally, increased sedimentation and riverbank erosion result in significant habitat loss and alterations in the distribution of mangrove species (Hossain *et al.,* 2021).

In Kenya, Omuombo *et al.,* (2013) predicted 5 and 17% shoreline changes by 2100 in Tana River and Mombasa respectfully due to sea-level rise. Shoreline change in Malindi, Kenya has led to the abandonment of seven boreholes, houses, a health centre, a mosque, and government offices through sediment input through River Sabaki (Alemayehu *et al.,* 2015). Erosion and accretion processes in Bamburi and Nyali beach influence the beach's stability, which also enhances littoral drift causing morphological dynamics of the beach (Ali *et al.,* 2007).

According to Cheshire *et al.,* (2009), land-based activities such as sand mining and large-scale agriculture contributes to the loss and degradation of the nearshore marine environment. Crucial biological diversity loss, health problems, reduction of marine productivity, increase of erosion and accretions, coastal flooding and loss of infrastructures are some of the challenges faced as a result of shoreline change (Abuodha, 2003). Human interventions through construction of seawalls, groynes and jetties interferes with longshore drift processes that modifies and affects sediment budget and accelerates erosion of the shoreline. Sea walls built to protect coastal properties increases reflected waves and currents energy, resulting to the erosion and flattening of the adjoining beach. Furthermore, Maselink & Gehrels, (2014) and Masselink & Gehrels, (2015) reports that hard infrastructures alters hydrodynamic and morphodynamic coastline processes which accelerate flooding and shoreline erosion downdrift. In addition, the hard infrastructures may amplify tides in the upper parts of river estuaries and also squeeze ecosystems migration towards the land with the sea level rise whereas the constructed infrastructure failure may result to a great damage (Gittman *et al.,* 2016; Lee *et al.,* 2017).

2.6 Hotspots areas for Shoreline Change Around the world

Shoreline change studies have been carried out in different parts of the global coastline to measure either the advancing or retreating of shorelines. According to Luijendijk *et al.,* (2018) the state of the world's beaches found that about 24% of sandy beaches is experiencing erosion, 28% accretion while stable sand beaches is 48%. He reported that globally we have 31% of sandy shoreline which is free from ice. Africa consists of 66% sandy beaches followed by Europe with 22%. Hotspot beach erosion occur in southern Texas which with erosion rates of -15m/y since 1980s (Luijendijk *et al.,* 2018). Shoreline changes along the Lithuanian Baltic Sea coast showed that some areas of shoreline position advancing in Sventoji (66m) coastlines while other areas showed retreating shoreline position Palanga (36m) during 1947-2010. The average shoreline changes, end point rate (EPR) was calculated for the same period. For Sventoji positive EPR value of 3.4 m was established and a negative EPR value of -0..5m/year was established at Palanga (Bagdanavičiūtė *et al.,* 2012). Synthetic aperture radar assessed land use and shoreline changes in Braganca coast, Para, Northern Brazil, where significant changes were detected. Based on the superimposition of vectors derived from synthetic aperture radar (SAR) images data, the coastline had been subjected to severe coastal erosion responsible for a retreat of $32km^2$ and accretion of $20km^2$, causing a loss of almost $20km^2$ mangroves (Souza-Filho *et al.*, 2003).

An assessment of shoreline changes along Karnakata coast, India, using DSAS and Remote Sensing techniques, substantial changes in the coastline were noted. As per the study, 70% of the coastline was either stable or accreting, with the remaining 30% of the region experiencing a varying magnitude of erosion. Extensive erosion rates were noted in the mouths of various rivers, including Kalinadi, Haladi, Sharavati, and Swana. In the Karnakata coast, the south of Kalinadi River, accretion was noted from 1989 to 2000. However, the same area also showed erosion patterns from 2000 through 2006. Overall, about 168 km of the coastline was noted to be accrediting in nature, an average of 1.5 m/year, followed by a 71 km coastal stretch and moderate erosion rates of 1.0 m/year (ChenthamilSelvan *et al.,* 2014).

A study analyzing shorelines in Keta Ghana investigated the reliability of using satellite imageries in detecting shoreline position. Five shoreline positions were extracted from 1986 to 2011 which was approximately 25 years. To calculate the rate of change End Point Rate and Weighted Linear Regression statistical methods were used as the statistical methods. Uncertainties quantified ranged from ±4.1m to ±5.5m. The results showed that the overall rate of erosion was estimated to be 2m per year. Along some transects, the rate could rise to 16m per year. The study indicated that some hotspot areas are highly eroded, depending on natural and land-based factors in the estuaries (Addo *et al.,* 2011). In Nigeria both erosion and accretion occurred along all coastlines, whereby 70% of coastline was under erosion while 30% experienced accretion (Ibitoye, 2017). In Zanzibar, satellite remote sensing was used to estimate the changes at Ruvu delta which revealed that the river mouth has been accreting rapidly. Most of the accretion occurred between 1986 and 1998. The Uluguru Mountains, located 200km from the coastal region, was a significant contributor of sediment input to River Ruvu. On the other hand, 1997/98 El Nin˜ o–Southern Oscillation (ENSO) mainly affected the delta as most observed growth occurred between 1986 and 1998. Slufter Texel, the Netherlands estuarine plays a critical role in coastal flooding mitigation. The river mouth consists of sand dunes, estuarine channels and a salt mash extending to about 1km wide. The estuary is facing land reclamation and illegal embankment constructions which is interfering with sediment movements. The human interventions such as sand nourishments and beach nourishment are increasing the risk to coastal flooding (Systems *et al.,* 2020). In Kenya, a study on shoreline change was carried out in Watamu Area in the period between 1969-2020 and realized alarming changes in the coastline. At least 64.4% of Watamu shoreline was experiencing erosion while 35.5% was experiencing accretion (Alemayehu *et al.,* 2015).

Effects of shoreline change include the increase of flood risk, submergence, salinization of surface and underground water, morphological changes such as sediment erosion and accretion, and loss of wetlands (Kaliraj *et al.,* 2014). Coastline ecosystems are among the keystone features of estuarine and marine ecosystems affected by shoreline changes. Their beds act as structural habitats, and they provide cover for vast benthic invertebrates and fish. Besides habitat, healthy ecosystems provide ecological services and functions such as regulating physical conditions within a bed by providing oxygen to the water columns, dampening wave energy, and slowing down water movements. They are also an essential remover of nutrients from the water column and hence assists in reducing the potential for harmful algal blooms and anoxia (Ferrer *et al.,* 2019). There has been a global decline in coastal ecosystems, which is attributed to land-use practices such as agriculture and urbanization, which reduce water quality through anthropogenic nutrient loading, high levels of suspended solids, and increases in colour dissolved organic matter, all of which are associated with shoreline changes, (Ohowa, 2013). Some of the impacts exerted on coastal natural capital may affect the coastal processes to the point that they may never be restored to their original state. Due to the increasing and rampant urbanization in coastal zones, which hinder achieving SDG 14-Life underwater, Integrated Coastal Management (ICM) advocates for sustainable development and conservation of marine ecosystems (Elnabwy *et al.,* 2020).

2.7 Shoreline change prediction

Predicting shoreline changes by the year 2100 involves considering a wide range of factors, including sea level rise, climate change, coastal developments, and natural processes (Pörtner *et al.,* 2019). For instance, rising sea levels can affect the sediment balance along coastlines, potentially exacerbating erosion in some areas and promoting accretion in others. The implications of these changes have significant environmental, economic, and social impacts, making it a critical area of study for coastal management and policy planning. Sea level rise is one of the most prominent factors in shoreline prediction for the 21st century (Venegas *et al.,* 2023). This rise is primarily driven by climate change-induced melting of polar ice caps and the expansion of seawater as it warms. Projections vary, but by 2100, sea levels are estimated to rise from 0.3 meters (30 cm) to more than 2 meters (200 cm) depending on various emission scenarios and melting rates (Jevrejeva *et al.,* 2012). The effects of sea level rise on shorelines are profound. Coastal erosion, increased flooding, and loss of coastal ecosystems are among the immediate consequences. Low-lying coastal communities, particularly in developing countries, are at high risk of inundation. Valuable coastal infrastructure, such as ports, roads, and buildings, may be severely impacted. Miami is one of the most vulnerable cities to sea level rise. It is taking steps to elevate roads, upgrade stormwater infrastructure, and invest in innovative flood protection solutions. However, the long-term viability of these efforts depends on the rate of sea level rise (Molinaroli, 2019; Zella *et al.,* 2019). The Netherlands has a long history of shoreline management and is known for its innovative approach to coastal protection. It relies on a combination of natural defenses (dunes and salt marshes) and hard infrastructure (dikes and sea gates) to protect against sea level rise (Ysebaert *et al.,* 2016; Brand *et al.,* 2022).

To address these challenges, adaptive strategies must be employed. These strategies involve anticipating and responding to shoreline changes, rather than attempting to prevent or control them. Coastal planners and engineers are increasingly focusing on moving existing infrastructure and populations away from vulnerable areas and allowing the shoreline to adjust naturally (Etongo *et al.*, 2021). This approach prioritizes long-term resilience over short-term fixes. While adapting to shoreline changes is crucial, mitigation measures to combat climate change should not be overlooked. Reducing greenhouse gas emissions is essential to slow the rate of sea level rise. Policies and initiatives aimed at transitioning to clean energy sources, reducing carbon emissions, and protecting and restoring coastal ecosystems contribute to mitigating climate change's impacts on shorelines (Howard *et al.*, 2023).

Human activities such as urbanization, coastal development, and the construction of hard infrastructure like seawalls and groins can significantly alter shoreline dynamics. These activities exacerbate erosion, disrupt sediment transport, and increase vulnerability to sea level rise. Coastal regions are often heavily populated and economically productive. Sea level rise and increased flooding will damage infrastructure, displace communities, and disrupt economic activities like tourism, agriculture, and shipping while shoreline will change landward side (Dede *et al*., 2023). A study by Kebede et al. (2012) used geographic information systems to quantify current and future coastal flooding risk in Mombasa. Currently, around 190,000 people and assets valued at $470 million in Mombasa face a 1-in-100-year extreme water level event, with about 60% of this risk concentrated in the Mombasa Island division, where approximately 117,000 people reside below 10 meters' elevation (as of 2005). Future projections by 2080, under the A1B sea-level scenario and associated socioeconomic conditions, exposure could increase to over 380,000 people and $15 billion in assets.

Coastal management strategies should consider these broader impacts and plan for potential relocations and adaptations (Molinaroli, 2019). Effective shoreline prediction and management require well-informed policies and governance structures. Governments, at various levels, need to develop and enforce regulations that guide responsible development, protect natural coastal ecosystems, and account for climate change impacts. Coastal management should be a collaborative effort involving multiple stakeholders, including government agencies, scientists, local communities, and non-governmental organizations (Griggs & Reguero, 2021).

2.8 Theoretical Framework

The Tragedy of the Commons Theory serves as the foundation for this research (Lloyd, 1833). By establishing a connection between the land-based activities and shoreline change, the theory explains how shoreline is being influenced by human related activities. Shoreline resources are communally owned and would inevitably deteriorate or even vanish if they are been utilized uncontrollably. These scenarios would accelerate shoreline change and wetland ecosystems will be at threat of been lost. Unsustainable fishing, coastal zone degradation, shoreline changes and increasing marine pollution are some of the environmental challenges that conform to the dynamics of the theory (Wilkinson & Salvat, 2012). The global population growth especially on coastal zones has the element of the tragedy scenario as discussed in the article (Leal, 1998). In the absence of laws, enforceable limits and poor implementation of laws and policies on the use of coastal resources, the locals tend to overharvest resources until the resource is depleted (Ostrom, 1999). Coastal resources share two common characteristics that include excludability and sub-tractability. Excludability is the situation whereby it is almost impossible to control the accessibility of a resource. Migratory resources such as fish and groundwater are challenging to monitor for their accessibility and resource use. Sub-tractability involves the capability of an individual excluding him or herself from the interest and welfare of other resource users. Suppose individual overharvest mangroves for raw materials from coastal zones if he can access the market easily, other resource users had incurred more efforts in resource restoration and accessibility and all shared consequences of impacts associated with blue carbon deforestation and degradation (Feeny *et al.*, 1990). Developing guidelines to govern the shoreline resource use is the most recommended way to prevent the tragedy (Jurjonas *et al.,* 2019). Some of this management strategies consist of voluntary restraints, temporal and permanent ban on accessibility of coastal resources. Incentives, shared responsibility and local community involvement is an additional strategy in shoreline management (Wilkinson & Salvat, 2012). Adoption and implementation of laws and regulations that coercively impose accessibility and limit coastal resource use helps to avoid the environmental tragedy. Resource privatization and nationalization of coastal resources can be adopted to avoid the tragedy of commons and assign each individual accessibility limits (Cabral & Aliño, 2011).

