A STUDY INVESTIGATING IMPACTS OF SEA LEVEL RISE ON COASTAL ECOSYSTEM SERVICES ALONG THE ETHEKWINI MUNICIPALITY COASTLINE AS A CONSEQUENCE OF CLIMATE CHANGE AND RECOMMENDATIONS TO BUILD/ENHANCE RESILIENCE

by

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ABSTRACT

Climate change during the 21st century is caused by the rapid increase in global warming because of human activity. The consequences of climate change include melting glaciers, rising sea levels, and extreme weather. The primary cause of global sea level rise (SLR) is melting of ice on land, followed by ocean thermal expansion. Extreme events are happening more often and are becoming more intense due to greenhouse gas emissions from human activities. Coastal ecosystems are exposed to SLR and its physical impacts, such as flooding or salinisation, which in turn increase ecosystems' vulnerability and decrease their ability to support livelihoods and provide ecosystem services such as coastal protection. Coastal ecosystems are also highly vulnerable to human-mediated drivers of climate change, such as land use change and coastal squeeze, because they are situated in the sea-land interface area that is favourable for urbanisation and development. This study focuses on the impacts of SLR on coastal dunes, and a protected tree species, *Mimusops caffra*, commonly known as coastal red milkwood, naturally occurring in part of the coastal forest in eThekwini Municipality. It further provides recommendations to enhance resilience along the Durban coastline. The results from the Coastal Vulnerability Index (CVI) analysis, classification of land use, developments impacted by a 300mm analysis, and the risk assessment of coastal ecosystems conclude that future SLR impacts will pose a threat to land demarcated under the Durban Metropolitan Open Space System, National Freshwater Ecosystem Priority Areas, and protected areas, as well as affluent high costing properties and coastal dunes and forests respectively, by a 300mm SLR along the eThekwini coastline in the next ±111 years if the current rate of SLR for Durban (2.74 mm/yr) remains constant. Further, whilst prior research suggests that the dieback of *Mimusops caffra* (*M. caffra*) is strongly related to fungal infections, results from this study indicate that *M. caffra* growing closest to the sea are stressed by environmental factors either wind or surge, thus increasing fungal infection as well. There is, however, little research on the impact of salt spray on these trees. Hence it is recommended that further investigation is required on milkwood to better understand the dieback observed in this study (i.e., due to fungus, or natural cause), especially as they are a protected species.

Adaptation measures must be considered in areas identified as “high” risk for the protection of development from future SLR impacts, as well as maintaining natural areas where biophysical functionality is unhindered. From the CVI analysis, the regions which contain developments (i.e., private property) within the 100m HWM, both local government and homeowners should consider working together when installing geofabric sandbags to avoid increasing the effects of coastal erosion, as risks can be relocated elsewhere along the EM coast if individual action is not

coordinated. From the classification of land use assessment, all areas within the respective land use that fall within the high-risk zone, the EM setback lines in conjunction with ecosystem-based adaptation should be implemented in order to protect these areas and ensure the functions of each land use is not unhindered. From the analysis of developments potentially impacted by future SLR, the total amount of estimated value of property loss within the given suburbs can assist coastal managers with deciding how money should be spent on defending properties and will yield the most protection from future SLR impacts along the EM coastline (i.e., a cost-analysis approach). Lastly, from the risk assessment of coastal ecosystems, future research on applying the vegetation index to certain parts of the EM coastline is necessary to get a better understanding of how vulnerable coastal ecosystems are to SLR impacts in Durban.

PREFACE

The experimental work described in this dissertation was carried out in the School of Agricultural, Earth & Environmental Sciences, University of Natal, Durban, from January 2020 to January 2022, under the supervision of Doctor Srinivasan Pillay, Doctor Andrew Mather and Doctor Sean O'Donoghue.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others it is duly acknowledged in the text.

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DECLARATION 1 - PLAGIARISM

I, …Carla Petersen…………………………. declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.

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ACRONYMS

%	per cent
°C	degrees Celsius
100HWM	a 'zone' or a 'strip' of land that extends landward for 100m as measured from the HWM
CAP	Climate Action Plan
CC	climate change
cm	centimetres
COL	cut-off low
CRDPs	climate-resilient development pathways
CVI	Coastal Vulnerability Index
CWG	Coastal Working Group
D'MOSS	Durban Metropolitan Open Space System
DCCS	Durban Climate Change Strategy
DDOP	Durban Dig-Out Port
DEA	Department of Environmental Affairs
DFFE	Department of Forestry, Fisheries and Environment
EDTEA	Department of Economic Development, Tourism and Environmental Affairs
EIA	Environmental Impact Assessment
EJ	environmental justice
EM	eThekwini Municipality
EMA	eThekwini Municipal Area
EMCCC	eThekwini Municipality Climate Change Committee

EPCPD	Environmental Planning and Climate Protection Department
ESL	extreme sea level
GHG	greenhouse gas
GMSL	global mean sea level
GMST	global mean surface temperature
GSCs	Geotextile sand-filled containers
HCCAS	Headline Climate Change Adaptation Strategy
HWM	high-water mark is the highest line reached by coastal waters; not as a result of abnormal floods or storms that occur maximum 1:10 years, or an estuary being closed to the sea
ICM	Integrated Coastal Management
IDP	Integrated Development Plan
km	kilometres
km^2	square kilometres
KZN	KwaZulu-Natal
LGCCSP	Local Government Climate Change Support Programme
m	metres
m^3	cubic metres
MCC	Municipal Coastal Committee
MCPP	Municipal Climate Protection Programme
mm	millimetres
NEMA	National Environmental Management Act
NFEPA	National Freshwater Ecosystem Priority Areas
NPAs	Natural Protected Areas
NPCC	New York Panel on Climate Change

PCC	Provincial Coastal Committee
R	Rands
RCP	Representative Concentration Pathways
SADC	Southern African Development Community
SANBI	South African National Biodiversity Institute
SDGs	Sustainable Development Goals
SLR	sea level rise
TTT	Technical Task Team
UNFCCC	United Nations Framework Convention on Climate Change
WWTP	Wastewater Treatment Plant

CHAPTER ONE: INTRODUCTION

1.1 Climate change and sea level rise

Sea level rise (SLR) is a key feature of climate change (Oppenheimer et al. 2019). Global mean sea level (GMSL) is increasing at an accelerating rate, with glaciers and sheets of ice melting, largely from Greenland and Antarctica, being the main source adding to this rise in sea level (IPCC 2019). Added to this rise in GMSL is ocean thermal expansion, which expands existing water volume, and over certain time scales is the main mechanism for SLR (Oliver-Smith 2009). Non-climatic human caused drivers, such as anthropogenic forcing, is the main cause of GMSL rise since 1970 (Oppenheimer et al. 2019). Nevertheless, it is essential to emphasize that, when speaking of SLR, it refers to annual GMSL and should not be confused with the water level changes during storms, storm surges, storm tides, autumn/spring high-tides, or erosional coastal retreat (Alves-da-Silva and Matlack-Klein 2019). These local phenomena are restricted in time and space and have nothing to do with GMSL or eustatic[1] sea level variability.

Sea level changes, due to natural and human caused alterations in the climate system, are happening on time and geographical (spatial) scales that pose a risk to cities along the coast and communities (Oppenheimer et al. 2019). Coastal megacities are characterised as dense concentrations of population and economic activities (such as production, consumption, and trade of goods and services), and society and built-up infrastructure have a high exposure to GMSL rise and extreme sea level (ESL) events (Meerow 2017). Durban's port is the busiest in sub-Saharan Africa (EM 2019). The city's population is 3.7 million people and a budget 50.8 billion Rands (R) (2019/20 financial year) of which R42.9 billion is operating budget and R7.9 billion is capital budget, making Durban one of the most significant urban and commercial centres in South Africa. If SLR impacts reduces the width of the coastline, there may be a reduction of economic income (i.e., the Gross Domestic Product) as both the port and tourism will be affected. Furthermore, unemployment rates will increase because both the port and the tourism market stimulate and supports high levels of job opportunities through manufacturing, sea trade and transport and tourism (EDTEA 2017).

Economic impacts of SLR can be reduced by an effective adaptation response. Responding to SLR requires taking plans and actions compliant with the appropriate legislation in order to lower risk and build resilience towards SLR (Oppenheimer et al. 2019). There are a range of responses, namely protection, advance, ecosystem-based adaptation, accommodation, and retreat, but it is not a simple task recognising the most suitable response to SLR due to the political and social contests accompanied by

1 Eustatic relates to changes in sea level on a global scale, as a result of ice sheets melting or the ocean floor moving.

a range of governance challenges/barriers arising. Therefore, governance plays a critical role in implementing effective climate adaptation (Abram et al. 2019). Governance, implemented through lawful and administrative processes, is vital to overcome the challenges and risks caused by climate change. Developing set back lines created with various SLR scenarios can enable the respective authorities/institutions to manage development in the coastal zone as well as prohibit any additional development in highly vulnerable/disaster-prone areas (Mather and Stretch 2012). Moreover, with the planned Durban Dig-Out Port (DDOP), for the decision making process, it is crucial to take into consideration climate change (CC) and SLR trends throughout the stages of retrofitting or port development to build resilience in relation to climate risk in ports (Mutumbo 2017).

Ecosystems situated within the coastal zone are extremely susceptible to drivers of climate change through human interference, such as coastal squeeze, changes and fragmentation in the land use type, and anthropogenic subsidence (i.e., sinking of the ground due to the removal of fluid substances such as gas, oil or groundwater from underground reservoirs), because they are situated in an area (sea-land interface) that is favourable for urbanisation and development (Mead et al. 2013). Natural ecosystems in the frontiers of coastal cities and surroundings have been misused for many years and in several instances completely destroyed (Oppenheimer et al. 2019). Coastal ecosystems are also exposed to SLR and associated physical impacts, such as salinisation or flooding, which in turn increase ecosystems' vulnerability and reduce their capacity to sustain livelihoods and deliver ecosystem services, for example coastal protection. Although the most densely populated areas of coastal cities benefit less in terms of receiving coastal protection provided by coastal ecosystems, the lower dense areas may benefit more and thus coastal ecosystems can be critically important for protecting such areas. In the Jamaica Bay/Rockaway sector of New York, for example, wetlands and sandy beaches protect nearby residential communities (Oppenheimer et al. 2019). Nonetheless, biodiversity plays a crucial role in delivering ecosystem services as well as for guaranteeing the resilience of functions and services from an ecosystem (van Wilgen et al. 2008).

This research focusses on induced SLR impacts on coastal ecosystems along the coastline of eThekwini Municipality (EM) as a consequence of CC. Ecosystems are essential to sustaining life for all living organisms because of the valuable ecosystem services in which they provide (e.g., provisioning, regulating, supporting and cultural services). Therefore, it is imperative that the ecosystem services provided by coastal ecosystems, including the storing and purifying of water, protecting a coastline and lowering the temperature in urban areas, are protected from SLR impacts as ecosystem services are viewed from an anthropogenic perspective, thus are important to people.

1.2 Aim and objectives

This research endeavour is aimed at assessing the areas of risk and the potential loss of coastal ecosystems and built infrastructure in relation to predicted climate change induced sea level rise along the eThekwini Municipality coastline.

The objectives are:

- To present existing modelled predictions of SLR.
- To identify and map areas along the Durban coastal zone where SLR impacts are the greatest. This will include the predetermined setback line as per the KZN-EDTEA (Economic Development, Tourism and Environmental Affairs) 100 meter (m) from the high-water mark (HWM), the EM's predictions of various scenarios of SLR (300, 600 and 1 000mm), the Coastal Vulnerability Index (CVI), as well as other available sources.
- To assess a coastal ecosystem within the existing modelled SLR scenarios that is at high risk and to provide recommendations that will aid or enhance resilience. To achieve this, the abundance, health status and susceptibility of a protected tree species, *Mimusops caffra* are assessed at two distinct zones along the EM coastline.
- To assess built (developed) areas at risk and evaluate the extent and amount of potential loss of infrastructure.
- To synthesize the information on thus derived and, provide information to assist decision making for the EM Coastal Management Line.

1.3 Study Area

The city of Durban is located in the KwaZulu-Natal (KZN) province on the east coast of South Africa and is the third largest municipality in the country (refer to Figure 1). The eThekwini Municipal Area (EMA) is 2,297 square kilometres (km^2) in size and an estimated two-thirds of this area is demarcated as rural or semi-rural. EM is the local government accountable for planning and overseeing the city. Durban is situated in the Maputo-Pondoland-Albany global biodiversity hotspot, which is one of 34 biodiversity hotspots throughout the world. This region is categorised by having significant levels of endemic species and loss of habitat (Roberts and O'Donoghue 2013).

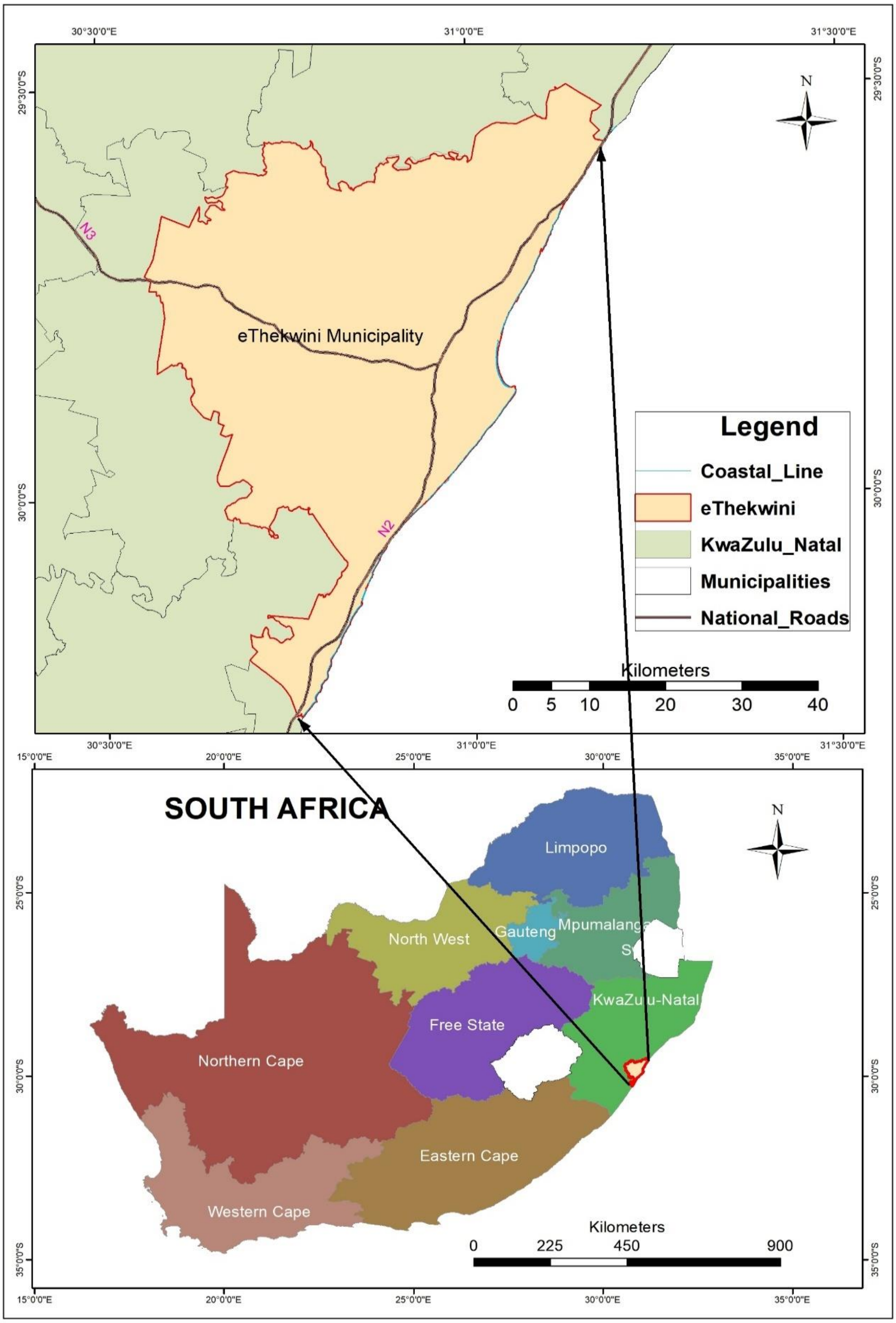

Figure 1: Map of eThekwini Municipality, its coastline and location within South Africa (drawn by Ballabh, 2020)

The 98 kilometres (km) stretch of coast in EM is perceived as a wealthy environmental asset, as it provides valuable economic, social and ecological opportunities, namely tourism, port activities in the Durban harbour, recreation, and the amenity value of property along the coast, which are all closely connected to the coastal and marine environment (EDTEA 2017). This, in turn, draws more people to reside within the coastal zone which adds to the economy but increases the demand for resources.

General climate of the region

KZN has a subtropical climate along its coast with rainfall during the summer season and high levels of humidity in the air. Durban has an average high and low summer and winter (respectively) temperatures of 32.6°C and 5.8°C (Cawthra et al. 2012). Approximately 1000mm of rain falls annually, often during storms which last for a short period of time (Bell and Maud 2000).

Aggregated rainfall in Durban is projected to increase by the year 2065 and with an increase of up to 500mm by the year 2100. Temperatures are expected to rise by between 1.5 and 2.5ºC by 2065 and by between 3 and 5ºC by 2100 (EM 2021). Along the EM coastline, SLR is currently rising at 2.7mm per year and the rate of SLR may accelerate in the years to come.

Vegetation characteristics

The coastal strip falls within the KZN Coastal Belt which was, historically before deforestation, likely mostly covered by subtropical coastal forest and of the remaining forest, only small patches are still present to date (Cawthra et al. 2012). Scrubby thornveld found inland, further away from the coast, has been replaced by sugarcane at large (Bell and Maud 2000).

Geology of the study area

The greater Durban region consists of various rock types, including the granites-gneisses found in the Basement Complex, the sandstones found in the Natal Group, the tillite found in the Dwyka Formation, and the shales and sandstones found in the Ecca Group. The rocks in the Ecca Group, specifically, have been widely encroached by dolerites (Bell and Maud 2000). Unconsolidated deposits occur mainly in the coastal zone and is of Quaternary age.

Within the coastal zone, the Bluff Formation consists of approximately 200m of cross-bedded calcarenite, which originates primarily from aeolian origin, and this sandstone is the parent material found in the Berea Formation (Bell and Maud 2000). This Formation shapes a portion of a coastal dune deposit superimposing the Ecca Group unconformably and the dunes were deposited towards the end of the marine regression during Tertiary age.

Topography and soils

The topography of the EMA varies from steep slopes/escarpments in the west to a fairly gentle gradient coastal plain moving eastwards (McDonald et al. 2004). The distribution of soil types is closely connected with the geology underneath them. Generally, thin soils develop above the sandstones (less than 1m in thickness on slopes located in the upper and middle regions, and between 2 and 4m on slopes located in the lower region and bottom of the valley) and are typically sandy in texture because of their porousness being fairly well drained under normal rates of infiltration (Bell and Maud 2000). However, high rates of infiltration, the little amount of clay and silt may hinder drainage, enabling quick saturation with a subsequent rise in the water table. Normally beneath the topsoil, an eluvial stratum of sand comprising of fine to medium sized granules with silt arises and is generally smaller than 1m in thickness and sandy clay of low permeability lies below it (Bell and Maud 2000).

Durban's beaches

Durban's sandy beaches make up an essential component of the KZN province's tourism potential which is an important economic activity (Mather 2007). Beaches in Durban are the most crucial tourist attraction in terms of income generation in the KZN province with 73 per cent (%) of domestic tourists visiting them. To accommodate tourists or residents visiting Durban's beaches, hotels and holiday homes have been built, predominantly along the shoreline, thus making it easier for tourists to access the beaches and its amenities. The coastline is a prime area for development and generating income, which is important for revenue generation for the city. In KZN, tourism within the coastal zone produces approximately R9 billion per annum (EDTEA 2017). The local tourism industry will adversely be impacted by SLR which will cause the expanse of beaches to reduce, and cause damage to coastal infrastructure, including those linked to tourism (Mather 2007).

The South African coastline is distinctly comprised of various coastal ecoregions that sustain a broad array of ecosystems at the coast. Along the eThekwini coastline, these include sandy beaches, coastal dunes, coastal forests, estuaries and lagoons, mangroves and wetlands, and coral reefs.

Coastal dunes

In northern KZN, a narrow belt of relatively pristine/undisturbed coastal dune forests is located between the sea and the hinterland, where it rarely stretches beyond 2km from the coast (Wiedemann and Pickart 2004). The dune forests of KZN are exposed to relatively high rainfall, therefore soil fertility may be limited due to the high leaching of soil minerals. Over many decades, the vegetation composition of dunes changed from forest to small scrub, attributing to human activities (e.g. agricultural and pastoral) which have a key impact on plant communities of coastal dunes in KZN (Wiedemann and Pickart 2004). Consequently, the national government adopted protective policies against human-induced disturbances (e.g., shifting cultivation and grazing, woodcutting, fire) which allowed a few of these native forests to recover. Recently, coastal dune forests have been fragmented because of the creation of exotic plantations for commercial use and by opencast dune mining with subsequent ecological restoration (Wiedemann and Pickart 2004). As a result, the significant fragmentation and transformation of the land severely compromised both species and ecosystems' ability to adapt and retreat to climate change (Govender 2013). For example, high levels of development on the beaches in Durban hinder the natural movement of dunes and as a result, severe damage is experienced along the coastline during extreme weather conditions (e.g., storm surges, increased wave intensity) and SLR which are expected to increase in frequency because of climate change.

Coastal forests

Coastal forests in EM cover the entire coastline on the gently sloping coastal plain from the dunes to approximately 580m above sea level (Turpie et al. 2017).

There are two species, namely *Mimusops caffra* (*M. caffra*), commonly known as Coastal red milkwood, and *Sideroxylon inerme* (white milkwood). *M. caffra* grows in dune forest from the high tide mark in KZN and is strictly a dune species (Mbambezeli 2006). It forms the majority of the coastal and dune forest and flourishes as far as the salty sea sprays. In Durban, they are found growing in abundance along roads to the north and south next to the coast. The National Forest Act of 1998 states that *M. caffra* is a protected tree species. Therefore, human activities for example cutting, removing or destroying of protected tree species are prohibited. Furthermore, products of protected trees may not be in the possession of individuals, transported, or used for transaction purposes (i.e., exporting, donating, purchasing or selling), unless the Department of Water Affairs and Forestry or a delegated authority has granted permission through the use of a license (Mbambezeli 2006). However, in KZN, *M. caffra* is used for timber as well as for building boats by locals (Mbambezeli 2006). The wood is also used in the framework of a fish trap that fishermen utilise.

Sideroxylon inerme grows from coastal dunes into bushveld and in littoral forests (forests along the seashore) and in KZN is far less threatened than *M. caffra* (Bosman 2006). However, it is one of South Africa's protected trees; therefore, they cannot be damaged, moved or chopped down. Bark and roots are used for medicinal purposes, the wood is used as timber for building boats, bridges and mills, and its fruits are a source of food (Bosman 2006).

This study will focus on *Mimusops caffra* because it is a highly threatened tree species in Durban and since it is a protected species, it should be under conservation. Furthermore, there is not much published literature on milkwood in Durban.

1.4 Outline of dissertation

Chapter One of this dissertation introduces CC and the repercussions of CC impacts, namely SLR, on coastal cities and coastal ecosystems, as well as what climate action needs to be taken to respond to SLR. It also highlights the motive for assessing CC related SLR impacts along the Durban coastline and the economic, social and ecological challenges the city may face if the width of the coastal stretch starts reducing through SLR impacts. Thereafter, it provides the aim and objectives of this research and concludes with a description of the study area. Chapter Two provides a detailed review of SLR, including the current SLR and projections on SLR for global, regional and local scales are discussed. Thereafter, the issue of SLR impacts on the EM coastline, and the current eThekwini Municipal strategy plans on coastal zone management that enforces the need to protect, conserve, manage and rehabilitate the coast, as well as actions taken to respond to SLR are also detailed (i.e., governance and legislation being on a national scale). A detailed review on the classification of coastal ecosystems along the EM coastline are discussed, and risk and vulnerability for these ecosystems will be framed according to international standards (i.e., the Intergovernmental Panel on Climate Change). Furthermore, quantifying the value of coastal ecosystems and the financial cost for rehabilitation methods will be discussed. Chapter Three provides a detailed description of the methodology adopted for this investigation. Chapter Four encompasses the results from the CVI Analysis, assessment of land use types and their relative value, the analyses of the potential loss of property, an assessment of risk on coastal ecosystems, and the analyses of the value of coastal ecosystem services. It also comprises the discussion on the findings of this research, followed by Chapter Five, the final chapter, which provides the recommendations and conclusions to the study.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of prior theory and research relevant to the study. The literature review also identifies assessment methods for climate change hazards related to SLR as well as dune rehabilitation methods along with its financial costs. Information garnered will be used to frame risk and vulnerability, establish rehabilitation approaches and determine the value of dunes and forest ecosystem services along the EM coastline.