2.9 Conceptual Framework

In this study, the independent variable is time in years as shown in Figure 2. Shoreline erosion and accretion and the cover extent of the nearshore marine environment are the dependent variables. Even though shoreline positions are dynamic by nature with changes in seasons and climate patterns, human-related activities and natural processes may quicken the rate of shoreline change, endangering recuperation. They influence short-term and long-term changes at the shoreline. Intervening variables include the policy framework, population growth along the coastline, technological and resource capacity. Natural factors are sometimes inevitable, but their impacts can be regulated, either by natural ecosystems or through human interventions. Technological advancement increases efficiency and encourages massive exploitation of marine resources for construction and other economic interests. The policy framework influences the sustainable use and management of coastal zone resources, ensuring that activities carried out on the coastal zone are controlled and monitored.

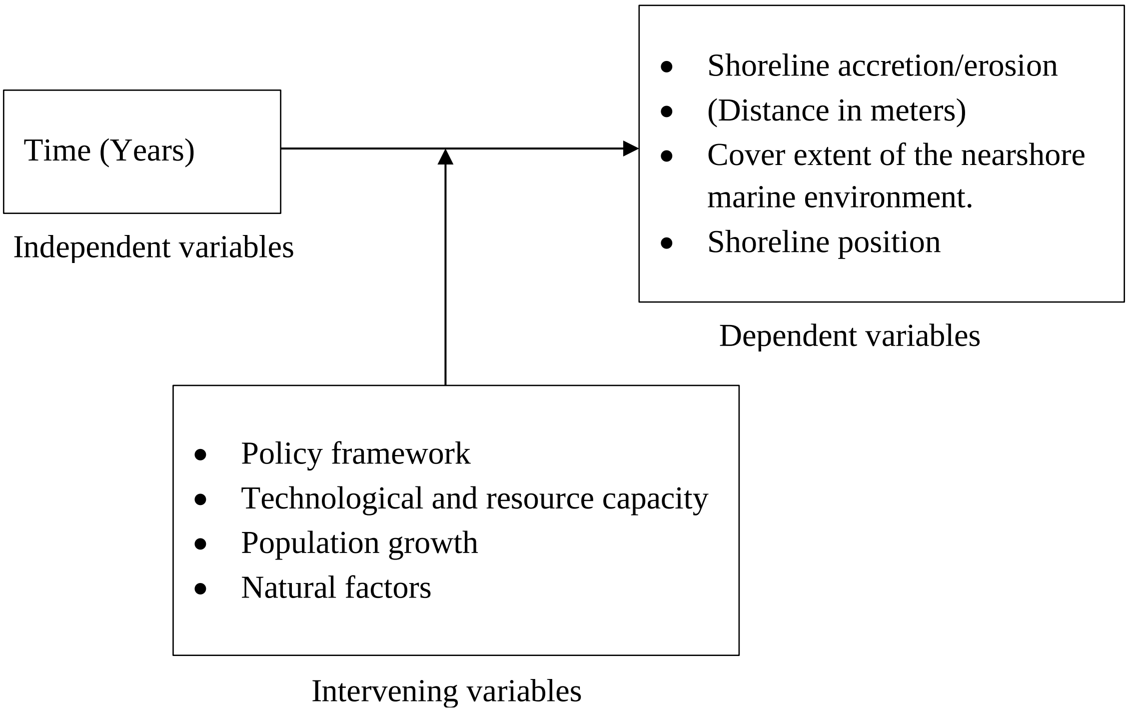

Figure 2: Conceptual framework

Anthropogenic factors are diverse and can affect shorelines either directly or indirectly. Population growth is closely intertwined with shoreline change, as the burgeoning coastal population drives various factors that impact the dynamic equilibrium of coastlines. As populations expand, there is often a surge in coastal development, including infrastructure and urbanization, which disrupt natural coastal processes and contribute to shoreline erosion. Additionally, the increasing demand for resources from coastal areas, such as seafood and freshwater, leads to overfishing, pollution, and habitat destruction, further influencing shoreline dynamics. The rise in coastal tourism and recreational activities driven by population growth disturbs coastal ecosystems and sediment patterns, affecting the balance between erosion and accretion. Moreover, population growth often necessitates the construction of protective structures against natural hazards, potentially altering shoreline dynamics. Effective policies and management practices are crucial for balancing the needs of growing coastal populations with the conservation and sustainable use of coastal resources, thus mitigating the impact of population growth on shoreline change. The intervening variables play a crucial role in shaping the interactions between the independent and dependent variables, ultimately impacting the health and sustainability of coastal zones.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

3.1.1 Geographical Area

This study was conducted in Gazi Bay, situated in Kwale County, Kenya (40°25'S and 390°30'E), and approximately 55 km south of Mombasa city. Covering an area of 18 km^2, the bay is protected by the Chale Peninsula to the east and bordered by a fringing reef to the south. The Bay consists of fringing coral reefs, 12 seagrass species and nine mangroves species which occupies about 7 km^2 (Kairu *et al.*, 2021). The Bay hosts approximately 180 different species of marine fauna species (Seys *et al.*, 1995). The study concentrated on south Western creek where shoreline change was observed as shown in Figure 3.

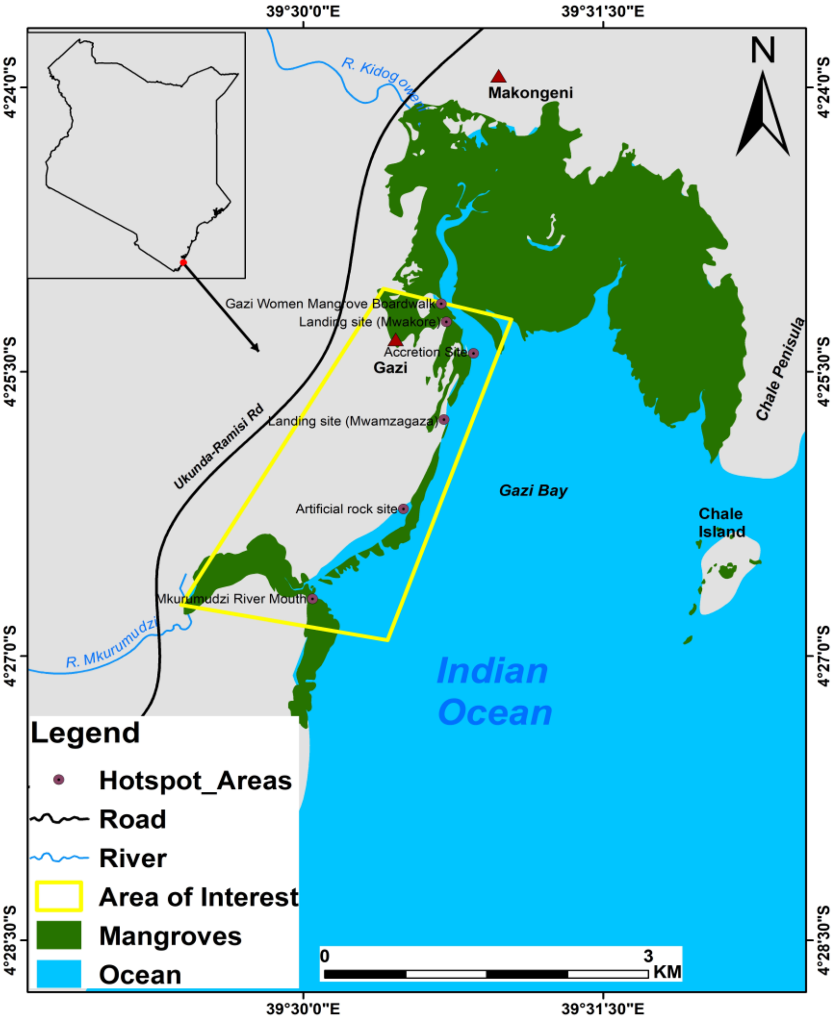

Figure 3: Study area: Gazi bay.

3.1.2 Climate

As in most of Kenya coast, the climate of Gazi bay is influenced by monsoon winds. Based on Koppen Climate classification system, climate of Gazi Bay may be described as tropical savanna climate. It has bimodal rainfall with long rains occurring from May to September during southeast monsoons winds and short rains from November to March during northeast monsoons. Total rainfall in Gazi range from 1,000 and 2100mm. The relative humidity is approximately 95% due to the proximity to the Ocean (Schott *et al.*, 2009). Temperat7ure varies between 24^{0}C and 39^{0}C depending on seasonal variations. Figure 4 shows the rainfall trend over the last three decades.

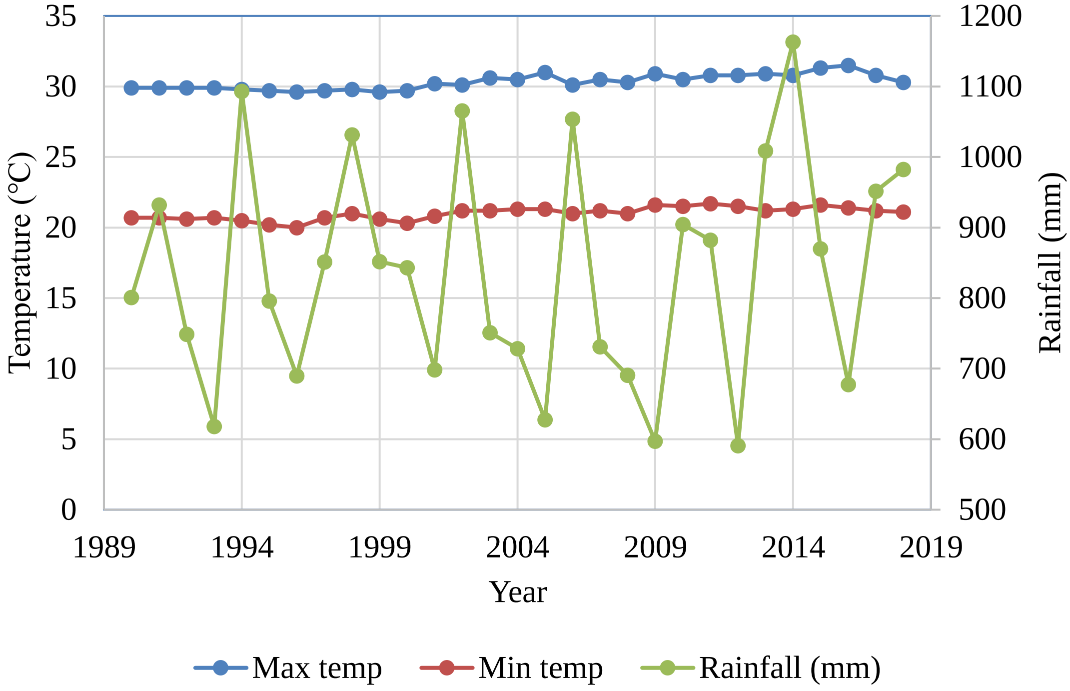

Figure 4: Rainfall graph for Kwale County

3.1.3 Drainage

Two seasonal rivers, Kidogoweni and Mkurumudzi, with their catchment in Shimba Hills, provide freshwater input into the Bay through western and southwestern creeks, respectively (Katuva, 2014). Their combined freshwater discharges are the primary source of dissolved inorganic nutrients. River Mkurumudzi though has a higher annual discharge. During the rainy season, the amount of salt in the water can be as low as 2.0% however, in the dry season, the salt content can increase to 37. 5% at Mkurumudzi River mouth. The turbid plume along the southwestern creek is attributed to westward flowing currents at the coral reef, while at the mangrove zone, the plume is trapped within the mangrove-fringed tidal creeks around the River Kidogoweni mouth. Freshwater mixes with the seawater at the estuary in the upper water layers balancing the water salinity favourable for blue carbon ecosystems (Kitheka *et al.,* 1996). The south western creek portrays positive and negative estuarine feedback whereby during dry season's salinity increases than the adjacent Indian Ocean while in wet seasons there is positive estuarine salinity lower than the adjacent Indian Ocean water intake at the river mouth during high rainfall season. The two rivers stabilize sediments along the shoreline and support various blue-carbon ecosystems (Ouédraogo *et al.*, 2018).

3.1.4 Land-Based Activities

The region lies in an Arid and Semi-Arid ecological zone of Kenya making it vulnerable to stressors caused by anthropogenic activities, natural events and impacts of climate change. Most of the land use in Kwale County seascape shore can be categorized into wildlife, forestry, roads, townships, mining, and arable farming. The main economic activities along the shore include subsistence farming, livestock keeping, commercial fishing, sand harvesting, commercial farming of sugarcane, and commercial mining. The primary source of livelihood in Gazi Bay consists of tourism and artisanal fishing, whereby fishing takes place throughout the year. The Monsoons blow from the northeast between December and March that marks the high fishing season and from the southeast from May to October that marks the low fishing season, whereby April and November are the transition periods characterized by weaker winds (Murungi, 2017). The seasonality fishing variations are brought by oceanographically changes in water temperatures, thermocline depth, and ocean currents that cause fish migration (McClanahan, 1988). Damming of River Mkurumudzi has consequent to imbalanced sedimentation at the river's mouth threatening the nearshore environment (Katuva, 2014). Section of the Bay has undergone shoreline erosion, while another section has undergone sediment accretion. In both instants, they have led to deaths of mangroves within the shoreline stretch (Mungai *et al.,* 2019). This has contributed to the loss of livelihood as most of the blue carbon resources have been lost (Murungi, 2017). Most of research on mangroves and other marine species started early in the 1990s in Gazi Bay which later in 2013 led to the formation of Mikoko Pamoja - a carbon offset project.

The population of Gazi has been increasing with time since 1990s causing an increase in land-based activities in the area. There was an approximately 900 people in Gazi Bay in the year 2000s (Dahdouh-Guebas et al. 2000) increasing to over 5,000 in 2019 (https://ke.geoview.info/gazi,197514). There has been degradation of mangroves in Gazi Bay and most of mangrove exploitation occurred in the 1970s to provide fuel for chalk, brick and limestone industries and building poles for export. The catch of fish in Gazi Bay has been considerably reduced during the last decade associated with the loss of habitat and increasing fishing pressure (Murungi, 2017). In 1990s, mangrove plantation experiments were initiated by KMFRI in Gazi; by 2020 more than 50 ha of mangroves had been restored in the bay (Huff & Tonui, 2017).

3.2 Research Design

Mixture of longitudinal and ecological research designs were used in the study. The longitudinal, design involved analysing of existing satellites data from 1989 to 2020. Landsat imageries were acquired and clipped to obtain the study area. The spatial changes of the nearshore marine environment were analysed from 1989 to 2020. Information collected was used to quantify variations of shoreline change and the relationship with the status of the nearshore marine environment for the last three decades. Under ecological design, changes in nearshore ecological units were analysed. The outcome of the area covered by the nearshore marine environmental change was compared to shoreline change over time to analyse the relationship. Ecological characteristics were observed over short and long periods to determine variations with the exposure of shoreline change and sediment budget variations. To achieve this, seven shoreline positions were delineated on the pre-processed scenes in form of vector data. Shoreline dates used in this study were 3/12/1989, 10/12/1994, 10/26/2001, 02/25/2005, 10/28/2012, 01/25/2015, 02/27/2020. The Shoreline positions in form of shapefiles for these dates were merged to form one shapefile and overlayed on a base map. A baseline was digitized by a buffering method at 150 metres along the merged shorelines which could help cast transects perpendicularly to the ocean. A total of 82 transects were cast using the Digital Shoreline Analysis System (DSAS) from the northern side of the bay towards the south and change statistics were computed from the seven shoreline positions. DSAS rates were reported in meters per year except

Shoreline change Envelope which was reported as the distance of shoreline change in meters.

3.3 Sampling Design

A systematic sampling method was used in casting orthogonal transects using DSAS software in ArcGIS at a 50-meter spacing along the 5kms shoreline stretch. 82 transects were obtained and subsequently used to calculate change statistics. The casted transects perpendicularly to the shoreline were used to detect changes over time. Shoreline and transects intersection provided location and valuable time in calculating shoreline change rates. The long-term shoreline change evaluation of south western creek of Gazi Bay was studied for the last three decades from 1989 to 2020. Shoreline change assessment were based on comparison of seven shorelines positions extracted and quantifying land use land cover change as shown in the methodology flow chart.

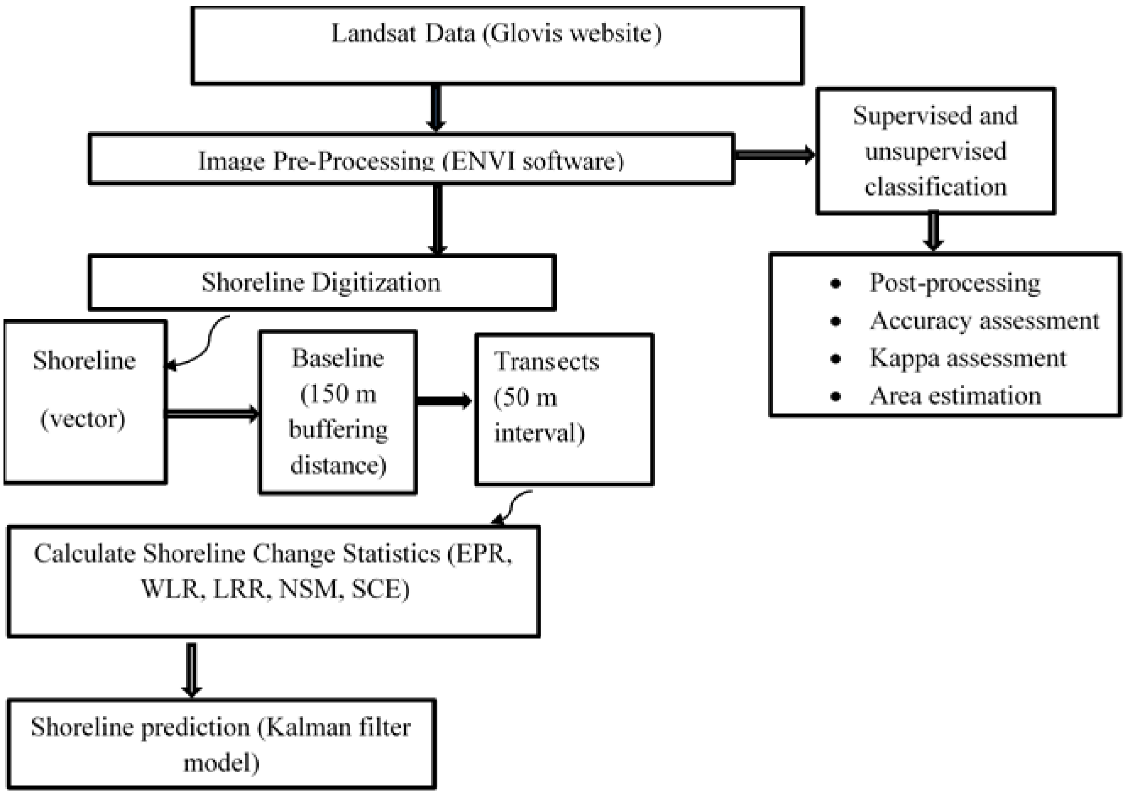

Figure 5: Methodology Flow Chart

3.4 Data Collection

3.4.1 Instrument of Data Collection

Both satellite and ground truthing data were processed to derive shoreline change and variations of the nearshore marine environment over time. Landsat data were obtained from the United States Geological Survey (USGS) Glovis Website for the current study. Its temporal consistency coupled with spectral bands, moderate spatial resolution, and high temporal resolution makes it reliable in accurate land cover change analyses and shoreline change detection among multiple uses. All the available Landsat images since 1989 with a spatial resolution of 30m was reviewed for quality and cloud-free scenes for analysis. A pre-processing analysis was carried out on the acquired data in ENVI software application for atmospheric, radiometric, and geometric correction. Coordinates obtained from the maps and Google Earth Pro software guided the researcher during ground-truthing to validate the produced map. On the other hand, GPS points were obtained from the study area guided the researcher during supervised classification.

3.4.2 Validity of Data and the Research Instrument

Assessment of classification accuracy was carried out using ArcGIS, Google Earth Pro software, and data obtained from the intensive fieldwork. An error matrix was obtained to derive producers' accuracy (PA), Users Accuracy (UA), Overall accuracy (OA), and Kappa co-efficient Statistics. Kappa co-efficient measured actual agreements whereby it used all cells in the matrix and considered both the commission and omission errors. Kappa co-efficient Statistics was generated using the following equation:

$$K\hat{} = \frac{\sum_{i=1}^{r} Xii - r_{i-1}\,(Xi\ + *\ X\ +\ i)}{N^2 - \sum_{i=1}^{r}(Xi\ + *\ X\ +\ i)}$$

Where, K^= Kappa Coefficient r = Number of rows in the matrix x_{ii} = Number of observations in row $_i$ and column i (the major diagonal in the confusion matrix) xi + and x+i = Marginal totals of row i and column i N = Total number of observations.

3.5 Ethical Considerations

Letters authorizing research was obtained from all relevant authorities before commencing the study. This included a research clearance form from the Graduate School of Chuka University, Kenya Marine and fisheries Research Institute and a research permit from the National Commission for Science Technology and Innovation (NACOSTI).

3.6 Data Analysis

3.6.1 Shoreline Extraction

The Landsat data obtained from Glovis website was imported in ENVI in the form of a GeoTIFF metadata. Radiometric calibration was done by applying FLAASH settings. Atmospheric correction method and statistics computation were also applied using band math. FLAASH technique in ENVI replicates atmospheric conditions that are near to the actual circumstances in the field by having sensor characteristics and geographical conditions. 20 points on Google Earth Pro were overlayed to the Landsat image to ensure that the image was geometrically corrected. Downloaded satellite images were projected in UTM projection WGS 84 datum zone 37S. The multi-date (1989–2020) shorelines were extracted on the pre-processed scenes and validation in google earth pro along the area of interest and converted to a shape file.

3.6.2 Shoreline Analysis

The historical shoreline changes were analysed using Digital Shoreline Analysis System (DSAS 5.0) software within ArcGIS Version 10.5. DSAS tool has been widely used in shoreline analysis as it allows data visualization with change rate displayed with symbology that helps to identify areas with shoreline accretion and shoreline erosion as well as stable areas. Additionally, a summary report is automatically generated which gives an overall shoreline change average rates. DSAS shoreline analysis mainly involved 7 stages which included adding both mandatory and optional fields, setting default parameters, casting transects, selection of the transect layer in the dropdown menu, calculating rates of change, data visualization and finally shoreline forecasting. The software estimated, performed and calculated rates of shoreline change as per Himmelstoss et al. (2018). DSAS robotized technique using beta model predicted 10 and 20-year future shoreline positions. Delineated shorelines were merged together in ArcGIS10.5 to create one shapefile consisting of different shoreline positions. A personal geodatabase was created and shoreline and baseline feature class developed. The merged shorelines were buffered and a baseline was generated by digitizing a line on the buffered shoreline. The software analysed the rate of change for all shoreline positions. Orthogonal transects were cast starting from the baseline intersecting the shoreline positions over the study period. The distance measurements in meters between the transect and shoreline intersection points were employed to calculate the shoreline change statistics. Shoreline threshold was zero, Confidence Interval (CI) selected was at 95%, Default Uncertainty was 10, Transect spacing length was 50 meters perpendicularly to the ocean, smoothing distance was 1000 meters and Coordinate system was WGS_1984_UTM_Zone_37S. Rates of shoreline change were calculated in the form of Linear Regression Rate (LRR), Weighted Linear Regression and End Point Rate (EPR) Net shoreline movement and Net Shoreline Envelop.