2.2 Sea level rise projections

Global

The mean sea level at both global and regional scales will change as a result of climate change (Oppenheimer et al. 2019). Sea level refers to the average height of the surface of the sea over a long period, excluding fluctuations such as waves, tides and surges which occur over a short duration (Oppenheimer et al. 2019). Therefore, global mean sea level (GMSL) rise is an increase in the amount of water in the ocean produced by warmer water rising due to its lower density, and by the expansion in size affected by melting of ice on land or a total loss in water reservoirs situated on land (Oppenheimer et al. 2019).

By the year 2100, GMSL is projected to rise up to between 0.43m under Representative Concentration Pathways (RCP) 2.6 and 0.84m under RCP 8.5 relative to the 1986 – 2005 (recent past) baseline (IPCC 2019). From the mid-19th century, the rate of SLR has been greater than the average rate before this period (Abram et al. 2019). By the year 2100, the rate of SLR is projected to be 15 millimetres (mm) per year under RCP8.5 and could outpace more than a few centimetres (cm) per year in the 22nd century (IPCC 2019). The rate of SLR is projected to continue rising and at an accelerated rate as a result of glaciers and ice sheets melting, subsequently adding freshwater to the ocean, and because of ocean expansion due to constant ocean warming (Abram et al. 2019). The Greenland and Antarctica ice sheets hold majority of the freshwater on the surface of the Earth and are the main contributors that affect variations in the sea level (Oppenheimer et al. 2019).

Beyond 2100

By the end of the 21st century, the sea level will be higher than the present-day sea level and will continue to rise under all emission scenarios even if the Paris Agreement is followed by respective Parties. This is mainly due to the slow response of melting glacier, thermal expansion and ice sheet mass loss (Oppenheimer et al. 2019). These processes function on long time periods, meaning that although the increase in global temperature decelerates or the temperature starts decreasing, SLR will continue (Oppenheimer et al. 2019).

Beyond the 21st century, the contribution of glaciers to the rate of SLR will decline under RCP8.5 over the 22nd century (Oppenheimer et al. 2019). On the contrary, for thermal expansion, the steady rate of the ocean absorbing heat will lead to further SLR for many centuries (Oppenheimer et al. 2019). Nevertheless, the influence on SLR of the Greenland and Antarctica ice sheets has the most significant uncertainty on long time periods due to the timescale of response of ice sheets (i.e., many centuries) (Oppenheimer et al. 2019). Therefore, if ice sheets contribute considerably to sea level in the year 2100, ice sheets will inevitably also contribute to sea level in the periods to come (Oppenheimer et al. 2019). However, under a low emission scenario, such as RCP2.6, substantial ice loss can be prevented.

Beyond 2100, thermal expansion and melting of ice from both the Greenland and Antarctic ice sheets will continue (Oppenheimer et al. 2019). Over the next era, a complete loss of Greenland ice will contribute around 7m to global sea level if sustained global mean surface temperature (GMST) occurs between 1ºC and 4ºC above pre-industrial levels (Oppenheimer et al. 2019). Moreover, it is estimated that ice sheet from the Antarctic will contribute between 2.3 – 5.4m for RCP8.5 to sea level beyond 2100. High emission scenarios or complete use of fossil fuels over centuries may result in rates of SLR as high as a number of metres per century in the long term, and low emission scenarios result in a reduced contribution (Oppenheimer et al. 2019). Distinguishing between 1.5ºC and 2ºC scenarios in relation to long-term sea level change is not feasible due to having limited evidence. Therefore, it can be concluded that on extremely long-time scales such as millennial years, SLR is strongly reliant on the emission scenario followed. This, together with the uncertainty of the tipping points, underscores the importance of mitigating emissions to reduce the associated hazard to shorelines situated in low-lying areas.

Local

There has been a vast amount of work done on global climate change and the associated impacts arising in recent years. However, currently there is not enough research on climate change undertaken for Africa, as well as the southern and eastern African region, except for South Africa (Mather and Stretch 2012). There has been more research in South Africa as opposed to the rest of the countries in Africa, though Mozambique has started conversations and project-based work on SLR (Mather and Stretch 2012). In South Africa, there is a raised awareness and interest of climate change and SLR, which resulted in some government agencies commissioning the study of these areas. Studies of both SLR and the effects of climate change have been done in Durban and the Western Cape region, respectively (Mather and Stretch 2012). Furthermore, Durban, Cape Town, and Port Elizabeth, which are three key coastal cities of South Africa, have undertaken studies to recognise and deal with SLR impacts as a consequence of CC.

There is still ongoing debate on global SLR projections (i.e., projected rates and extent of global SLR in future), however there is consensus that the rate and magnitude of sea level will increase. Numerous countries have embraced SLR scenarios established on work done by the IPCC, particularly after 2007 (e.g. Germany and California) (Mather and Stretch 2012).

Recent regional sea level analysis has revealed that there is inconsistency in the rate of sea level change in southern Africa with almost all tide gauges showing a rise at 3.6mm per year, except for Zanzibar (Mather and Stretch 2012). Looking at this analysis together with the current IPCC projections, the Durban coastline may encounter SLR ranging from 0.3 meters (m) under RCP2.6 and 1m under RCP8.5 by the year 2100 (EM 2019). From the South African Navy's tide gauge, situated close to the harbour in Durban, tidal records show a linear increase in the level of the sea at Durban, with a rate of 2.7mm per year from 1970 (Mather 2007). For the east coast of South Africa, the rate of SLR is 2.74mm per year (Mather and Stretch 2012). To model the consequences of any SLR, various scenarios were selected and have been established as the following:

- Scenario 1: 300mm built on existing linear SLR
- Scenario 2: 600mm built on two times the existing SLR rate
- Scenario 3: 1 000mm built on an enhanced melting of ice situation.

The third scenario was incorporated due to current literature suggesting there is accelerated melting of ice.

The rate of SLR for Durban (i.e. 2.7mm per year) and its neighbouring shoreline is consistent with global research, grouping in a band between 2.4 – 3.2mm per year (Mather 2007). These results are vital because for the first time a measured rate of SLR on a local scale is provided and can be utilised for coastal management, strategic coastal planning, and future design in port infrastructure in Durban.

2.3 Risk and vulnerability along the eThekwini Municipality coastline

Risks and impacts are assessed stemming from variations in the ocean and cryosphere linked to climate (Abram et al. 2019). Understanding risk is important for creating and implementing adequate responses.

Risk is considered from effects related to climate change on the ocean and cryosphere by the interaction between environmental *hazards* caused by climate change, *exposure* of people, structures and ecosystems to those hazards, and *vulnerabilities* of natural and human (social) systems (Abram et al. 2019). Risk is described as the probability for adverse consequences, and impacts is described as the materialised/visible effects of climate change (Abram et al. 2019).

Hazards

Variations in the ocean and cryosphere put coastal populations at risk to hazards that affect people's well-being, including their health, security and safety. SLR or coastal erosion are some of the direct impacts that can displace coastal residents. Coastal areas are extremely dynamic as they are impacted by local natural and/or anthropogenic processes or deriving from both the ocean and land. Therefore, variations within the catchment can have acute consequences for areas in the coastal zone, specifically in sediment supply and pollution (Abram et al. 2019). In eThekwini Municipality (EM), the main source of beach sand originates from catchments inland with rivers transporting most of the sand from the bed load and a small amount of sand by suspended load (Turpie et al. 2017). However, the erection of dams and sand mining have reduced the supply of sand from catchments to the coast, with more than one third being trapped behind dams, while another third is being mined commercially for the construction industry (Theron et al. 2008). Not only does this contribute to beach erosion problems, the trapping of sediments in dams is costly, and the cost increases when sediment yields from the catchment are heightened by human activities (Turpie et al. 2017). In this instance, ecosystem services serve a purpose in reducing the potential amount of these costs as a result of growing human activity in catchments. Sedimentation problems are mainly associated with the three main water supply dams, namely Inanda, Hazelmere and Nungwane, and the Durban Harbour (Turpie et al. 2017). Moreover, the topography of EM is steep, therefore limiting drainage networks for sedimentation.

The coastal sediment budget is roughly estimated to be sand inputs from rivers and equally all other sand sources feeding the coast along the EM coastline (Theron et al. 2008). The actual total potential loss of sand, compared to estimated "natural" rates, is estimated to be about 300 000m^3 per year. Furthermore, the current combined effects of the dams and sand mining might cause an average coastal erosion greater than 1m per year (Theron et al. 2008). However, actual erosion is often quite variable and episodic which might be associated to extreme weather events.

Climate change and SLR are also indirectly threatening the coastal sediment budget on top of the current human activities such as dam trapping and sand mining (Theron et al. 2008). The combined impacts of SLR and more frequent sea storm events are expected to have serious consequences in terms of coastal erosion probably similar to the KwaZulu-Natal (KZN) 2007 storm event. Coastlines that have a surplus of sand supply/reserves could potentially accommodate the effects of projected moderate rates of SLR, having lower detrimental coastal erosion. However, coastlines with a deficit of sand supply are highly vulnerable to severe erosion (Theron et al. 2008). Furthermore, rainfall is predicted to decrease over parts of KZN as a consequence of climate change (Theron et al. 2008). As a result, reductions in KZN river runoff could potentially cause reductions in sediment yields to the coast. However, there is still uncertainty and requires further studies to better predict the expected impacts on KZN fluvial yields (Theron et al. 2008).

Besides human-induced effects and SLR contributing to erosion, different components of wave climate also cause erosion (Corbella and Stretch 2012a). For instance, a huge wave height lasting for a long period of time can cause erosion, as well as a rise in wave period can enhance erosion (Corbella and Stretch 2012a). The amount of time between each storm event does not inevitably affect the amount of sediment removed for the duration of a given storm event as a new equilibrium beach profile is established throughout the first storm and a following storm of the same or different wave energy will not wear down the profile anymore (Corbella and Stretch 2012a). The new equilibrium profile, however, does affect coastal developments' vulnerability as a storm event erodes a shoreline and decreases the natural barrier between the sea and the hinterland. This places urbanized coastlines at risk of experiencing acute damage from a storm event to follow, which may be less extreme, before the coastline has completely regained itself to its level before the storm (Corbella and Stretch 2012a).

Beaches with rocky outcrops and conservation of sand within the intervening rocky embayment, for example the first 3 kilometres (km) south of Cave Rock (south of the Durban Harbour along the coast, refer to Figures 2 and 3), and Nyoni Rocks (2km south of Amanzimtoti, refer to Figure 2) to Karridene (15km north of Umkomaas, refer to Figure 2), have no significant eroding or accreting long-term trend (Theron et al. 2008). On the contrary, beaches with steep slopes (e.g., Bluff) are susceptible to erosion as the high-water mark (HWM) recedes, therefore large volumes of sediment will be eroded. Sand that is transported by wind and deposited on the seaward side of dunes subject to occasional partial erosion during storm wave conditions, is returned into the marine sediment budget during such storm events. On the contrary, sand that is blown further inland and further away from any interaction with waves (e.g., into backshore dunes or areas where sand is removed by anthropogenic actions such as from car parks, etc.) is effectively lost to the marine sediment budget (Theron et al. 2008). This potential loss of sand is of relevance to coastal erosion and sand supply along the EM coastline.

Conservation areas which include habitats within the coast can perform significant roles in lowering risks associated to certain coastal hazards (Abram et al. 2019).

Exposure

Exposure to risk associated with climate change occurs for nearly every organism, habitation and ecosystem along the coast through various processes (Abram et al. 2019). Inundation and salinisation, due to rising sea levels, will affect the quality of water resources on the Earth's surface (e.g., estuaries, rivers, reservoirs, etc.) (Oppenheimer et al. 2019). This may result in restrictions in drinking water supply (i.e., National Freshwater Ecosystem Priority Areas wetlands in Durban), as well as to a shortage of freshwater in reservoirs for future use elsewhere (Oppenheimer et al. 2019). It is expected that intrusion of salt water into aquifers at the coast as well as waters and soils on the surface will be more frequent and encroach further inland (Oppenheimer et al. 2019). Communities which depend on fish may face profound consequences where habitat loss for several freshwater fish species are expected due to an increase in salinity levels, for example the Sibaya Forest community in Durban. The food security of many communities within the coastal zone, developing countries in low-latitude parts of the world in particular, is vulnerable to a shortage in the supply of food sourced from the ocean because these communities are heavily reliant on seafood to meet their basic nutritional necessities, and their food security is exposed to many hazards (Bindoff et al. 2019). Moreover, predicted decreases in both possible fish catches in tropical areas and in the quality of seafood will further enhance the risk of impacts on food security, and this risk being larger under high emission scenarios.