3.6.3 Impacts on the Nearshore Marine Environment

Both supervised, and unsupervised classification methods were used in mapping and analysing the shore-zone ecosystem change over the study period 1989-2020 using ArcMap Version 10.5. High-resolution Google earth images and primary data collected during the fieldwork was used in the validation stages.

3.6.4 Statistical Analysis

The Linear regression was calculated as follows.

$$y = b + mx$$

Where

(y) represents the distance in meters from the baseline, (x) shoreline dates interval (m) the slope of the fitted line (m/year) (i.e., represents the shoreline change rate, (LRR), and (b) is the y-intercept.

Net Shoreline Movement (NSM) was also calculated to enumerate the actual distance between the oldest shoreline (1989) and the youngest shoreline (2020) for each transect laid perpendicularly to the shorelines (Himmelstoss *et al.*, 2018).

$$NSM = (d_{2020} - d_{1989})\ m$$

Where

d represents distance in meters

The End Point Rate (EPR) was calculated as per DSAS 5.0 user guide 2018, thus;

$$EPR = \frac{(d_{2020} - d_{1989})\ m/year}{t_{2020} - t_{1989}}$$

Where

ERP represents End Point Rate, *d*, the shoreline distance and t the overall period of study.

In a Weighted Linear Regression, more weight is given to the most reliable data in achieving a best-fit line. This is whereby the point with smaller uncertainty are given more emphasis when computing change rates. The weight (w) is as indicated by the formula below:

$$W = 1/e^2$$

Where

(e) is the uncertainty value of the shoreline.

The Pearson Correlation coefficient between shoreline change and mangrove cover loss was used to determine whether there was a statistically significant difference between the calculated area covered by the nearshore marine environment in 1989 and 2020. The results obtained was compared with results obtained from the Digital shoreline analysis system to further describe shoreline characteristics from 1989 and 2020.

Table 1: Summary of data Analysis

Objective	Independent Variable	Dependent Variable	Types of analysis/Statistic
To estimate change in shoreline in Gazi bay between 1989 and 2020.	Time	Shoreline	Descriptive Maps, graphs, Shoreline positions visualization, Shoreline Change Statistics (End Point Rate, Weighted Linear Regression, Linear Regression Rate, Net Shoreline Movement, Shoreline Change Envelop)
To determine the temporal-spatial changes of the nearshore marine environment.	Time	Cover extent of the nearshore marine environment. (Area in hectares)	• Descriptive • Tables, Graphs, Maps, percentages
To establish hotspot areas of shoreline change.	Time	Shoreline accretion/erosion (Distance in meters)	Descriptive Maps, Graphs

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 To Estimate Change in Shoreline.

4.1.1 Overall Change in Shoreline in Gazi Bay Between 1989 and 2020

A total of seven shoreline positions obtained are as shown in Figure 6.

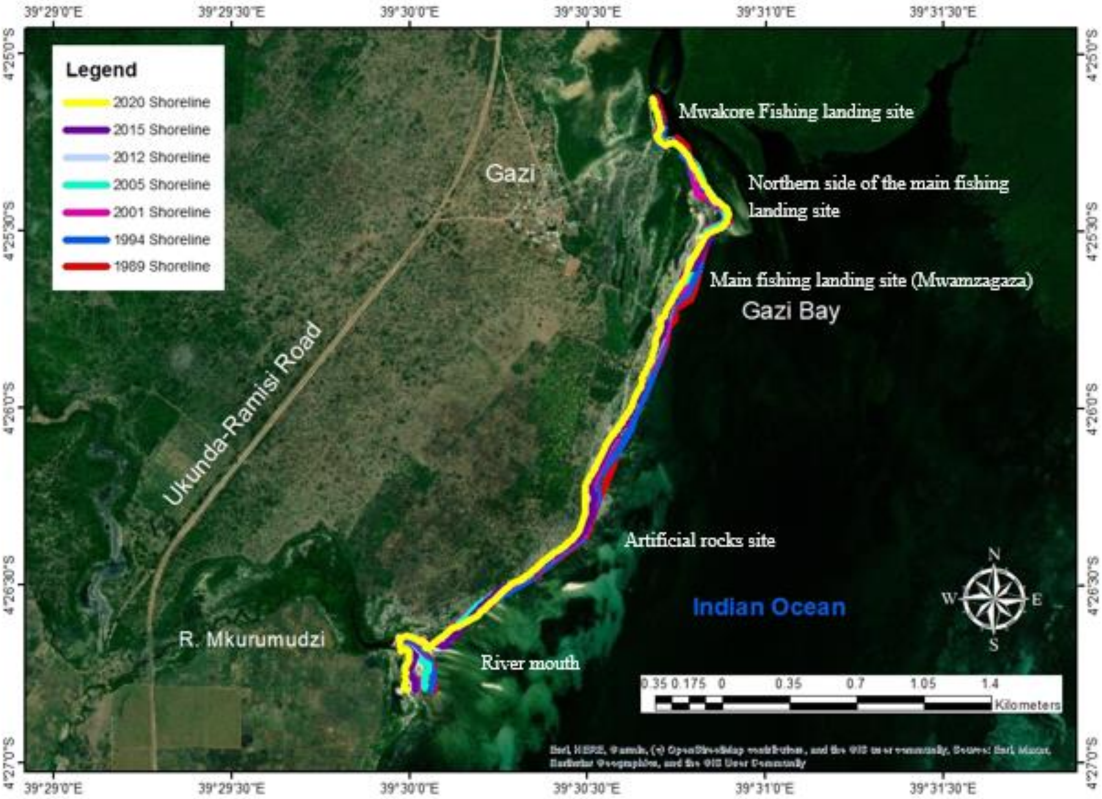

Figure 6: Shoreline changes in Gazi bay between 1989-2020

The average shoreline change of the 5 km stretch of south western creek at Gazi bay has been estimated at 56.84m; ranging from 17.2 to 154.64m. The average Net Shoreline Movement in all the 82 transects was -42.51m indicating erosional activities in most of the transects. Maximum erosion distance was estimated at -154.64m occurring in transect 81 at Mkurumudzi River mouth whereas maximum accretion was estimated at 52.01m occurring in transect 12 at the accretion site (northern side of south western creek). The average loss of land was -50.84m and average gain was 17.52 along the 5km stretch. In the first transect at the Gazi women mangrove boardwalk the shoreline was almost stable with the minimum distance of shoreline change of 17.2m. The mangroves at this point are intact mainly *Soneratia alba* and *Avicenia marina* species, however pest infestation to *Soneratia* alba is causing mangrove dieback which is exposing the land to landward shoreline change as mangrove are not be able to hold sediment together and break waves.

The average rate of shoreline change in the western creek of the Bay has been estimated at -1.38 ± 0.46 m/y (range: 1.68 to -4.99m/y). At least 72 transects (or 87.8%) exhibited erosion activities. The maximum accretion rate was estimated at 1.68m/y with only 12.2% of south western creek experiencing seaward shoreline movement mainly due sediment deposition at northern side of south western creek from the southern side of the bay especially where sediment is being eroded. The average shoreline erosion rate was -1.65m/y whereas accretional rate was 0.57m/y.

On the other hand, Linear Regression Rate (LRR) had an average rate of -1.29± 0.33 m/y. Number of erosional transects was 76.83% and the transects that had statistically significant erosion was 62.2%. The maximum value erosion was -5.53m/y in transect ID 77 whereby the average of all erosional rates was -1.86m/y and 23.17% of all transects were accretional. 3.66% of all transects had statistically significant accretion. The maximum value accretion was 1.96m/y in ID 12 at the northern side of western creek and the average of all accretional rates was 0.61m/y. Results of WRR resembled that of LRR. Shoreline change pattern from transect ID 1 at Gazi women mangrove boardwalk to ID 82 at Southern side of Mkurumudzi River mouth has been elaborated in the Figure 7.

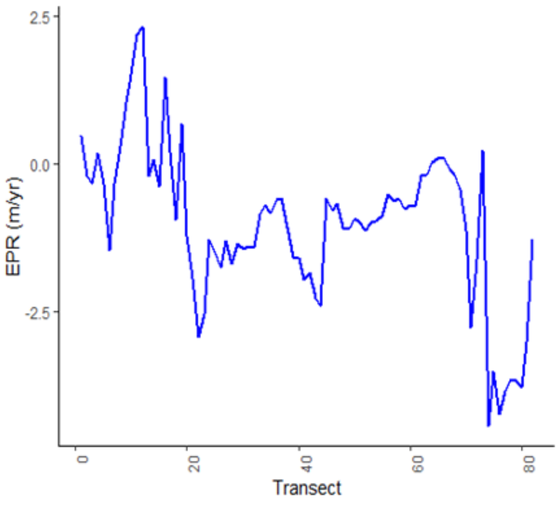

Figure 7: The graph shows the average trend of erosion and accretion from the Gazi Women Mangrove Board Walk (transect ID 1) to the Mkurumudzi River mouth transect ID 82 from 1989 to 2020.

4.1.2 Shoreline Change with time

The trend of shoreline change was different between different periods as shown in Figure 8. Average rate of shoreline change between 1989 and 1994 was estimated at -1.47m/y (range: 3.26 and -10.39m) indicating that most parts of the shoreline were eroding. Between 1994 and 2001 erosion rate increased to -2.34m/y (range: 2.69 to -11.22m). Between 2001 and 2005 the western creek experienced average accretion rate of 0.07 m/y (15.32 to -9.63m). At least 33 transects (or 40.24%) experienced accretion. The period between 2005 and 2012 the shoreline was changing at a rate of -1.18m/y (range:5.48 and -11.6m). The rate of shoreline change was positive at 0.98m/y (range:18.69 and 21.84m) between 2012 and 2015. Community focused mangrove restoration in the western creek between the period could have contributed to reduced shoreline change. Shoreline change between 2015 and 2020 was estimated at -2.25m/y (range 19.49 and -10.52) where 82.72% of the shoreline was eroding. During this period there was much loss of mangroves at the entire study area. This could be attributed to the heavy rainfall in the year 2015 and the unsustainable human activities (GoK, 2017).

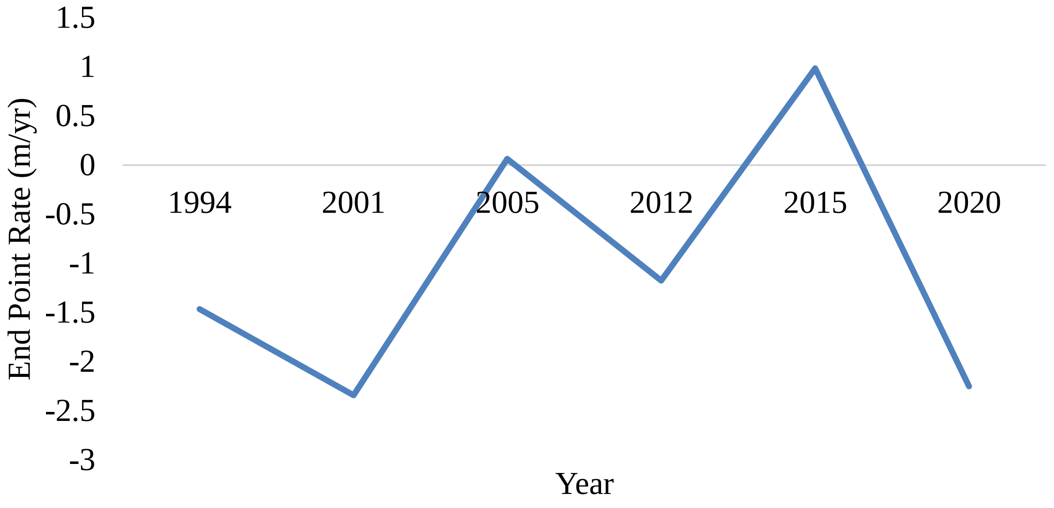

Figure 8: Shoreline change pattern from 1989 to 2020

4.1.3 Shoreline Change Pattern between the Decades

The rate of shoreline change varied between decades as shown in Figure 9. The shoreline change between 1989 and 2001 had an average End Point Rate of -1.97 +/- 1.12 m/y. 88.89% of all transects experienced erosion while 11.11% of the transects were accretional. The shoreline movement varied from a maximum value erosion of -6.98m to maximum value accretion of 0.34m. The year 2001 and 2012 the average rate was -0.8 +/- 1.28 m/y with 67.07% erosional transects and 32.93% of all transects that were accretional. The maximum value erosion was -8.72m whereas maximum value accretion was 6.46m. Between 2012 and 2020 there was an average rate of -1.28 +/- 1.93 m/y. The percentage of erosional transects was 79.01% while 20.99% of all transects were accretional. The maximum value erosion was -6.86m whereas the maximum value accretion was 7.92m. The rate of erosion was high during the first decade 1989-2001 due to the high rate of deforestation in the 1970s and El Nino of 1998. The stabilization of the natural processes, restoration programs and ban of mangrove cutting contributed to reduced erosion during the second decade 2001-2012 (Kirui *et al.*, 2013). Land-based activities and 2015 El Nino mainly could be the cause of the increasing rate of erosion during the last decade 2012-2015 as shown in Figure 8.

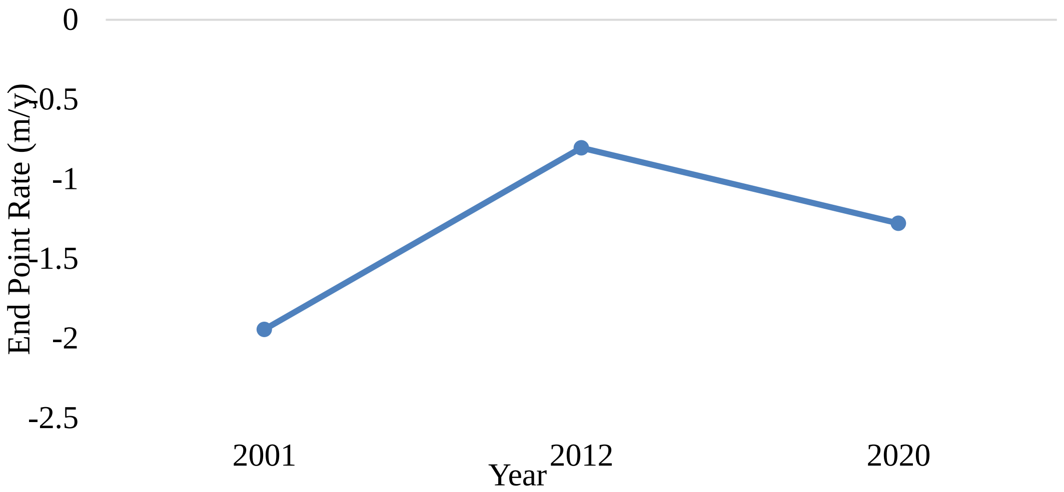

Figure 9: Shoreline change pattern between the decades 1989-2020

4.1.4 Shoreline Change Prediction

Predicting shoreline change is crucial for coastal management, as it helps anticipate the impact of environmental changes and human activities on coastal areas. In this study, a Kalman filter model was applied to forecast future shoreline positions based on historical shorelines (Kalman, 1960). The model predicted future shoreline positions by using the linear regression rate calculated in DSAS, with forecasts made at 10-year intervals. Historical shoreline positions provided data in forecasting future shorelines as per Long and Plant (2012). The linear Regression Rate was calculated for three decades in 1989, 2001,2012 and 2020. The average LRR of -1.35 suggests that most parts of the shoreline in Gazi Bay have been experiencing a landward shift. This trend can be attributed to several factors, including natural processes and anthropogenic influences. Finally, the LRR rate was used in predicting shoreline positions for the year 2032 and 2042 by as shown in Figure 10

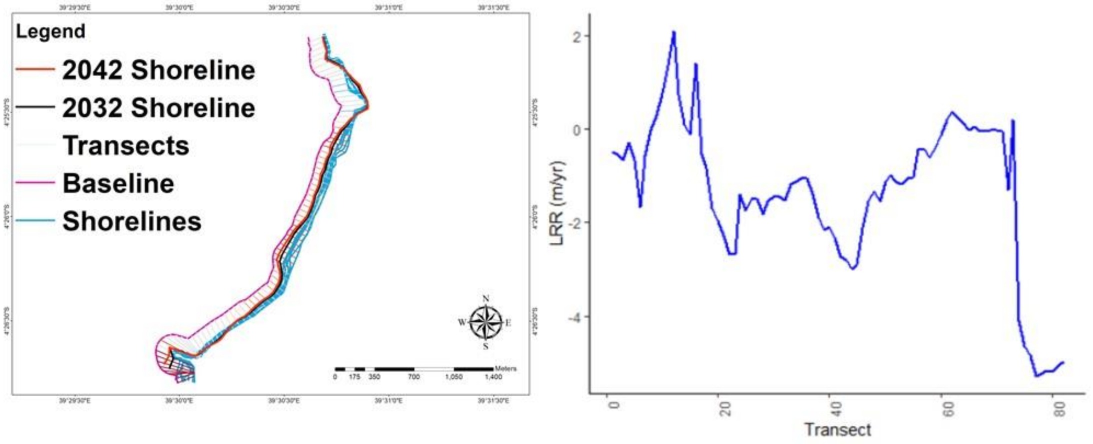

Figure 10: Shoreline change map with shoreline prediction for 2032 and 2042 and the graph of change as per the transects

The results of the shoreline prediction suggest that the most significant erosion is expected to occur along the southern side of River Mkurumudzi, followed by areas with artificial rocks and fish landing sites. Conversely, on the northern side of the primary fish landing site and the southern side of the artificial rocks site, there will be a noticeable advancement of the beach toward the ocean (as illustrated in Figure 11). These two contrasting scenarios are likely to result in substantial losses of mangroves and the degradation of the nearshore environment. Furthermore, the sediment eroded from these areas is anticipated to contribute to the formation of sandbars within the bay. This dynamic interaction between erosion and advancement highlights the complexity of the shoreline's future in this region and underscores the need for effective coastal management strategies.

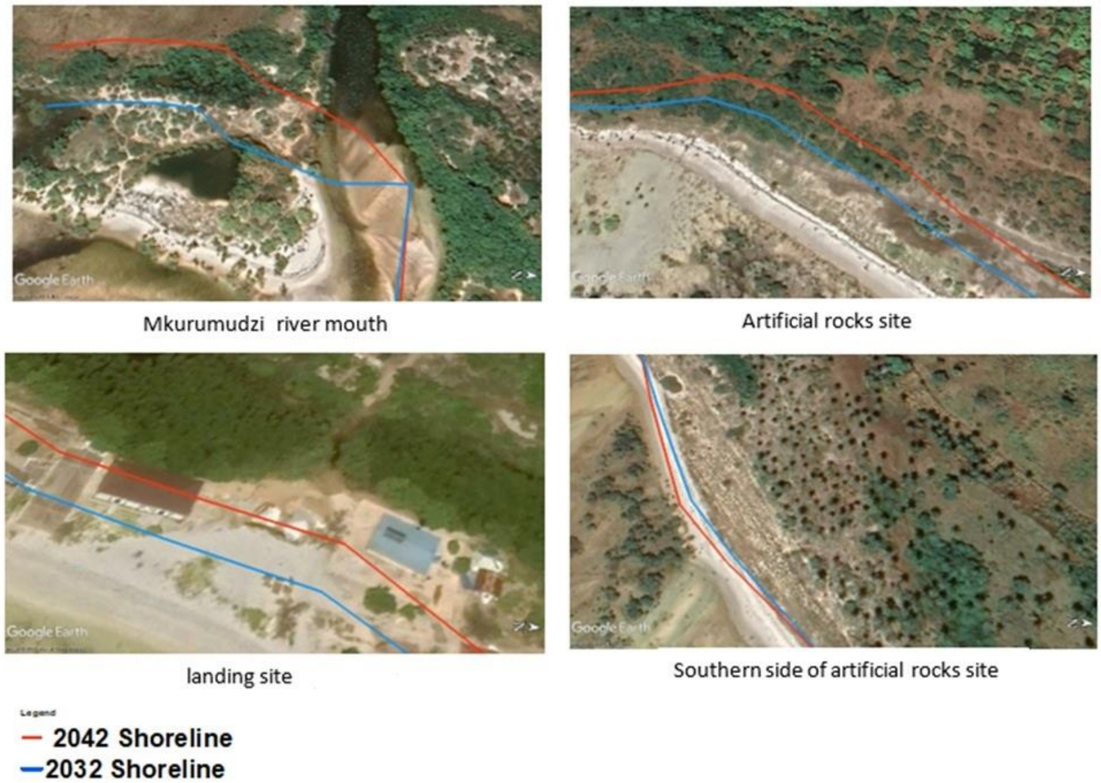

Figure 11: Shoreline prediction hotspots areas of shoreline change

The shoreline change patterns and nearshore environment geomorphology are predicted to continue changing with similar rates. The future shoreline predictions indicate significant loss of land and infrastructures which calls for shoreline management interventions such as protective structures and mangrove restoration. The sediment erosion would reach the agricultural land at southern side of the Mkurumudzi River mouth by the year 2042 and the nearby mangrove will be at threat of sedimentation. Due to the increasing human activities at Mwamzagaza fishing landing site since the year 2020 which involve infrastructure development and seaweed farming related activities, the rate of shoreline changes on the landward side will increase beyond what is predicted by 2042. The two infrastructures Seaweed operation building and the Gazi Beach Management Unit (BMU) building might be at risk of being washed away due to shoreline erosion in the next 20 years. Similar studies have found that shoreline is changing requiring human interventions either directly or indirectly to mitigate coastal vulnerability and hazards.

According to Ballesteros, (2021) 22% of East Africa's coastline are prone to coastal hazards and it is anticipated to increase to 39% due to the continuous loss of mangroves, seagrass and corals. The coastline of Madagascar and Mozambique are most vulnerable to coastal hazards compared coastline of Kenya and Tanzania which is bio-shielded by the mangroves and associated ecosystems. A similar study by Awad & El-Sayed, (2021) found that shoreline erosion and accretion alternated at different rates and future shoreline prediction showed that unless urgent long-term shoreline change mitigation measures were done there could be complete loss of beaches and tourism infrastructures. It is predicted that sea level rise due to climate change, upstream water abstractions, and coastal developments will continue to rise and this will accelerate the rate of shoreline change and sediment dynamics globally (Drammeh, 2013).

4.2 Spatial-Temporal Changes of the Nearshore Marine Environment

The Second objective involved identifying spatial-temporal changes of the nearshore marine environment at Gazi bay. To achieve this Land use land cover in Gazi Bay was classified into seven classes from the seven Landsat images as shown in Figure 12.