Along the coastline of southern Africa, the south-eastern region experiences cyclonic and other extreme weather events regularly which produce large wave events along the coastline (Mather and Stretch 2012). The March 2007 storm event along the KZN coastline, South Africa, Cyclone Gamede caused significant flooding and erosion. Infrastructural responses or management interventions were considered from assessments based on each locality along the coastline (Mather and Stretch 2012). More recently in April 2019, there was heavy rainfall and flooding over KZN, resulting in 71 deaths, over 1400 people displaced and an estimated damage of around USD 71 million (Bopape et al. 2021).

The level of protection provided by coastal ecosystems such as tidal wetlands, coral reefs and seagrasses have been well studied, specifically on how much of wave height can be reduced, and how much of wave energy can be attenuated (Oppenheimer et al. 2019). Coastal ecosystems with rich vegetation, particularly mangrove forests, salt marshes, and coral reefs, shield the coastline from erosion by reducing the impacts of storm events, as well as buffer the impacts of SLR, moderate-sized tsunamis and dissipate wave energy (Bindoff et al. 2019). The KZN coastline is protected by beaches, coastal dunes as well as rocky shorelines that afford a good measure of protection. The loss or degradation of these coastal ecosystems under climate change would, therefore, reduce the benefits to coastal communities of providing them with protection services, and therefore raise the risk of damage and mortality from hazards.

Vulnerability

Risks, both direct and indirect, to natural systems are affected by vulnerability to climate change as well as deteriorating ecosystem services. Non-climatic pressures (e.g., overfishing, coastal development, and pollution) also increase coastal ecosystems' vulnerability to climate-related changes (Abram et al. 2019). The vulnerability of ecosystems within the coast to SLR and associated coastal hazards varies across the type of coastal ecosystem (Oppenheimer et al. 2019). It is also dependent on human mediations (e.g., coastal squeeze, land use change and fragmentation) and degradation (e.g., pollution), as well as changes in climate (e.g., shifts in temperature and precipitation patterns). Furthermore, SLR, including flooding or salination, increase the vulnerability of ecosystems along the coast and decrease its capability to sustain livelihoods and deliver ecosystem services, mainly protection along the coastline. Therefore, pristine, varied and attached coastal ecosystems can aid in adaptation to SLR and its effects on a local scale (Oppenheimer et al. 2019).

Vulnerability is not spatially and temporally fixed, nor equally experienced. The vulnerabilities of persons, social groups, and populations to climate change is varied, and this suggests shifting societal and environmental conditions (Abram et al. 2019).

Along much of the South African coast, the topography and the site of existing developments puts certain developed areas at risk to the physical impacts of SLR in future by the year 2100 (Theron and Rossouw 2008). In EM, portions of the coastline are vulnerable to coastal erosion. As a result, current and future coastal management need to establish the most well-suited response to SLR (i.e., protect or retreat), taking into consideration the nature, value and lifespan of infrastructure, as well as the likely impact along the coastline if infrastructure is completely destroyed (Palmer et al. 2011).

Subsequently, a Coastal Vulnerability Index (CVI) was developed to assess the level of risk (i.e., ranking of five classes ranging from very low risk to very high) along the coastline and to identify how much of the coast falls within each class (Palmer et al. 2011). The CVI should inform management, therefore coastal risk assessment should make an effort to deal with social, ecological and economic circumstances by finding indicators and evaluating them relative to the CVI findings. This will establish what type of infrastructure (i.e., built-up or ecological) are within areas of very high CVI scores (Palmer et al. 2011). Basically, the information produced is entered into a decision support tool to assist with conveying this valuable information which is effective and user-friendly (Palmer et al. 2011).

Furthermore, vulnerable zones can be recognised for management in future centering on risk along the coastline. However, implications for management may arise in urban areas where there may be limited space for retreat or relocation or adaptation under future SLR scenarios, therefore management mediations should be meticulously planned by using the Coastal and Shoreline Management Plans (Palmer et al. 2011).

2.4 Climate change adaptation and resilience

Adaptation is defined as the process of natural or social systems changing to current or future climate and associated effects, with the intention to diminish harm or take advantage of beneficial opportunities (Abram et al. 2019). Climate change impacts on the ocean requires efficient and bold adaptation to facilitate climate-resilient development pathways (CRDPs) that reduce residual risk (i.e., the risk that is experienced after implementing adaptation and risk reduction efforts), and loss and damage.

Ahead of mitigation, adaptation is a crucial path to lower risk. Appropriately chosen human interventions can enhance natural systems’ ability to change to climate change (Abram et al. 2019). Adaptive responses such as nature- and ecosystem-based approaches are social adaptation choices for impacts of climate change on the ocean and cryosphere (Abram et al. 2019). Such mediations, through influencing an ecosystem’s physical or operational properties, for example restoring ecosystems, may reduce climate change stresses, improve natural resilience and/or re-direct responses of an ecosystem to decrease cascading risks on people (Abram et al. 2019). Other social-based methods for human beings to adapt vary from community-based and infrastructure-based methods to managed retreat, as well as additional types of internal migration. The literature on SLR responses has grown significantly, particularly the four main modes (protect, advance, accommodate and retreat) of adaptation to mean and extreme SLR (Oppenheimer et al. 2019). Most adaptation responses to impacts and risks along the coast that have been employed worldwide use a reactive approach to actual coastal risk or experienced disasters (Oppenheimer et al. 2019). The northwest region in Europe, East Asia, and around many cities and deltas along the coastline commonly use dykes, surge barriers, embankments, and sea walls as hard coastal protection measures provide risk-based levels of safety (Oppenheimer et al. 2019). Ecosystem-based adaptation is growing in recognition across the world, because of the multiple co-benefits provided, however its cost and long-term effectiveness is still uncertain (Oppenheimer et al. 2019). There is inadequate proof and low consensus on the costs of ecosystem-based methods to make general applicable approximations of the unit costs across substantial spatial scales. The efficacy differs substantially depending on weather conditions (storm), ecosystem type and landscape parameters, which becomes challenging to produce the physical and financial benefits across topographies (Oppenheimer et al. 2019). Advance, which is defined as the creation of new land by way of constructing into the ocean (e.g., land reclamation), is often practiced in areas that have dense coastal populations although there are limitations to using this approach. Accommodation procedures, for example early warning systems for extreme sea storm events, are also a common practice used throughout the world (Oppenheimer et al. 2019). Early Warning Systems are often integrated into overall risk reduction approaches and are employed for several hazards along the coast for instance tsunamis in areas along the coastline of Indonesia and hydro-meteorological coastal hazards in Uruguay and Bangladesh (Oppenheimer et al. 2019). Lastly, retreat is still being experimented on but largely limited to small size communities or conducted with the intention of producing new habitation. In Europe, managed realignment carried out with aims of creating new habitat, enhanced the management of flood risk and there is an increase in more inexpensive coastal protection, but on small-scale projects and areas that have few people (Oppenheimer et al. 2019). In Germany and the United Kingdom, most of the projects focusing on managed realignment have been carried out for the purpose of producing new habitation and to cut spending on coastal defences (Oppenheimer et al. 2019). Proactive coastal relocation (e.g., repositioning of properties and infrastructures that are extremely near to the coastline) is anticipated to perform a significant role in reducing risk under all SLR scenarios (Oppenheimer et al. 2019). This can offset the increasing magnitude of flooding and associated damages along the coast.

In EM, the Municipal Climate Protection Programme (MCPP) and the Headline Climate Change Adaptation Strategy (HCCAS) identified important sectors in the municipality likely to be affected by climate change, and recommended suitable and feasible adaptation responses (Roberts 2010). The coastal zone, biodiversity and disaster risk reduction were part of the sectors reviewed in this process. Currently, adaptation response to SLR and coastal hazards in EM is to shield and reposition municipal infrastructure that exists today currently in areas of high-risk along the coastline (EM 2019).

Adaptation options that include mitigation strategies are most effective for ongoing climate change because of limitations to effective adaptation. Insufficient global mitigation action will increase adaptation effort that is required (and cost), and certain measures of adaptation may increase greenhouse gas (GHG) emissions (Abram et al. 2019). There are limits to adaptation and barriers to adaptation which are different from each other, but limits to adaption are occasionally regarded as barriers to adaptation. In theory, barriers can be overcome if there is available adaptive capacity (e.g., where grant or financial support is made accessible), although conquering barriers is often challenging, especially for communities and countries that have limited resources (Abram et al. 2019).

Adaptation efforts reduce present and future risk (Abram et al. 2019). Addressing the different components of risk (exposure, vulnerability and hazards) includes evaluating and identifying options for policy and action which includes assessment of the effectiveness and approval of actions. Adaptation responses are highly efficient when they support resilience to climate change, regard credible futures and black swan events, improve fundamental or required characteristics as well as values and/or make modifications of the responding system to prevent unsustainable pathways (Abram et al. 2019).

Already coastal ecosystems are being impacted by SLR in conjunction with other changes in the ocean linked to climate and harmful effects from anthropogenic activities within the coast and inland (Oppenheimer et al. 2019). However, there is still a challenge attributing such impacts to SLR because of the impact of other drivers related to both climate and non-climate, for example developing infrastructure and degrading habitat caused by humans) (Oppenheimer et al. 2019).

Dunes with vegetation and sandy beaches, are ecosystems along the coast that can build vertically and develop towards the shore in response to SLR, but their ability differs across locations (Oppenheimer et al. 2019). Changes at the scale of a catchment have direct impacts on the coastline, specifically on both water and sediment budgets. If changes are rapid, it can alter coastlines over quick time scales, surpassing the effects of SLR, thus resulting in enhanced exposure and vulnerability of social-ecological systems (Oppenheimer et al. 2019). Management of processes within catchments can reduce exposure and vulnerability. In addition to influences from the hinterland, coastal squeeze reduces the barrier zone between the ocean and infrastructure behind the habitation along the shoreline, and as a result increases coastal exposure as well as vulnerability (Oppenheimer et al. 2019). Coastal ecosystems increasingly become unable to deliver regulating services relating to coastal hazards, including playing a role as a coastal defence barrier against SLR and its physical impacts (Oppenheimer et al. 2019). Vulnerability is also augmented if saltwater enters freshwater resources, mainly those freshwater resources which are already scarce. The exposure and vulnerability of communities living along the coast is intensified by the loss of other coastal ecosystem services, which is especially problematic for communities which depend on the coast (Oppenheimer et al. 2019).

Climate change impacts on ecosystems differ in regions and timescales (Abram et al. 2019). The variety of pressures these ecosystems come into contact with hinders acknowledgement of people or ecosystem responses to a particular change in the ocean and/or cryosphere (Abram et al. 2019). Moreover, the connection between populations within ecosystems indicates that a population's adaptive response, or the connection between populations of an ecosystem and their adaptive responses, is not only influenced by direct climate change pressures but happens together with other species' adaptive responses in the ecosystem, thus further confounding efforts to distinguish exact trends of adaptation (Abram et al. 2019).

Decisions made for adaptation and mitigation relate to financial concerns. The two chief financial approaches used are the Total Economic Value method and the valuation of ecosystem services (Abram et al. 2019). Total Economic Value method deems the model of sustainable development in connection to the relationships between climate change impacts on ecosystem services and the effects on Sustainable Development Goals (SDGs), including food security or poverty eradication. The valuation of ecosystem services, on the other hand, uses formal decision analysis methods which aid in recognising options or alternatives that work best with respects to particular objectives (Abram et al. 2019). These formal decision analysis methods involve cost-benefit analysis, multi-criteria evaluation and vigorous decision-making and are particularly pertinent for evaluating decisions for long-term investment in the framework of coastal adaptation (Abram et al. 2019).

Building resilience

Resilience is the ability of social, economic and ecological systems working together to manage with disruptions or shocks to the systems by adjusting in manners that preserve their fundamental function, structure, and identity (Abram et al. 2019). Addressing risk associated to climate change, impacts such as severe events and shocks, and trade-offs together with influencing the pathways of each system is aided by bearing in mind resilience.

Building the capacity/ability of a social-ecological system, through employing the theory of resilience in adaptation and mitigation planning, can help such a system to work through projected changes in climate and unexpected weather events (Abram et al. 2019). Resilience also emphasises the dynamics of a social-ecological system such as the probability of crossing crucial limits and undergoing a regime shift (i.e., a change in the system's current state). The theory of resilience also lets analysts, risk accessors and decision makers to identify how risks related to climate change often cannot be completely prevented or lessened even with adaptation (Abram et al. 2019).

There are ongoing efforts applying resilience thinking in evaluations, management procedures, policy making and the daily habits of affected sectors and local communities in the Pacific small island developing states, the Philippines and Arctic Alaska (Abram et al. 2019). Considering the resilience concept is vital for allowing CRDPs (Abram et al. 2019).