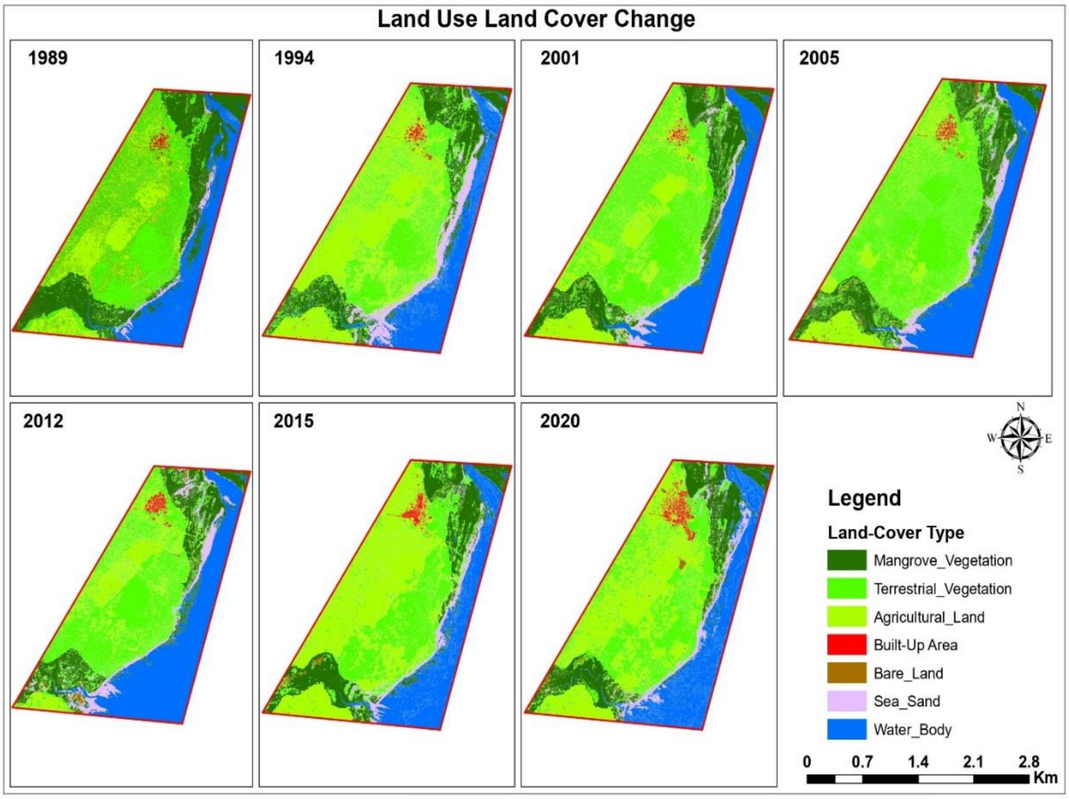

Figure 12: Land use land cover change from 1989 to 2020

The overall accuracy was computed and eventually Kappa co-efficient Statistics was computed using the following equation to validate the accuracy of the land use land cover classification for each year of study using the following equation.

$$K\hat{} = \frac{\sum_{i=1}^{r} Xii - r_{i-1}\,(Xi\ +*\ X\ +\ i)}{N^2 - \sum_{i=1}^{r}(Xi\ +*\ X\ +\ i)}$$

Where, K^= Kappa Coefficient r = Number of rows in the matrix xii = Number of observations in row i and column i (the major diagonal in the confusion matrix) xi+ and x+i = Marginal totals of row i and column i N = Total number of observations.

The accuracy assessment for the year 2020 is shown in table 2.

Table 2: Accuracy assessment for the year 2020

Predict	Agricultural	Bare Land	Built Up	Mangrove	Sea Sand	Terrestrial	Water Body	Row Total	% Accuracy
Agricultural	41	2	2	2	3	1	3	54	75.9
Bare Land	1	33	1	6	2	3	1	47	70.2
Built Up	2	1	38	4	6	3	1	55	69.1
Mangrove	1	6	0	67	0	1	2	77	87.0
Sea Sand	6	1	2	0	51	1	1	62	82.2
Terrestrial	0	5	1	2	1	40	1	50	80.0
Water Body	1	2	0	1	2	0	30	36	83.3
Column Total	52	50	44	82	65	49	39	381	78.7

The year 2020 the overall classification accuracy was 78.7%. The Kappa co-efficient Statistics for the year 2020 was calculated as follows.

$$K = \frac{381 \times 300 - 21776}{381^2 - 21776}$$

The classification accuracy was within the satisfactory range, hence allowing output interpretation. A summary of the overall and Kappa coefficient accuracies was 78 & 0.73, 78% & 0.75, 80% & 0.77, 80% & 0.76, 76% & 0.71, 80% & 0.77, 79% & 0.75 for 1989, 1994, 2001, 2005, 2012, 2015 and 2020 respectively.

Table 3: Land use/Land Cover Change (Area in Hectares)

Land Use/Land cover/Year	1989	1994	2001	2005	2012	2015	2020	+Gain/ −loss
Agricultural land	76.62	81.87	98.54	119.62	161.30	186.61	179.92	103.3
Bare land	2.06	2.15	3.18	2.67	2.45	3.63	6.08	4.02
Built up	2.17	2.89	3.04	3.06	4.77	5.96	7.55	5.38
Mangrove	161.7	138.38	109.99	94.99	82.54	79.46	73.08	-88.62
Sea sand	12.08	24.41	19.31	14.34	17.72	19.35	19.50	7.42
Terrestrial	195.38	197.9	211.94	211.15	179.62	150.56	159.74	-35.64
Water body	100.21	102.62	104.21	104.38	101.81	104.64	104.38	4.17

It was observed that since 1989 there was 103.3 hectares gain of agricultural land, 4.02 hectares gain of bare land, 5.38 hectares gain of built-up area, 88.62 hectares mangrove cover loss, 7.42 hectares gain of sea sand, 35.64 hectares loss of terrestrial land and 4.17 hectares gain of water body. In South Western creek of Gazi Bay it is estimated a mangrove cover loss of 88.62 hectares since 1989 to 2020 which is approximately 55%. A study by (Hamza & Esteves, 2022) reports that the rate of mangrove cover loss are higher in Kwale County as compared to other coastal counties whereas the overall mangrove cover loss in Kenya was estimated at a rate of 0.15% annually. In a study by Kirui *et al.,* (2013) the total mangrove coverage in Kenya has 18% reduction (equivalent to an annual decline rate of 0.7%) over a span of 25 years, from 1985 to 2010. Tudor area experienced an alarming 86.9% decline in mangrove forest cover, while Mwache recorded a substantial loss of 45.4% between 1992 and 2009, translating to notable degradation rates of 5.1% and 2.7% per annum, respectively (Bosire *et al.,* 2014). Over the extended period from 1969 to 2010, Mida Creek witnessed the degradation of 8.8 hectares of mangrove ecosystems (Alemayehu *et al.,* 2014). The ramifications of these mangrove losses are multifaceted, encompassing the forfeiture of critical ecosystem services, including coastal protection and the provisioning of habitat for juvenile fish, which has profound implications for the sustainable livelihoods of local communities.

The current carbon storage in Kenya's mangrove ecosystems amounts to 77 million metric tons of CO2 equivalents (CO2e), and there exists an opportunity to safeguard more than 2,000 hectares of mangroves through carbon financing. Furthermore, mangroves demonstrate an impressive capacity to sequester carbon, surpassing terrestrial trees by a factor of 3 to 5. This ability not only contributes to climate regulation but also delivers a wide array of social and ecological advantages. Despite to their values they are facing both natural and human-induced stressors (Abuodha & Kairo, 2001). A similar study by Dahdouh-Guebas *et al.,* (2004) found that there was a loss of R. *mucronata* by 20% between 1965 and 1992 in Gazi bay and sediment increase by 35% mainly due to deforestation and other human activities. In addition to the human stressors (Dahdouh-Guebas *et al.*, 2004) reports that sediment accretion at northern part of the bay is resulting to a sandy beach expansion with mangrove reorganization and cover loss. He predicted that the scenario will cause the sandy ridge to be inhabited by terrestrial vegetation. This has been observed in the current study using the historical satellite data and ground truthing as mangrove stumps and dead standing mangroves were observed within the expanding sandy beach as shown in plate 1.

Plate 1: (a) Mangrove dieback at Northern side of Gazi Bay due to sediment accretion, (b) Mangrove dieback at Southern side of Mkurumudzi River mouth.

As sedimentation processes were occurring both erosion and accretion, mangrove cover was decreasing with time as shown in Figure 13. The Pearson Correlation coefficient between shoreline change and mangrove cover loss was -0.536 indicating a moderately strong negative linear relationship between shoreline change and mangrove cover loss while significance value was 0.273 indicating that the relationship was not statistically significant. This could be attributed by other factors like insect infestation to mangroves, inadequate freshwater and impacts of fishing activities. The continuous loss of mangroves and other blue carbon ecosystems will increase the vulnerability of Kenyan coastal zones to hazards from 16% to 41% (Hamza & Esteves, 2022). Ballesteros, (2021) also reports that the degradation of blue carbon is increasing coastal vulnerability to coastal hazards whereby in East Africa, 22% of its coastline is vulnerable to coastal hazards, which is anticipated to rise to 39% due to the continuous loss of mangroves, seagrass and Corals. Narayan *et al.*, (2016) found that blue carbon ecosystems have the potential to reduce 35-71% of wave height whereby coral reefs contribute 54-81%, mangroves 25-37%, seagrass and kelp beds 25-45% and salt marshes 62-79%. A study by Maina *et al.*, (2021) indicates that 50% on mangrove ecosystem are highly exposed to impacts of climate change while sediment erosion and drought are increasing mangrove vulnerability to climate change.

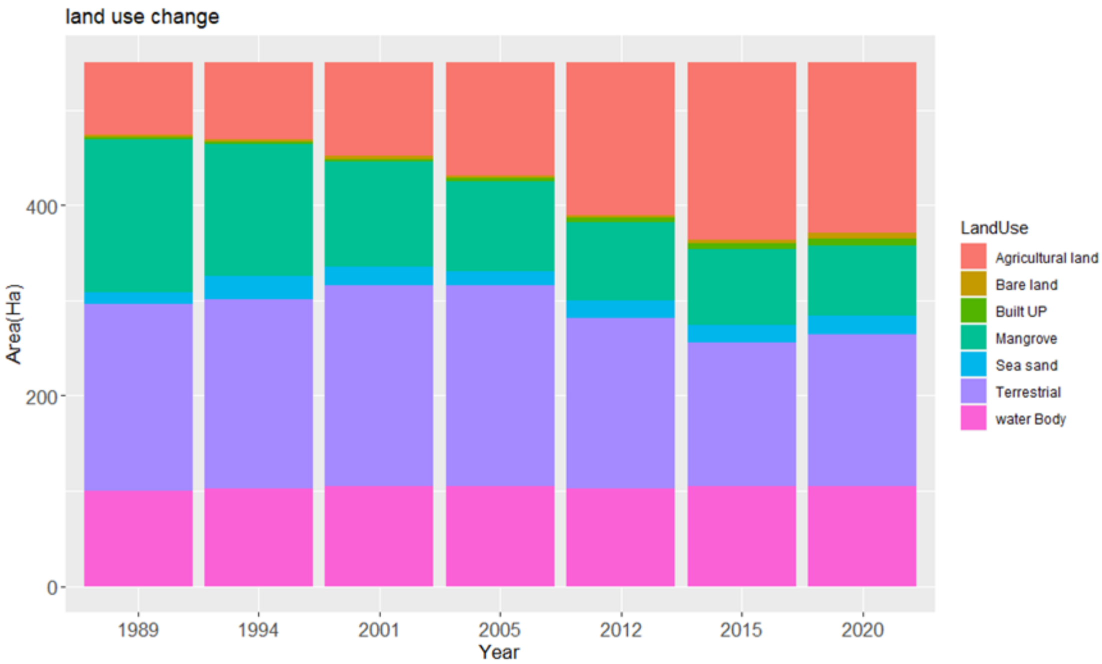

Figure 13: Graph showing Land use/land cover change trends from 1989 to 2020

In Gazi bay there has been shortage of freshwater from the rivers due to upstream activities and climate change which have accelerated mangrove cover loss (Ferrer *et al.*, 2019). The changes in hydrodynamics are also associated with sediments accumulation at the Mkurumudzi River Mouth as the energy from the ocean is exceeding the river flow and hence the sediment is not washed away back to the ocean as expected. Although mangroves are adapted to flooded areas saline environment and sediment deposits, slight changes may cause mangrove dieback and loss (Bosire *et al.*, 2014). Mangrove cover loss and sedimentation at Mkurumudzi River has led to degradation of river mouth estuary by excessive accumulation of ocean sand and mangrove dieback. Lack of necessary estuarine nutrients cycle has led to an extinction of fish species like kamba (indian white shrimp), kamamba (small spotted grunter), and crabs that has reduced ecosystem services at the river mouth. This is in addition to the illegal mangrove harvesting, Insect's infestation and sedimentation that has also contributed to loss of mangroves in South Western creek of Gazi Bay (Murungi, 2017). A study by Ndirangu *et al.,* (2017) in Gazi concluded that mangroves acts as bio-shield and reduce risks of coastal disasters as they reduce an average of 7.8% of wave energy hence protecting the shoreline. This study found that areas open to the ocean like at Gazi main fishing landing site had higher rate of erosion compared to areas with mangroves. Another study by Khomsin *et al.,* (2021) in Indonesia found that shoreline was advancing seaward as mangrove cover increased whereas in another side mangrove deforestation, aberration and impacts of natural processes resulted to landward movement of the shoreline with mangrove cover loss.

Gazi Women Boardwalk and the Mikoko Pamoja Community Organization are the two main mangrove user groups in South Western creek of Gazi Bay. Gazi Women Boardwalk is found on the northern side of the bay along the mangrove zone near the coastline. Mangroves at this site are threatened by pest and insects which is causing mangrove dieback that could accelerate the rate of shoreline change and negative impacts on the tourism sector (Jenoh *et al.,* 2016). In addition, phase three of Mikoko Pamoja project, which consists of 0.4ha is found within South Western creek is facing challenges of shoreline erosion and natural mangrove regeneration have failed (Kairo, *et al.,* 2018). Some of the restoration activities have suffered from seedling low rate of survival, as most of them are washed away at a higher rate due to changes in physical characteristics and shoreline erosion processes (Lang'at *et al.,* 2009). The mangrove cover loss is increasing at this site despite the Gazi Bay residents putting more efforts with KFS to safeguard the forest. The carbon credit project gave the locals a greater sense of ownership over the mangrove forest conservation which is contributing to reduced deforestation by the local people.

Coastal regions are increasingly vulnerable to the impacts of sea-level rise, storm surges, and extreme weather events due to climate change. In the absence of adequate protection, these events can result in catastrophic damage to coastal infrastructure, loss of property, and disruptions to local economies. A study by Neumann *et al.,* (2015) emphasizes the financial risks associated with climate change impacts on coastal communities and underscores the urgency of proactive investments in resilience and protection. A study by (Atwood *et al.,* 2017) recommends mangrove restoration and conservation efforts which will contribute to recovery of blue carbon ecosystems in already degraded sites that will ensure sustainability of coastal natural capital. Likewise, a study by Hinkel *et al.*, (2014) recommended investing in protection of the coastline which is less costly compared to damage cost once the protection action has not taken place. A study by Storlazzi *et al.*, (2018) conducted in the United States found that for every dollar invested in beach nourishment and coastal protection, there can be a return on investment of several dollars in avoided damages during a storm event. Moreover, it can have positive implications for tourism and recreation, which are vital economic drivers in many coastal areas. A study by Mcivor *et al.*, (2013) highlights the importance of protecting and restoring mangroves for both storm protection and eco-tourism opportunities.

4.3 Hotspot areas of Shoreline Change in Gazi Bay

The third objective involved identifying hotspot areas of shoreline change to understand which areas are much affected by shoreline erosion and accretion. It was observed that in most parts the shoreline has been moving landward due to sediment erosion, while in some parts the shoreline has been moving seaward. At northern part of South western creek, the shoreline has been moving seaward at a rate of 1.68m/y as a result of sediment deposition. At southern side of the Mkurumudzi River mouth there was the highest shoreline erosion rate at -4.99m/y and sedimentation processes while at Northern side of the Mkurumudzi River mouth is considered stable. There is also observed development of a sandspit and formation of sandbars at Mkurumudzi River's mouth. Sediment transportation towards the northern side of the bay by the action of waves, tides and longshore drift has caused formation of sandbars at the northern part of the bay. Sediment erosion is causing death to mangroves by uprooting them and nearshore terrestrial and agricultural land is lost by sediment removal. On the other hand, sediment deposition at the shoreline is causing land to move seaward, resulting to loss of mangrove by sediment covering the rooting system of mangroves and reduction of regeneration due to habitat changes. Regeneration of mangrove in the eroding areas is also facing problems of seedlings been washed away or the habitat affected by removal of mud and nutrients by the influence of waves and tides. At southern side of

Mkurumudzi River mouth despite having the highest rate of shoreline erosion it is also facing sediment accretion within the mangroves zones as water channels and ridges are transporting sediments from the ocean which is deposited within the mangroves. The sediment deposits are not only covering the rooting system of mangroves but also blocking water channels that distribute the brackish water within the mangrove zones. The two scenarios of landward movement and sediment deposition within the mangroves are contributing to mangroves dieback and loss. The study indicates that in some parts the process of erosion and accretion has been alternating with time.

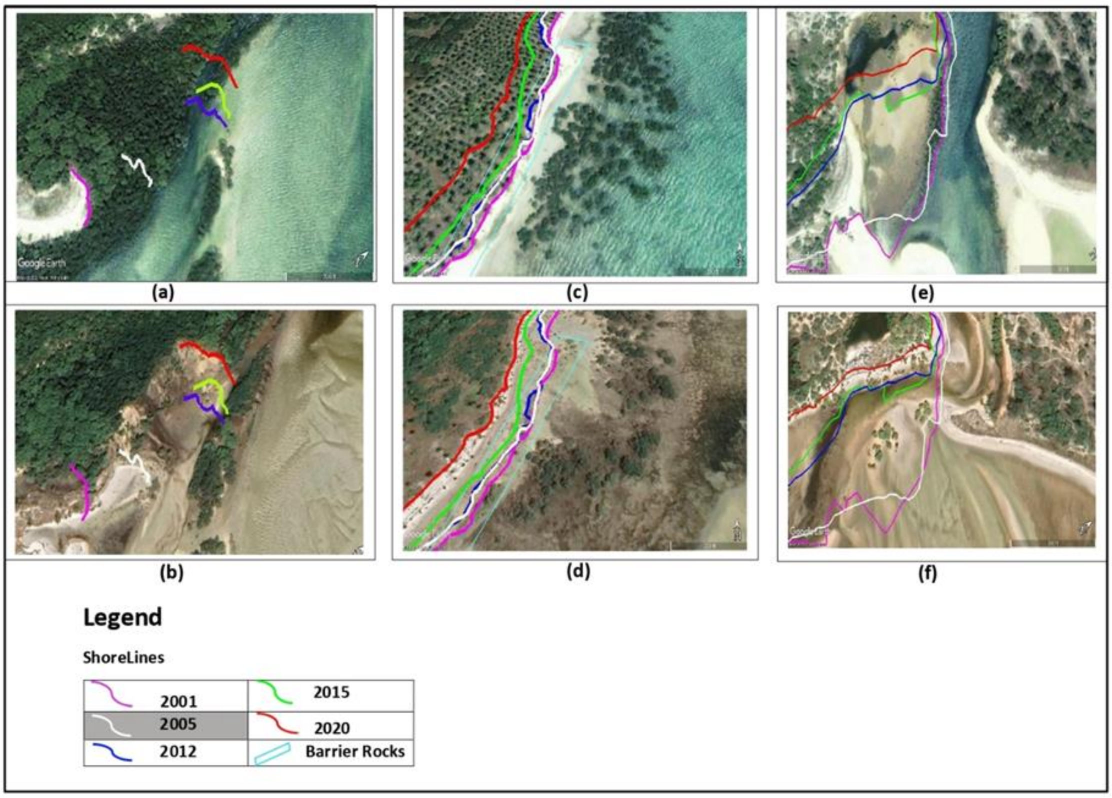

Figure 14: Shoreline change hotspot areas at the accretion site (a) 2001, (b) 2020, artificial barrier rocks site shoreline position (c) 2001, (d) 2020, Southern side of Mkurumudzi River mouth shoreline position (e) 2001 (f) 2020.

The shoreline change most vulnerable areas has been observed in the old fishing ground (Mwakore) northern side of the main fishing ground, main fishing landing site Mwamzagaza, artificial rock site and in both northern and southern parts of River Mkurumudzi (Figure 15).

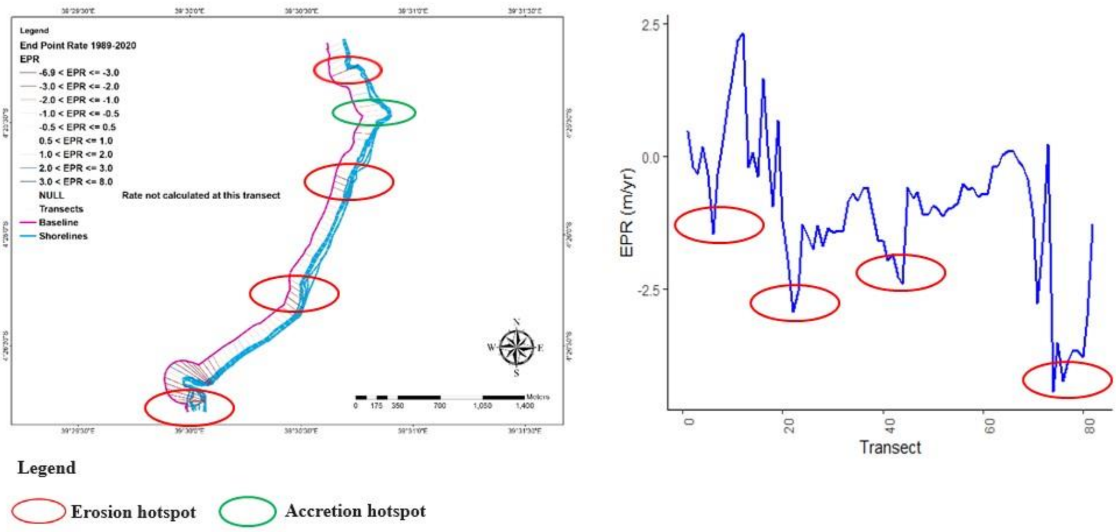

Figure 15: Shoreline change hotspots areas

Gazi bay is characterised by estuaries, creeks, tidal flat, mud flat, mangroves, seagrass and other terrestrial biodiversity which have directly or indirectly been affected by shoreline change. The deposition of sediments in some parts of the bay is threatening seagrass and seaweed farming reducing their productivity and area extent. At Mkurumudzi River estuary the formation of sandspit and sandbars is interfering with estuarine processes which could increase the vulnerability of mangroves to climate change. These have led to continuous loss of estuarine ecosystem services and reduction of resilience to climate change. Both land-based activities and natural processes has greatly contributed to the observed shoreline changes. Natural processes such as oceanographic, geological and meteorological conditions have heavily affected the phenomena of shoreline processes in Gazi bay. Amount of rainfall have impacts on sediment transportation whereby low amount of rainfall reduces amount of sediment supply along the coastline. Heavy rainfall on the other hand, results to excessive sediment supply and imbalance along the coastline. In addition, excess rainfall can indeed contribute to flooding along the coastline, and this inundation has specific consequences for mangrove ecosystems as they are uniquely adapted to brackish and intertidal environments. They need a balance between periods of immersion and exposure to air. The 1997-1998 and 2015 El Nino contributed to great loss of mangrove cover which is documented in GoK, (2017).

During the southern Monsoon winds from April to August there has been observed much uprooting of mangroves which are then carried towards the shore by the action of waves. This has also been reported by Alemayehu, (2015) whereby wave energy is strong during April to August accelerating sediment transportation and erosion of beaches along the Kenyan coastline. *Sonneratia alba* is the most affected mangroves species in South western creek whereby they are dying from the continuous sediment deposition through wave actions which is also documented in Okello *et al.,* (2014). A similar study by Deepika *et al.,*(2014) also reports that seasonal variations affects the direction of currents which influence littoral drift and eroded sediment is redistributed by the action of hydrodynamic processes. Furthermore, the artificial rocks introduced in 1990s in South Western creek of Gazi Bay has interfered with sediment transport dynamics hence accelerating the rate of shoreline erosion. This can also be found in Quang *et al.,* (2021) whereby constructed shoreline barriers affected the sediment transport energy equilibrium that caused sediment redistribution imbalances along the coastline. Yum *et al.,* (2023) reports that there were cyclical shoreline changes with some periods experiencing shoreline erosion and seaward shoreline movement whereas hard infrastructures implemented harmonized shoreline change locally but transferred it to another location that experienced higher rates of shoreline erosion. In addition, Hinkel *et al.,* (2013) reports that 6000–17,000 km^2 of land would be lost globally due to the shoreline erosion associated with natural processes such as sea level rise and land-based activities in areas without coastal nourishment by 21st century. A study by Duvat *et al.,* (2021) highly recommends use of nature based solutions like by mangrove restoration, coastline revegetation and sustainable use of coastal resources rather than construction of seawalls which provides a short term solution and squander resources.

The rate of shoreline change was separately analysed at the northern side of the main fishing landing site due to its dynamic nature and mangrove zonation to estimate the rate of sediment accretion (Figure 16).