2.5 Classification/characteristics of coastal ecosystems along the eThekwini Municipality coastline

Coastal ecosystems are extremely vulnerable to human-mediated drivers of climate change as these ecosystems are situated in an area (sea-land interface) that is favourable for urbanisation and development (Mead et al. 2013). The South African coastline is distinctly comprised of various coastal ecoregions that support wide-ranging coastal ecosystems (Mead et al. 2013). Along the EM coastline, these include sandy beaches, coastal dunes, coastal forests, estuaries and lagoons, mangroves and wetlands, and coral reefs.

Coastal dunes

In South Africa, coastal dunes have been classified into four vegetation zones, one of these being coastal dune forests (Wiedemann and Pickart 2004). Relatively pristine/undisturbed coastal dune forests form a narrow belt between the ocean and the hinterland where it rarely reaches beyond 2km from the coastline in northern KZN. The dune forests of KZN are situated on Pleistocene and Recent sands and are exposed to moderately high rainfall, therefore high level of leaching of soil minerals may reduce the fertility of soil (Wiedemann and Pickart 2004). Over many decades, the vegetation composition of dunes changed from forest to small scrub, owing to human activities (e.g., agricultural and pastoral) which have a key influence on plant communities on dunes along the KZN coastline (Wiedemann and Pickart 2004). Consequently, the Department of Forestry (which is the previous name) adopted protective policies against fire, cutting of wood, shifting cultivation and grazing which caused some of these indigenous forests to recover. In recent times, coastal dune forests have been disintegrated due to establishing commercial exotic plantations as well as opencast dune mining proceeded with ecological rehabilitation (Wiedemann and Pickart 2004). The removal of human-induced disturbances typically introduces habitat variations in vegetation structure and form because of successional procedures which provides temporary habitats for wildlife to colonise the coastal dunes herein (Wiedemann and Pickart 2004).

Coastal dunes provide for a fairly high-level of diversity of vertebrates which may be attributed to the narrowness of coastal dunes, letting vertebrates from adjacent habitats open entry to additional resources (i.e., food and shelter) (Wiedemann and Pickart 2004). Coastal dunes are also fairly young, geologically, and therefore have not had enough time for the evolutionary growth of rare species or subspecies, thus having limited endemism (Wiedemann and Pickart 2004).

Dunes adjoined by sandy beaches comprise roughly 80 per cent (%) of the coastline in South Africa and both dunes and beaches create a shielding natural barrier and protect the entire resources and developments situated inland from the immediate effect of wave and wind energy (Olivier and Garland 2003). Dunes keep sand accumulated during calm weather conditions with low wind speeds, and only release sand under stormy conditions. This, in turn, offers a “wall of protection” to secondary dunes and other landward structures under erosive environments and provides substance to replace the beaches under favourable circumstances (Olivier and Garland 2003).

Coastal forests

In EM, coastal forests cover the entire coastline on the coastal plain, extending from the dunes to around 580m above sea level (Turpie et al. 2017). In the northern region of EM, the coastal forest is comprised of two forest types, namely the KZN Coastal Forest and KZN Dune Forest. The latter is found predominantly along the edge of the dunes further than the salt spray zone (Turpie et al. 2017). However, the KZN Dune Forest has become highly fragmented due to coastal development pressures and is classified as Critically Endangered (Turpie et al. 2017). Most of the remaining portion of the Dune Forest area sits in formal development plans (e.g., residential, open space and utility), non-planning farming areas and traditional authority areas which may lead to contested discussions on use and ownership of land (i.e., development or protected areas) (Turpie et al. 2017). In EM, a very small portion (2%) of Dune Forest is officially protected in the Umhlanga Lagoon Nature Reserve and Beachwood Mangroves Nature Reserve (Turpie et al. 2017). Of the remaining untransformed/pristine KZN Coastal Forest, the majority of the land also sits in formal planning scheme areas, however only 1% of the Coastal Forest is officially protected in the Happy Valley Nature Reserve (Turpie et al. 2017).

Mimusops caffra, commonly known as Coastal Red Milkwood, grow in dense thickets along the South African coast which makes them one of the few trees that are tolerant to soil salinity and wind-borne salt; however, they may experience moderate to severe salt and wind injury during extreme weather events, for instance a storm surge (Bezona et al. 2009). The majority of the Milkwoods that remain along the coastline of EM thrive within the remaining intact Admiralty Reserve. Admiralty Reserves are strips of land, more than 60m wide, adjoining the landward side of the HWM. The Admiralty Reserves were reserved for the government in their original deeds of grant (Freedman 2006).

The Milkwood is a protected species in South Africa; therefore, they cannot be damaged, moved or cut down, yet they are threatened by unsustainable urbanisation practices (Jami et al. 2018). Unfortunately, Milkwoods sit within prime real estate land and are at most threat from developments. The Admiralty Reserve is what buffers the coastline against extreme weather events, but it is in the way of a great sea view (Freedman 2006). Private landowners clear parts of the bush to open up the view and in the process unearth some very old Milkwoods. A major issue is that people have limited understanding of protected tree species and are probably not aware of the existing Admiralty Reserve.

Sandy beaches

The KZN coastline comprises of sediments with coarse granules and sandy intermediate beaches (Smith et al. 2010). The coast mostly experiences large southerly swells, mostly generated by cold fronts coming from the west with low pressure systems sweeping over to the south of southern Africa (Smith et al. 2010). Large swells commonly occur in the KZN Bight[2] during mid-winter storms. Swells associated with mid-winter storms usually come from the south and southwest, but once in shallower water they change course and approach the shore from a south-southeast direction (Smith et al. 2010). The coastline at KZN is also affected by easterly to south-east swells coupled with cut-off low (COL) storms and tropical cyclones (Smith et al. 2010). Sandy coastlines, combined with the dominance of high-energy waves and swells and 2m diurnal tidal cycle during spring tides only make the coast highly susceptible to coastal erosion, which is exacerbated by SLR and increasing storm frequency (Smith et al. 2010).

Biodiversity areas

The EM has identified key regions for ecosystem services provision, known as 'ecosystem service hotspots', of which these areas provide 13 ecosystem services and in 2012, the Environmental Planning and Climate Protection Department (EPCPD) commissioned the mapping of those ecosystem services (Rouget et al. 2016). An assessment was carried out and areas with conservation importance relative to the eThekwini Municipality Draft Systematic Conservation Plan (2012b) were identified. These areas are classified: crucial biodiversity areas, conservation areas and portion of the Durban Metropolitan Open Space System (D'MOSS) (Rouget et al. 2016).

Crucial biodiversity areas are areas of great conservation importance, and include terrestrial, estuarine and freshwater crucial biodiversity areas (Rouget et al. 2016). Conservation areas consist of territory that has been formally/legally protected for conservation objectives, including proclaimed areas, municipal and state-owned land, and private nature reserves, where circumstances have been obligatory by the title deed such as a servitude. These methods of protection were mainly established by the EPCPD as a way of acquiring D'MOSS (Rouget et al. 2016).

Conservancies

Land owned by the State comprises of almost 9175 hectares which is 4% of the municipal area (Rouget et al. 2016). Ezemvelo KZN Wildlife is the legal nature conservation organisation delegated to protect and manage natural resources and biodiversity respectively as well as enforce and implement both national and provincial laws pertaining to conservation in the KZN province (Rouget et al. 2016). This

[2] A bight is a concave bend in the shoreline of an open coast that forms a wide, open bay.

organisation oversees six officially declared nature reserves which falls under parts of the land owned by the State in the municipal district.

In the coastal zone, areas that are under management are often restricted by the high water mark, low water mark, or allocated land in the coastal zone (i.e., marine vs. terrestrial) which generally is managed by different government institutions with their respective legalities and stakeholder groups (Harris et al. 2019). Therefore, these independent planning and governance processes for both terrestrial and marine do not consider the importance of connectivity and bidirectional ecological methods and movements throughout the coastal zone which is vital for the resilience and perseverance of an ecosystem (Harris et al. 2019).

A study by Harris et al. (2019) developed a theoretical context for demarcating the types of ecosystem within the coastal zone to assist with conservation planning and assessment which is of global relevance. Furthermore, the framework was applied to the South African coast to exemplify the importance for coastal conservation and management.

2.6 Risk assessment of coastal ecosystems

Durban's coastline is predominantly sandy and is susceptible to coastal erosion through the impacts of SLR and storm events because of climate change, along with human-induced factors such as sand mining in catchments and/or rivers, and potentially coastal squeeze (Mather and Stretch 2012).

Risk assessment techniques have been developed and improved during the last decades considering several variables like stability and characteristics of the beach, geo-indicators, susceptibility to SLR, and physical and human indicators (Sousa et al. 2011).

The word "indicator" is described as a parameter or a value derived from certain observations or measurements that can be utilised to illustrate a situation and evaluate fluctuations and trends throughout a period (Li Chang et al. 2022). Previously, indicators were used as a tool for describing the environmental condition and recently, coastal indicators were developed to be used as tools for strengthening coastal management, with a focus on encouraging the communication between researchers of the coastal environment and coastal managers in applying science (Carapuço et al. 2016).

Indicators ought to share a set of essential attributes to present a simple way to explain intricate data and information between various groups (Carapuço et al. 2016). Indicators should be SMART-based (specific, measurable, achievable, relevant and time-bound) which implies that an indicator should be clearly defined, quantifiable in qualitative or quantitative terms, depend on methods (implementation and collection) that are attainable with accessible resources and wealth of knowledge, be relevant for the current issue and lastly to be sensitive to changes within policy timeframes and deliver information on time (David and Rudolf 2008). SMART indicators perform a major role in management strategies based on result and are the most appropriate to guarantee that they are comparable.

A conventional framework on coastal geo-indicators for sandy coastal environments has been undertaken (Carapuço et al. 2016). The geo-indicators are divided into sandy environments (in general), beaches, coastal dunes and coastal barriers which are further subdivided into more detailed environmental descriptions. The indicators address key issues relating to coastal protection and risk assessment, and therefore stresses the significance of coastal indicators in delivering valuable information for coastal management (Carapuço et al. 2016).

2.7 Prior studies of dune and beach rehabilitation along the EM coastline

For this study, a preliminary assessment on dune rehabilitation methods conducted previously is discussed below. Scholarly articles on dune rehabilitation methods carried out in EM were reviewed. A literature survey on both soft engineering methods and hard engineering methods was done for the purpose of providing a rationale as to which method would be the most suitable/appropriate to carry out along the coastline in future. This study provides recommendations on dune rehabilitation methods that are site-specific, as well as have the least impact on the environment.

The total value of sandy beaches in Durban was estimated around 5.13 billion Rands (R) per annum in 2008 (Theron et al. 2008). In terms of insurance, sand helps to alleviate damage to infrastructure and properties during severe storm events by acting as a buffer against wave action. However, the ability of sand to provide storm protection services is dependent on the volume of sand, as well as the severity of the storm event at the time the event takes place (Theron et al. 2008). Wider beaches contain more sand and can therefore reduce the impact of coastal erosion. Consequently, the cost on damages to infrastructure and property value is reduced (Theron et al. 2008).

The transport rate of longshore sediment moving in the north direction along the Bluff coastline, south of Cave Rock, is estimated to move between 450 000 to 650 000m^3 amount of sand per year (Theron et al. 2008). The potential longshore sediment transport rate associated to wave energy is higher. In previous years, the average annual dredging rate was approximately 460 000m^3 per year (Theron et al. 2008). If the mean annual dredging rate declines with a continuous trend, combined with the impacts of dams and river sand mining, beaches in the Bight area will have serious consequences due to these beaches having insufficient sand (less than 250 000m^3 per year) available to maintain and prevent these beaches from progressive coastal erosion (Theron et al. 2008). Additionally, projected climate change impacts will exacerbate coastal recession and therefore accelerate the onset of such erosion problems.

Soft engineering methods

Historically, Durban undertook substantial beach monitoring of beach profiles as well as a sand bypass scheme (Corbella and Stretch 2012b). The Durban Bight beach experienced significant alterations by implementing a sand-bypassing scheme at the entrance of the Durban harbour to offset for the loss of sand moving from the south towards the north, because of the building of the southern sea wall at the

Durban harbour (Rautenbach and Theron 2018). In 2008, the then KZN Department of Agriculture and Environmental Affairs issued a guideline document which focuses on a best practice guide on a short-term base using a combination of techniques and schemes (i.e., both hard and soft engineering techniques as well as managed retreat) to mitigate coastal erosion (Breetzke and Mather 2013). The preferred soft engineering solution proposed included constructing a berm using geofabric sandbags of suitable weight and should be, at most, the height of the original frontal dune, placed at an angle of between 18 and 24 degrees (Breetzke and Mather 2013). This berm was planned to be covered with sand and planted with appropriate dune vegetation as was found in the original natural zones. In some cases, extra protection to be made of gabion baskets filled with sandbags was proposed for the purpose of protecting the toe of the berm created. Then, this method of defence was thought to be cost-effective compared with hard protection methods (Breetzke and Mather 2013). Although recognising that this method would need constant maintenance, it was believed to be efficient in enhancing slope stability, dissipating wave energy, and supporting the uninterrupted natural coastal processes and beach amenities (Breetzke and Mather 2013).

In 2012, a review of Durban's coastal defences was undertaken and approximately 20 000 geotextile units with a total cost estimated at R70 million was installed along the entire coastline (Breetzke and Mather 2013). Geotextile sand-filled containers (GSCs) are a cost-effective approach and are perfect for using for emergency work because they can easily be transported and removed if required, however the containers left permanently are prone to vandalism (Corbella and Stretch 2012b). When GSCs are used for the purpose to defend dunes, they must permanently be covered with sand to safeguard the containers from vandals and to re-establish a natural look to the coast, as well as constantly be vegetated to alleviate blown sediment and stabilise the backshore geomorphology (Corbella and Stretch 2012b).

Beach nourishment, generally, is supplying sand to beaches from offshore dredging and from an environmental perspective, it is the preferred method of protecting the coastline (Corbella and Stretch 2012b). Compared with other measures of coastal protection, beach nourishment is a cheaper method to employ, however the cost to not see a visible result is expensive. For instance, there is reassurance where taxpayers see their money being invested in a seawall that can be seen versus huge piles of sand left simply offshore. Therefore, it is particularly important to not starve a coast (Corbella and Stretch 2012b).

Studies on global and local scales prove that soft protection measures for example beach nourishment is cheaply useful in zones of concentrated tourism growth because of the huge profits produced within the tourism sector (Oppenheimer et al. 2019).

Beach nourishment and seawalls made up of geotextile sandbags are the preferred soft engineering methods to be implemented together with coastal setback lines for protection along the EM coastline (Corbella and Stretch 2012b).

Hard engineering methods

Groynes assist with stabilising the shore by interrupting the natural flow of sediment to allow for accretion (Corbella and Stretch 2012b). Groynes coupled with the sand bypass scheme has been successful in sustaining a steady coast along the EM coastline. However, they are a costly investment and are often complicated to build (Corbella and Stretch 2012b). Inappropriate design can potentially intensify erosion and therefore, the protection services provided is reduced. For example, during the 2007 storm event where the poor design in groynes structure failed to protect the promenade and caused damages to the adjacent commercial node along the Durban coastline (Corbella and Stretch 2012b). It is not anticipated that groynes will entirely avoid damage under such extreme events, however they can successfully reduce the impacts by acting as a barrier between the promenade and the sea.

Retaining walls are different from seawalls in the coastal context (Corbella and Stretch 2012b). In the city of Durban, a substantial amount of dry-stacking and interwoven retaining walls, made up of Loffelstein™ walls, have been utilized improperly or have progressed into an unsuitable situation as a consequence of chronic erosion at Brighton Beach, Umhlanga and Umdloti (Corbella and Stretch 2012b). Essentially, Loffelstein™ walls are structures that are built at the backshore with the intention of coastal retention and not to endure direct wave action (Corbella and Stretch 2012b). Therefore, it would not be appropriate to install Loffelstein™ walls in areas exposed to frequent extreme wave run-up, such as in Umhlanga and Umdloti.

Seawalls are the most popular method used for coastal protection and residents often considered it the most desired physical wall/barrier between the land and ocean (Corbella and Stretch 2012b). Unfortunately, seawalls can create a coastline that is static and are one of the least appropriate solutions from an environmental perspective. Seawalls potentially develop rigid barriers, thus affecting and altering coastal processes (Schoonees et al. 2019). They often cause increased wave reflection, which may result in scour. This makes seawalls, especially concrete ones, likely to cause coastal erosion (i.e., loss in sediments) and in turn to structural instabilities. Seawalls with concrete armour units can provide long-term protection (up to 100 years) as opposed to sand-filled bag seawalls which can provide short-term protection (up to 5 years); however, these structures often cause a sudden shift in ecological balances at the site (Schoonees et al. 2019).

Even though Loffelstein™ walls are not a propitious solution, portions of the walls that had not broken under extreme events were deemed more efficient to maintain, particularly as an endless wall (Corbella and Stretch 2012b). However, walls that were badly damaged were substituted with geotextile sandbags.

2.8 Legislation on coastal zone management

International

The United Nations Framework Convention on Climate Change (UNFCCC) deals with coastal adaptation working with countries across the world to promote and collaborate in planning for adaptation to impacts of climate change (Stephens 2013). Coastal adaptation includes conserving and restoring ecosystems, as well as developing and expanding suitable and integrated schemes for management in the coastal zone.

The UNFCCC recognises the threat of SLR to coastlines, specifically on small island countries and countries with coastal areas lying in low elevation zones (below 10m), as well as the importance of marine ecosystems in connection with the ecosystem they provide, however, it only mentions their importance as carbon sinks instead of their protection service (Stephens 2013).

The international legal framework for climate change adaptation in coastal and marine environments focuses on adaptive polices that can enable a social-ecological system to cope to rising sea levels (Stephens 2013). Furthermore, coastal cities are urged to protect their power in littoral areas, either by implementing coastal defence measures and land reclamation, or through technical legal responses to SLR.

Throughout the world, countries agreeing to the Sustainable Development Goal for the ocean and coast is essential for sustainable ocean governance as well as achieving sustainable ocean management (Visbeck et al. 2014).

National

The National Climate Change Response White Paper is a national policy for climate change of the South African government's response to global warming, with a focus on aiding in the equilibrium of GHG emissions and intervening in existing practices which are harmful to the environment (Parramon-Gurney and Gilder 2012). It defines the country’s vision of efficient climate change response across all timeframes (i.e., short-, medium- and long-term) and of the shift towards an economy and society that produces less carbon.

The National Adaptation Strategy for South Africa aims to decrease vulnerability to the impacts of climate change by way of enhancing resilience and adaptive capacity, help with the incorporation of climate change adaptation into suitable new and current strategies and work programmes (i.e., development scheme procedures and policies within all applicable sectors), enhance consistency of policy between sectors to achieve adaptation outcomes that support development aspirations, facilitate the incorporation of adaptation strategies into key sector plans, as well as for the adaptation responses that need harmonization between sectors, provinces and local government (Mbanjwa 2014).

The Southern African Development Community (SADC) Regional Disaster Preparedness and Response Strategy, which is in line with the Sendai Framework, was developed in November 2016 as a sign of commitment by South Africa and other SADC countries (EPCPD 2019). The Disaster Management Amendment Act 16 of 2015 also puts importance on resilience and risk reduction as a result of ecosystem and community-based adaptation. Section 53 of the Act stipulates a solid directive to cities to carry out risk and vulnerability assessments, expand adaptation plans and assign a financial plan for adaptation programmes (EPCPD 2019).

The Integrated Coastal Management (ICM) Act of South Africa (Act No. 24 of 2008) mostly resembles the National Climate Change Response White Paper where it aims to ascertain the coastal zone of South Africa, offer coordinated and integrated coastal zone management in the context of cooperative governance aligning with the principles of the National Environmental Management Act (NEMA), conserve, defend, increase the range and improve the status of State-owned coastal public buildings and infrastructure in the best interests of all South African citizens and next generations, offer fair entry to coastal public property and give effect to the country's commitments in terms of international legislation concerning coastal management and the marine environment (Amra 2015). In the National Climate Change Response White Paper, in Goal B.4, the state is the legal custodian who is responsible for all coastal assets on behalf of South Africans (Freedman 2006). The state must hold ownership of coastal waters and seashore and must ensure effective management of these spaces, including public land along the seashore, thus reiterates the international legally binding obligation in the UNFCCC (Freedman 2006).

South Africa is a co-signatory to the Paris Agreement and has a set of Nationally Determined Contributions to make towards addressing climate change globally. The South African government will maintain meaningful engagement in the current debates to further support and improve the international response to the climate change crisis (Parramon-Gurney and Gilder 2012).

Local

The Durban Climate Change Strategy (DCCS) was established after Durban hosted the UNFCCC COP17 in 2011, which raised awareness among residents, sector leaders and city officials, and secured political champions to lead the development of Durban's climate change work programmes (EPCPD 2019). The DCCS, which was approved by the EM council in 2015, outlines a city-wide method to integrating climate change mitigation and adaptation responses into city functions and operations.

The Durban Climate Action Plan (CAP), which was built on the 2015 DCCS, is a city-wide plan that gives a trajectory to shift the city in the direction of climate resilience and becoming carbon neutral by the year 2050, while ensuring inclusivity (EM 2019). The significance of climate change adaptation policies and inclusivity echo greatly in the CAP because the city recognises the unique challenges committing to the Paris Agreement of restricting temperature increase to 1.5°C shows to municipalities in the global south. The CAP will facilitate Durban to deal with its climate needs and other vital SDGs priorities, particularly those focusing on social and environmental needs (EM 2019).

Climate change, resilience and sustainable development work in EM is guided by international agreements reached by the United Nations (EM 2019).

2.9 Governance and Institutions

Governance is defined as the way in which systems (political, social, economic and environmental) and their relationships are ruled or handled through decision making, overseeing, executing and monitoring policies in light of changes in the ocean and cryosphere (Abram et al. 2019). Governance directs how various actors discuss their concerns and share their roles and duties. Institutional and organisational arrangements are established and modified to bring order in social processes, lessen conflicts and recognise mutual gains, therefore assists with how things are governed (Abram et al. 2019). Within institutions, there are strict and casual social laws and norms that guide, constrain and form human interactions/conduct. Formal (strict) institutions comprise of constitutions, rules and regulations, and agreements, while informal (casual) institutions consist of traditions/rituals, social rules and taboos (Abram et al. 2019). Both administrative or State (national) government organisations and indigenous/local or customary governance groups rule the coastal environment (Abram et al. 2019).

Governance, applied through legal and administrative processes, is vital for alleviating and adjusting to risks related to climate change (Collins et al. 2019). Roles in the exercising of power and thus who makes the decision is determined by these processes. Making decisions about unforeseen change or extreme events is not self-governing, but requires formal and informal institutional processes (Collins et al. 2019). Appropriate decision-making on managing unexpected change and extreme events is challenging due to the high levels of uncertainty. Therefore, new models need to be built that integrate different uncertainties under extreme scenarios as well as assess value for money (Collins et al. 2019). For example, when assessing coastal impacts and adaptation options, rapid SLR scenarios should be included. Good coordination between sectors affected by climate change and agencies related to disaster management, working together to reduce the risk from extreme climate change impacts can lead to successful adaptation (Collins et al. 2019).

One issue negotiated by local governments of the metropolitan area of Mexico City is the difficulty to embed climate adaptation action in formal and administrative practices (Solecki et al. 2021). This is frequently because action strategies created lack clarity or as the timeframe for their implementation and tangible results outpaces local governmental administrations (Solecki et al. 2021). Local agendas on environmental issues, such as clean air quality (which is a climate mitigation action), are therefore noticed as a more tangible means of furthering both climate change and environmental agendas in the framework of partial resources, capabilities, and timeframes for executing actions. Visions that are short-term still regularly exist, which in turn affect the kind of measures being put into effect (Solecki et al. 2021). In South Africa, issues of development take precedence over issues concerning the environment (e.g., risk reduction, environmental management and sustainability, however if the latter regards securing a city's development pathway while at the same time tackling sustainability, then there is a high likelihood of interpreting resilience to disaster events into spatial planning practices in the country (Niekerk 2013).

City of Durban climate change governance

In the city of Durban, climate change and SLR will affect numerous sectors (e.g., the economy, food security, health, infrastructure, water security and biodiversity) and more people will be vulnerable to risks related to disasters (Niekerk 2013). In the past, EM had few strategies that worked together using a proactive approach to lower disaster risks as a result of extreme weather events (Niekerk 2013). Furthermore, the disaster management sector responded mostly to emergencies, with limited proactive thinking in the planning process to reduce exposure and vulnerability, which includes the relocation of infrastructure and people to areas of lower risk, or on developing early warning systems. The Municipality started to realise the devasting consequences extreme weather events started to have on the city, especially on how these events began to cause more destruction, especially the 2007 storm event where severe flooding and coastal erosion produced substantial damage to the coast, during the last decade, and the Municipality also acknowledged that many of the development gains after the Apartheid era are now being damaged or lost, and will be aggravated further by climate change (Niekerk 2013). As a result, climate change adaptation, or interventions focused on resilience, began to gain importance in the city because of the promise it presents for co-benefits related to development that can alleviate poverty and slow growth in development (Niekerk 2013).