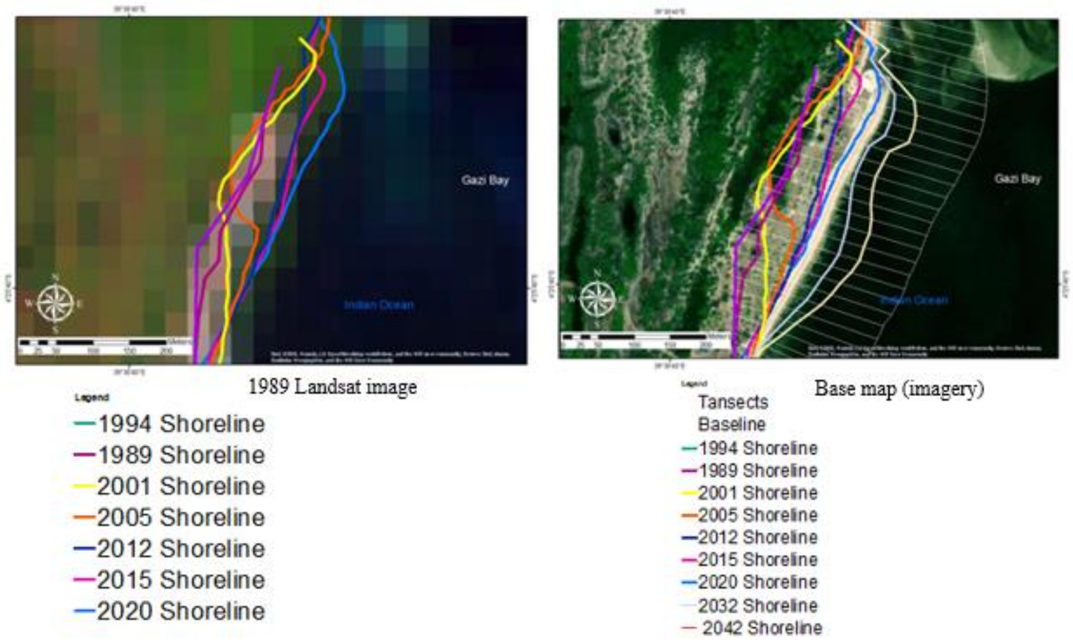

Figure 16: Shoreline accretion at northern side the main fishing landing site and shoreline prediction for 2032 and 2042 at the site.

Shoreline change at the site was mainly sediment accretion at a rate of 2.38m/y since 1989 to 2020. As per the 27 transects cast at a 20m spacing 77% percent of all transects had statistically significant accretion. Mangrove dieback has been occurring towards the northern side of the bay as the sediment deposition ridge develops towards the north. It was also observed that mangroves also relocated to new zones on the seaward side due to the impacts of sediment deposition at the site by the ocean processes. The water channels and ridges within the mangrove zones has been moving towards the seaward side and mangrove species has been found alternating, establishing and colonizing in new areas where they were not found before. On the other hand, shoreline positions and water channels has been extending northward side mainly due to the stress of the increasing sediment deposit from southern side of the bay. *Soneratia alba*, *Avicenia marina* and *Rhizophora mucronata* are the most dominant in the area and mostly affected mangrove species by the shoreline change at the northern side of the bay. Since the water channels has been diverted by the sediment deposit in some areas, the ocean water does not reach to some areas it used to be before hence mangrove dieback and changes of mangrove composition. The community has planted coconut trees and casuarina trees to rehabilitate the area which used to be part of the sea before as terrestrial vegetation is also establishing as the sediment ridge develops. The mangrove cover loss at the site is a threat to marine species, birds and socio-economic activities due to changes in physical-chemical and biological characteristics. Though the historical change in shoreline positions indicates that the northern side of Mwamzagaza fishing landing site is experiencing land advancement toward the ocean, the reverse will take place as the mangrove cover on the ocean side has reduced exposing the land to shoreline erosion. From the empirical observations and present ground truthing, future projected shorelines indicate seaward shoreline change however this might not occur and rather the shoreline position will change towards the land. The mangroves were acting as bio-shields and breaking the waves energy and their degradation exposes land to erosion. The eroded sediment will further be deposited further on the northern side of the bay and sandbars will continue to build up and there will be continuous loss of mangroves and seagrass cover.

Shoreline change hotspots have been extensively studied in various regions to understand the dynamics and impacts of coastal processes. One such case study is the Gulf of Mexico, which has experienced significant shoreline change due to a combination of factors, including hurricanes, sea-level rise, and human activities (Morton, 2008). Research conducted by Jr *et al.,* (2012) in "Hotspot of accelerated sea-level rise on the Atlantic coast of North America" highlights how the Gulf Coast is particularly vulnerable, with notable erosion and land loss. In contrast, the Sundarbans mangrove forest in Bangladesh and India has been another hotspot, where shoreline change is closely linked to climate change impacts (Sreelekshmi *et al.,* 2023). The work by Roy *et al.,* (2023) provides insights into the vulnerability and adaptation strategies in coastal regions. These case studies demonstrate the multidimensional nature of shoreline change, driven by both natural and anthropogenic factors, and emphasize the need for comprehensive research to address its complex dynamics and implications.

CHAPTER FIVE
SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The study assessed shoreline change at Gazi bay, Kenya, for a period spanning from 1989 to 2020. Systematic review of shoreline changes and its impacts to nearshore environment was conducted at national, regional and global levels. The tragedy of the common's posits that where there are no central control common pool resources leads to ruins. This is the case for most coastal and marine resources. The study looked at independent, dependant and intervening variables contributing to shoreline changes in Gazi bay. Both ecological and longitudinal research design was applied whereby shoreline positions were extracted from 1989 to 2020. Linear Regression Rate (LRR) and End Point Rate (EPR) was used in detecting the shoreline changes that has occurred in Gazi Bay.

Both sediment accretions and erosions have been occurring in Gazi over the years. The computed rates of shoreline change indicates that the southern parts of western creek experienced overall erosion of -1.38m/y (EPR) and -1.29m/y (LRR) from1989 to 2020. Overall, 87.8 % of the southern parts of the western creek has exhibited erosion and the rest accretion. This has contributed to 55% loss of mangrove in the western creek of Bay since 1989. Causes of shoreline changes in Gazi has been attributed to both human and natural causes. Deforestation, land use change, and fresh water abstractions are the anticipated human induced factors influencing mangrove losses; which in turn has accelerated shoreline change in Gazi bay. Heavy rainfall and exposure to the open sea has also contributed to shoreline change at Gazi Bay. Future projections show increased erosion/accretion contributing to death of mangrove forests and loss of River Mkurumudzi estuary. The expanding sand bars within the bay will continue covering seagrass while the seaweed farm will be suffering from excessive sediment deposits. The infrastructures along the southern parts of the western creek of Gazi Bay are at threat of being eroded. Increased erosion and accretion will also contribute to mangrove loss in some areas as well as recolonization in other parts. The current study provides baseline data for future monitoring and management of shoreline change in Gazi bay.

5.2 Conclusion

In conclusion the shoreline change at South western creek of Gazi Bay was calculated using the DSAS tool an extension in ArcGIS 10.5. Shoreline changes are dynamic processes influenced largely by human and natural factors. Understanding these changes can help in development of appropriate shoreline management strategies. It is estimated that 87.8% of south western creek of Gazi bay has eroded compared to 12.2% accretion. Shoreline erosion is estimated to reach a maximum of 42.5 m perpendicularly to the waterline. The rate of shoreline change was high between 1994-2001 as well as 2015-2020.

Further, the assessment of land use land cover change indicate that shoreline change is negatively impacting the nearshore marine environment especially the mangrove ecosystem. Erosion activities rate is low in areas with semi-intact mangrove forests; and high in areas with no mangroves. Sediment accretion has choked mangrove breathing roots leading to their death in the western creek of the Bay. Without human interventions, predictive analysis points to increased accretions/erosions on the western creek and more loss of mangroves. Return of lost mangroves can serve as natural solution to protect shoreline from future erosion/sedimentation.

Hotspot area of change was established at the mouth of River Mkurumudzi due to increased upstream activities and other causes such as the impacts of climate change. Other area that recorded high shoreline change are; close to where gabions and rocks had been used to mitigate erosion, as well as at Mwamzagaza and Mwakore fish landing sites due to increased sediment erosion. Increased sedimentation may block the mouth of Mkurumudzi River affecting physical chemistry of the estuarine.

5.3 Recommendations

The western creek of Gazi bay is vulnerable to shoreline change due to human and natural causes. Land based activities have intensified habitat losses leading to increased sedimentation downstream. Sediment accretion further clogs mangrove roots leading to the death of the forest. The study recommends;

i. The study recommends understanding of the dynamics of shoreline changes to develop mitigation actions. Nature based solutions involving restoration and protection of mangroves are some possible interventions that could be used to control shoreline changes in Gazi bay.

ii. In addition, all stakeholders should be included in decision making regarding coastal managements and development of appropriate policies targeting shoreline change. Effective coastal management requires the participation and cooperation of all stakeholders, ranging from local communities and government agencies to environmental organizations and private enterprises. By engaging local communities in decision-making processes is particularly vital, as they often have an intricate understanding of their coastal environment and its challenges. Likewise, inclusive decision-making not only enhances the legitimacy of policies but also ensures that the needs and concerns of all parties are considered.

iii. Water resource users of River Mkurumudzi should develop and implement joint monitoring of freshwater resources with a bid to development conservation approaches. Equally, efforts should made to intensify mangrove conservation through training and capacity building on conservation, rehabilitation and sustainable utilization of mangrove resources.

5.4 Suggestion for Further Study

The study assessed shoreline change in south western creek of Gazi bay. Future studies may focus on the following areas:

i. Drivers of shoreline change, sediment transport processes and the factors contributing to the sediment transportation.

ii. The physiochemical changes of the soils, check whether the areas can be restored and finally identify mangrove species that can be given priority in restoration.

iii. Social ecological vulnerabilities of shoreline change and alternative sources of livelihood, shoreline management options and adaptation mechanisms to support local communities.

iv. The impacts of shoreline change on seagrass and coral ecosystems to estimate how the sedimentation is impacting their distribution and abundance to enhance management of the all the near shore marine environment at Gazi Bay.

v. Natural capital accounting of marine ecosystems at Gazi bay

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APPENDICES

Appendix I: Ground truthing /Validation Checklist

Name of the observer…………………………………………………………………...

Date: ……………………….......................Time……………………………….………

Location…………………………………………………………………………………

Tide: (either spring or Neap) …………………………………………………………

Transect ID	Type of nearshore marine environment	Type of land use	Mangrove species	Altitude	Latitude	Longitude	Other observations

Appendix II: Chuka University Research Authorization

CHUKA UNIVERSITY

Knowledge is Wealth *(Sapientia divitia est)* Akili ni Mali

CHUKA UNIVERSITY INSTITUTIONAL ETHICS REVIEW COMMITTEE

Telephones: 020-2310512/18
Direct Line: 0772894438 **Email: info@chuka.ac.ke.** **P. O. Box 109-60400, Chuka**
Website: www.chuka.ac.ke

REF: CUIERC/ NACOSTI/375 **16th May, 2023**
TO: **Pauline Nyambura Mwangi**

RE: **Assessment of Impacts of Shoreline Change on the Nearshore Marine Environment at Gazi Bay, Kenya**

This is to inform you that *Chuka University IERC* has reviewed and approved your above research proposal. Your application approval number is *NACOSTI/NBC/AC-0812*. The approval period is 16th May, 2023 – 16th May, 2024.

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used

ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by *Chuka University IERC*.

iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to *Chuka University IERC* within 72 hours of notification

iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to *Chuka University IERC* within 72 hours

v. Clearance for export of biological specimens must be obtained from relevant institutions.

vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.

vii. Submission of an executive summary report within 90 days upon completion of the study to *Chuka University IERC*.

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely

Dr. Benjamin Kanga
SECRETARY

Chuka University is……. …Inspiring Environmental Sustainability for Better Life

Appendix III: NACOSTI Research Authorization

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **123665**

Date of Issue: **30/June/2023**

RESEARCH LICENSE

This is to Certify that Miss.. Pauline Nyambura Mwangi of Chuka University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Kwale on the topic: ASSESSMENT OF IMPACTS OF SHORELINE CHANGE ON THE NEARSHORE MARINE ENVIRONMENT AT GAZI BAY, KENYA BETWEEN 1990 TO 2020 for the period ending : 30/June/2024.

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Director General

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

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