Durban is recognised as one of the leaders in climate change adaptation to date (Niekerk 2013). The Headline Adaptation Strategy (which was published in 2006 and the development of this strategy was commissioned by the Environmental Management Department) summarises adaptation actions, in general, that could be carried out by departments in each sector, however, did not identify aims and activities for certain departments (Niekerk 2013). At the time, many departments had backlogs of work and overloaded with work, as well as a shortage of funding and limited capacity. The EPCPD ensured that climate change in the city is given priority and understood that to achieve extensive backing for an adaptation plan, resilience to disaster risks had to be presented as an issue that is not separate from the work urban planners are now undertaking, therefore planners would see disaster resilience or adaptation as significant (Niekerk 2013). Work commenced on individual plans for certain departments in each sector by integrating adaptation planning into present business plans and development goals. These plans expressed actions and procedures to preserve or enhance the operating of systems, services and infrastructure in the municipality while considering the projected climate change impacts. Also, climate change concerns were incorporated into the municipality's overall long-term strategies and financial plans (Niekerk 2013).

The city of Durban has achieved a successful adaptation plan because of three main features, namely strong leadership on the climate change discussion, the technical excellence of staff and the communication process (Glavovic et al. 2015). At the political level, the mayor champions discussions on climate change, and supported with sound technical contribution by officials in certain departments within the municipality. Academics, consultants, and internal specialists are some of the technical staff who focused on a technical agenda and provided credible and representative work plans with novel study into local downscaled climate change effects arising. As a result, for the first time in Durban, ground-breaking and pioneering climate tools were established (Glavovic et al. 2015). Lastly, the communication process included ongoing stakeholder meetings that helped in both the communication of concerned issues and gaining the public's trust, providing user-friendly information to assist stakeholders' understanding of the risks concerned, and dialogue across sectors guaranteeing that adaptation in one sector does not negatively impact on other sectors. EM found means to connect adaptation to present policies and strategies to prove that this was a familiar issue and was already existing in priorities and initiatives across the city. Adaptation is still central to ongoing work of departments in the municipality and is beginning to impact on planning practices in Durban (Niekerk 2013).

To reinforce the execution and coordination of climate action in Durban, the eThekwini Municipality Climate Change Committee (EMCCC), as well as the DCCS Technical Task Team (TTT) were established (EPCPD 2019). The EMCCC, which is chaired by the Mayor, provides political oversight of the DCCS and the DCCS TTT, comprised of Heads of Units in EM, focuses on the technical administrative side and leads the implementation of the DCCS in a coordinated manner, as well as ensuring the DCCS achieves its aims and addresses any gaps in implementation (EPCPD 2019). One important aim is to coordinate the DCCS across departments within the municipality to reduce the silo effect of operations in Durban.

Generally, there is a challenge with a need for harmonisation between local and regional government (Solecki et al. 2021). There are no official incentives for cooperation across all levels of government even though it is recognised that it would be advantageous to take advantage of further collaborations and co-benefits. National or regional governments, who may have greater capability to support coordinated attempts, still have not been effective in linking objectives and incentives on a national level with needs and actions on a local level (Solecki et al. 2021). However, the DFFE's Local Government Climate Change Support Programme (LGCCSP) has had some success in the programme's design and roll out to national scale which reflects a vast, reiterative collaborative learning process between national and local government (Reddy et al. 2021). Moreover, the flexible and collaborative approach, working across local, provincial and national levels has permitted the LGCCSP to better comprehend and answer to changes in local needs and it guaranteed that there is ongoing communication across all levels of government.

Coastal governance in EM forms the broader national coastal governance framework which is embedded in the constitution of South Africa (Amra 2015). The ICM Act requires that municipalities (local government) within the nine provinces may establish coastal committees to support the application and management of the ICM Act and the creation of an obligatory coastal management programme for each municipality. Both national and provincial coastal committees are mandatory (Amra 2015). The Municipal Coastal Committee (MCC) reports on matters related to the coast within its territory to the Provincial Coastal Committee (PCC) by way of informing the manager and council of the municipality and the PCC.

Ever since the enactment of the ICM Act, the MCC in EM has not been convened, however the eThekwini Coastal Working Group (CWG), which is a voluntary group including government, statutory bodies, civil society groups and researchers, was operating for almost a decade prior to the ICM Act (Amra 2015). However, in 2010, the CWG stopped meeting due to the establishment of a MCC which replaced the CWG. The overall aims of the eThekwini CWG include strengthening dialogue between all state and public stakeholders, be influential over legal matters (i.e., advising compliance with policy, monitoring implementation in alignment with legislation and framing regulation), promote education and awareness, empowering and building capacity of all stakeholder groups relating to coastal management issues, as well as promote sustainable coastal development and tourism, and to recognise research and gather information that can help with alleviating poverty in the coastal zone and various other issues relating to the coast (Amra 2015).

Climate responses by cities networks

Researchers need to have a leading-edge scientific knowledge of climate, risk, vulnerability, impact, adaptation, and mitigation, as well as identifying areas of significant unknowns in relation to main concerns of practitioners, and related procedures to research them (Solecki et al. 2021). For instance, current evaluations of SLR projections have augmented the research network's study of the low possibility, high-consequence climate scenarios, swift melting of ice scenarios and the possible changes in flood incidence in coastal cities situated in low elevation coastal zones (Solecki et al. 2021). On the contrary, practitioners require evidence-based science, which is practical and in accord, to employ mitigation and adaptation actions, with thorough evaluation of interactions and trade-offs of certain actions (Solecki et al. 2021). Most often, practitioners are generally interested in data, information and projections showing circumstances with the highest probabilities and highest confidence that will impact cities. For instance, the Climate Ready Boston report developed a worst-case scenario that a city is facing, which included projections as far as the year 2200 (Solecki et al. 2021). Policymakers of a city need tangible/solid examples of what other cities are doing and the successes and failures and/or lessons learned on being effective (Solecki et al. 2021). They need a framework and leadership to shape overall mandates for their municipalities to abide by, not only in the discipline of climate change but as well as with possible relationships of climate change with the intricate socio-ecological system in urban areas. City action networks (e.g., C40 and ICLEI) play a vital part in delivering this framework and supervision for their partner cities, for both practitioners and legislators (Solecki et al. 2021). Local policymakers' networks (e.g., the South African, Argentinean, Portuguese, or Chilean networks of municipalities) enhance this role for climate action that make room for spaces to share and collaborate, generally with the help of international alliances and collaboration agencies (Solecki et al. 2021).

Meaningful and effective strategies, such as local universities and local governments partnerships, can be exploited to create co-generated solutions that are innovative, just, empowering and relevant to local actions and needs (Solecki et al. 2021). There is an increased recognition by local governments in the importance of engaging with local academic knowledge by way of developing important climate information, wherein some of these collaborations have generated once-off reports, or a sequence of formal reports (Solecki et al. 2021). In fewer circumstances, cities have established formal panels for advising on climate, that serve as an independent body focusing on science that immediately acts to the city's science questions and needs, by local law. For example, the New York Panel on Climate Change (NPCC), created by New York city, serves the city with regular updates on climate information (Solecki et al. 2021).

Mechanisms such as partnerships between the private and public sectors and think tanks, strict partnerships between local higher education institutions and cities, and embedded scientists/researchers within the city have proved helpful at the city-scale (Solecki et al. 2021). Cities which are characterised as small- and medium-sized populations and low- and middle-income may find it difficult to implement many of these approaches, nevertheless, knowledge action networks and information hubs on a regional scale can assist with filling these drives and requirements, if appropriately resourced and supported (Solecki et al. 2021). It is important that indigenous and local knowledge sources obtained through official and casual systems ought to be recognised in the initial stages in any partnership.

Promoting sustainable partnerships between practitioners, policymakers and scientists for medium- and long-term is challenging (Solecki et al. 2021). The timeframes for political work and the dynamics in practitioner work generally deviate from the timeframes for scientific work which are usually longer.

Scientists quickly need to interpret and co-produce data and results, while legislators and practitioners must act now but also consider the climate change challenge from a long-term perspective (Solecki et al. 2021). Subsequently, there is a demand for knowledge advisors to handle the process at all levels (international, national and regional) including to assist with co-creation and use of novel knowledge (Solecki et al. 2021). Platforms have been designed to link knowledge and action, for instance the Future Earth Knowledge platforms, however, currently, it cannot achieve this goal mainly because of a shortage of adequate resources and problems in engaging with practitioners, thus signifies the challenges faced in constructing these new joint-systems (Solecki et al. 2021). It is also known that increased cooperation and partnership among policymakers, practitioners and scientists will promote more trust, understanding, and changes in viewpoint that can produce more opportunity for the management of each of these institutions and their differing timeframes and professional procedures.

Discussions on linking science-policy-practice communities require continual attention and comprehensive negotiation to possibly help thrust cities ahead to more vigorous decisions, foster adaptable results, and valuable indicator and monitoring methods, in spite of current ambiguities (Solecki et al. 2021). Simultaneously, research should be kept independent and objective from the influence of other actors (e.g., government, private interests, sponsorship) which is supported by the credit that the overall cost of procrastination on climate change rises over time and the vital position that cities currently and in the future play a part in taking action towards climate change must be exploited (Solecki et al. 2021).

Use of indigenous knowledge and recognised institutions

Indigenous knowledge and local knowledge are important in coastal governance, observing and responding to a changing climate and such knowledge is recognised by international organisations as important in global assessments (Abram et al. 2019). To bridge knowledge systems, transdisciplinary and/or working with multiple stakeholders are approaches which can be used. Using all knowledge related to a precise challenge includes methods such as building scenarios across groups of stakeholders to capture the different viewpoints of how people their environment and interact with it, co-producing knowledge to achieve co-operative management efforts, and engaging with local/indigenous communities to recognise common standards and insights that aid in adaptation plans that are specific to context (Abram et al. 2019). Indigenous or local knowledge in governance can help avoid populations from being negatively affected by unsuitable climate change mitigation and/or adaptation rules, especially those that further ostracise their expertise, ethnicity, beliefs, and livelihoods (Abram et al. 2019).

In recent years, the need to accelerate climate change adaptation and mitigation through academic, political and practitioner institutions, particularly in cities, working together has become much more apparent (Solecki et al. 2021). Globally, cities and urban areas are identified as crucial places of GHG emissions and vulnerable to climate change, but also innovation for low carbon and climate change adaptation (Solecki et al. 2021). However, solutions and funds for municipalities and by municipalities are still not adequately prioritized in policy development on an international level. A pressing demand occurs to completely organise climate action on multiple levels in which cities perform a key part, although municipalities and urban zones have started to be recognised within the UNFCCC (Solecki et al. 2021).

2.10 Responding to sea level rise

SLR responses includes enforcing legislation and undertaking plans and actions to decrease risk and enhance resilience to SLR (Oppenheimer et al. 2019). When selecting and implementing types of responses to SLR, integrated and coordinated efforts, as well as cooperation between stakeholders is required (Oppenheimer et al. 2019). The responses to SLR include protection, accommodation, advance, and retreat.

Protection includes 1) hard protection (e.g., dykes, seawalls, breakwaters, barriers and barrages), 2) soft protection (e.g., beach nourishment, dunes) and 3) ecosystem-based adaptation, all of which serve a purpose of protecting the coastline against flooding, erosion and saltwater intrusion (Oppenheimer et al. 2019). These are frequently employed in combination, which are known as hybrid procedures, such as a dune system in front of a sea wall. Ecosystem-based adaptation responses is a mixture of protect and advance responses and provides benefits for sustainable management, protection and restoration of ecosystems (Oppenheimer et al. 2019). The protection or restoration of ecosystems within the coastal zone is an example of an Ecosystem-based Adaptation measure, which serves as a barrier and attenuates waves and storm surge flows, as a result protects the coastline. It also reduces the rates of erosion by trapping and stabilising sediments along the coast (Oppenheimer et al. 2019).

Accommodation incorporates a range of biophysical and formal responses that alleviate risk and impacts at the coast, for example early warning systems, preparation for emergencies, insurance policies and coastal setback zones (Oppenheimer et al. 2019). Accommodation reduces the vulnerability of residents in the coastal zone, and both the built-up and ecological infrastructure. It also allows for living conditions to remain within the coastal zone, even with increasing frequency and intensity of coastal hazards (Oppenheimer et al. 2019).

Advance involves building into the sea, creating new land, and therefore reduces coastal risks for the surrounding communities and the newly raised land (Oppenheimer et al. 2019). This type of response consists of land reclamation above sea levels by filling the land through pumping sand, planting appropriate vegetation with the purpose to maintain natural accretion of land, and surrounding low-lying areas with dykes, which also involves drainage and often pumping systems (Oppenheimer et al. 2019).

Retreat includes relocating people, resources, and human endeavours away from the coastal zones which are exposed to risk, and subsequently reduces coastal risk (Oppenheimer et al. 2019). Retreat involves *migration* when people volunteer to move permanently or semi-permanently for at least a year, *displacement* which is the spontaneous or unexpected movement of people because of environmental impacts or political strife and *relocation* which is managed retreat or managed realignment of small locations and/or communities and is initiated, supervised, and implemented by all spheres of government (Oppenheimer et al. 2019).

In EM, the response measures to SLR include both protecting existing municipal infrastructure that is currently in the high-risk zone and relocating such infrastructure to low-risk areas where appropriate (EM 2019). For protection of existing municipal infrastructure placed in the high-risk zone, recommendations on modification and retrofitting of infrastructure and development are being developed to reduce damage from sea storms. A revision of both coastal storm and SLR projections will be considered by the Municipal Asset Management Plans when an assessment of the condition of coastal assets is being done and will include the guidelines (EM 2019). The municipality will ensure that information on the coastal erosion and setback lines is made accessible to all departments within the municipality which are accountable for or oversee municipal infrastructure and development, as well as capacitate relevant officials through educating them to guarantee that no new nonessential infrastructure is developed within the zones of high risk (EM 2019). The municipality will also prioritise preservation and restoration of all coastal dunes and other natural coastal defences, where deemed appropriate.

Implementation of soft protection measures is a more effective and adaptive measure to address SLR and they provide multiple benefits such as enhancing safety, recreation, and natural systems (Oppenheimer et al. 2019). In an urban context where space is limited, soft protection measures such as beach nourishment and dune management can provide co-benefits (i.e., ecosystem-based adaptation), and can be useful for protecting the coastline against flood impacts because the beach and associated environments are preserved, and tourism is improved through the aesthetics and recreational activities (Oppenheimer et al. 2019).

In EM, regarding relocating existing infrastructure that are in high-risk zones, areas which have existing coastal municipal infrastructure that are currently within high-risk zones are being identified to be relocated to areas of low risk in the long-term (EM 2019). Municipal infrastructure currently within zones of high risk along the coastline that have reached the end of their fiscal lifespan, or when they are badly broken by seastorms, will be relocated to low-risk areas (EM 2019).

Throughout the world in low-lying areas exposed to the effects of coastal hazards, there is strong proof of strategic relocation happening on reducing long-term environmental risks, including SLR, and which are led by government (Oppenheimer et al. 2019). Most relocation schemes are negotiated after an extreme weather event has occurred. It is an effective response to SLR as it immediately lessens the exposure of human communities and actions, as well as built and natural environments to the risks and impacts of SLR (Oppenheimer et al. 2019). This can also avoid overcrowding in urban coastal cities and cities reaching their carrying capacity and allows for the creation of more economic hubs (i.e., deurbanization). There has been successful planned relocation in Alaska where resettlement of local communities has improved housing standards and reduced their vulnerability; however, relocated communities can become further impoverished due to them being removed from resources which they depend on, heightened by inappropriate implementation processes of relocation, failing to meet social and environmental equity and welfare (Oppenheimer et al. 2019).

The EM has also modelled SLR projections for three scenarios (300, 600 and 1 000mm) and in response to these modelled projections, a dune rehabilitation programme is being implemented along the coastline to strengthen the natural protection role of dunes along the coast (EM 2019). There are ongoing detailed analyses being conducted on the latest coastal storm and SLR projections, including HWMs and KZN's established setback lines, to identify areas along the coastline that are at greatest risk from damage and flooding from seastorms (EM 2019).

Governance challenges to respond to SLR

Governance is essential to shaping SLR responses, however each of the different responses brings about particular governance challenges linked to the costs, benefits, and negative effects on society (Oppenheimer et al. 2019). Recognising the most suitable approach to respond to SLR is complex and is governmentally and socially disputed with a variety of governance challenges/barriers occurring.

Current planning and establishing decision-making practices are challenging due to the considerable ambiguities about SLR beyond the year 2050, and the significant impact projected. This also introduces the need for coordinated governance across all spheres of government and policy domains (Oppenheimer et al. 2019). SLR responses also bring up justice worries about ostracising those most at risk and could possibly generate or heighten community conflict. A shortage of resources, worrying about trade-offs between security, preservation and economic development, the different perceptions of understanding the problem of SLR, power relations, and conflicting interests between several coastal stakeholders on future development within the coastal zone are other challenges encountered when choosing and implementing responses (Oppenheimer et al. 2019).

Implementing coastal adaptation measures is hindered by governance challenges. There are conflicting interests between stakeholders which support coastal protection and those who are harmfully impacted by adaptation actions and, thus, need resolving (Oppenheimer et al. 2019). The distribution and use of municipal money between coastal communities being given municipal support for adaptation and communities inland who pay for this public support with their taxes is another source of conflict

(Oppenheimer et al. 2019). Normally, access to economic resources for adaptation often constrain adaptation, especially in the case of homeowners who are regularly not prepared to pay taxes or levies for public protection or soft protection methods even though homeowners immediately benefit from the service (Oppenheimer et al. 2019).

Another challenge associated with governance is guaranteeing the effective maintenance of coastal protection (Oppenheimer et al. 2019). In the past, ineffective maintenance has frequently played a part in many coastal disasters due to the absence of having adequate funds, policies, and technical skills. Cities often have a shortage of economic resources and widespread technical knowledge to effectively act in response to climate risks that residents and important infrastructure face (Solecki et al. 2021). Normally, local governments do not have the lawful mandate to raise economic resources required to deal with the environmental risks and strongly depend on institutions ranked higher (e.g., provincial and national government) or international monetary sources (e.g., World Bank, International Monetary Fund, Green Climate Fund) to financially support projects focusing on climate adaptation and mitigation on a large scale (Solecki et al. 2021). Although international givers and financial organisations favour discrete projects and infrastructure initiatives to fund, science-policy-practice partnerships can help increase efficiency, achievement, and long life of climate action by allowing increased ability by way of using knowledge that is readily available, offering legislation and governing backing, and strengthening community cognizance over the long timeframes required for the response of climate change (Solecki et al. 2021).

South Africa has good policies in place but has faced challenges implementing them. The City of Cape Town focuses on coastal climate change adaptation efforts towards SLR and coastal flooding (Abram et al. 2019). The Milnerton coastline HWM is shifting landwards due to SLR. Consequently, the HWM is intersecting with private property boundaries, posing a threat to beaches for the public and the line of dunes, and putting private property and municipal infrastructure at risk during sea storm events. As a result, this is creating a governance conflict (Abram et al. 2019). Private property owners are causing more erosion impacts along the coastline because of the usage of a mixed approach (i.e., formal, ad hoc, and in some instances illegal), of coastal defence methods to shield their properties from coastal risks such as SLR and sea storms (Abram et al. 2019). The City of Cape Town is legally not accountable for reforming private land impacted by coastal erosion, yet officials feel obliged to act for the commonwealth using an advanced, multi-stakeholder participatory method, which includes creating chances for discussion and generating knowledge together with the homeowners rather than a state-centric method (Abram et al. 2019). The city’s activities abide by both climate change international contexts and legislation and policy from both national and provincial government but navigating the power struggles that will arise in this consultative approach still remains a major challenge as different stakeholders describe and convey their interests, roles, and responsibilities (Abram et al. 2019). Nonetheless, public participation, conflict solution practices, and planning can aid in addressing governance challenges in responding to SLR. Identifying and traversing these challenges is critical to understanding the importance of preparing for SLR risk reduction, and participatory preparation procedures that resolve conflicting concerns are crucial to this attempt (Oppenheimer et al. 2019).

Therefore, governance needs to be included when making decisions on how to respond to SLR to resolve social conflicts and reach mutual agreements amongst all stakeholders (both public and private) when presenting opportunities.

2.11 Conclusion

This chapter focused on background literature relevant to the study. The key aspects discussed were SLR projections by 2100 for both global and local scales and the current rate at which sea level is rising, areas along the EM coastline that are at risk and vulnerable to SLR impacts, the importance of climate change adaptation and building resilience to reduce risks related to CC and SLR with a strong focus on coastal ecosystems and ecosystem services provision (e.g., coastal protection), comparing the cost and effectiveness of both hard engineering and soft engineering dune rehabilitation methods implemented along the EM coastline, complying with relevant legislation on coastal zone management in order to protect both built-up and ecological infrastructure along the coastline from SLR impacts together with reiterating the role in which governance and institutions can help to achieve this (also noting the challenges when implementing adaptation actions), and concluded with the appropriate responses to SLR (protection, accommodation, advance and retreat) implemented in EM.

This chapter, therefore, provides the basis upon which different aspects of the study were carried out and framed upon. The following chapter presents the methods used for this study.

CHAPTER THREE: METHODOLOGY

3.1. Introduction

This study required the acquisition of a range of primary and secondary data. Background information was extracted via an exhaustive literature survey and from interviews with consultants. Secondary GIS-based spatial data was acquired from the EM whilst primary data was compiled from field surveys. The spatial data was then used to develop maps for showing the spatial distribution of target ecosystems and for the vulnerability assessments. Analyses comprised of using existing datasets provided by EM and maps developed by the researcher for incorporation of the overall vulnerability attributes. This part of the study was thus primarily desktop in nature. The analysis of maps for the EM coastline, particularly those containing the modelled SLR erosion lines, allowed the researcher to use the database to ascertain the geographic location of the coastal stretch where SLR impacts would be the greatest. This was used to aid with targeting highly vulnerable areas and thus recommended methods for coastal protection.

The methods utilised to achieve this are outlined in this chapter.

3.2. Research Methodology

3.2.1 Literature survey

A literature review was carried out to identify assessment methods for climate change hazards related to SLR as well as dune rehabilitation methods along with its financial costs. Information garnered were used to frame risk and vulnerability, establish rehabilitation approaches and determine the value of dunes and forest ecosystem services along the EM coastline.

A preliminary assessment on dune rehabilitation methods was conducted. Scholarly articles on dune rehabilitation methods carried out in EM were reviewed. A literature survey on both soft engineering methods and hard engineering methods was done for the purpose of providing a rationale as to which method would be the most suitable/appropriate to implement along the coastline in future. This study provides recommendations on dune rehabilitation methods that are site-specific, as well as have the least impact on the environment.

3.2.2 Consultations

Staff from the EPCPD in EM were consulted together with staff from the Coastal Policy department. EM officials provided information in respect of development rights and development proposals (e.g., the Radisson Hotel at Beachwood) on coastal properties to get a sense of future squeeze from development.

The 300, 600 and 1 000mm SLR erosion lines for EM were retrieved from Dr Andrew Mather as well as the provincial 100m HWM setback line, which is the Environmental Impact Assessment (EIA) regulations buffer zone. These were used for identifying and mapping high risk areas to SLR along the EM coastline. Coastal dunes and forests at risk were identified and used as target areas for this study.

3.2.3 Identifying and mapping high risk areas to sea level rise

It is vital to identify extreme wave run-up levels during planning processes (Mather et al. 2018). These levels can provide the basis upon which appropriate development setback lines can be determined. In built-up areas the estimation of extreme wave run-up is useful in determining the risk to current structures located beyond the littoral zone. The wave run-up is factored into both the EM and Provincial (KZN) Coastal Management Lines, which the latter is based on the model developed by Mather (2009).

The ICM Act requires Coastal Management Lines to be developed sequentially by each sphere of government, from national to local. As of the end of 2019, the provincial sphere was busy with their Coastal Management Lines development. To date, a standardised Coastal Management Line for the KZN coastline has not yet been formally developed and authorised by the relevant governmental departments. Authorities have accepted the 100m setback from the HWM as an interim setback measure for developmental purposes for KZN in general. Additionally, EM also utilises the 300, 600 and 1000mm SLR erosion lines developed by Mather (2009) using the Bruun Rule model as part of planning Durban’s climate change adaptation response for SLR. The three SLR setbacks have been made available by the EM for utilisation in this study.

The 100m from the HWM coastal setback line, as determined by the KZN Department of Economic Development, Tourism and Environmental Affairs (EDTEA), as well as the projected inland positions of the 300, 600 and 1000mm SLR erosion lines were first superimposed onto Google Earth™ images to delineate the HWM along the eThekwini coastline. Thereafter, this data was added into ArcGIS™ to delineate the 100m setback line as a buffer, taking into consideration the landscape variations. Natural areas, built-up infrastructure and properties along the EM coastline where SLR impacts are the greatest were digitised on Google Earth™. The layers created on Google Earth™ were exported into ArcGIS™. Risk maps were produced in ArcGIS™. The development of risk maps will be described in the next section.

Coastal Vulnerability Index and CoastKZN Maps

Palmer et al. (2011) ranked areas of the coastline based on their comparative level of vulnerability according to the CVI as high risk, moderate risk, and risk by calculating CVI scores based on the physical coastal parameters. Instead of calculating CVI scores, this study used more of the principles of categorising risk based on the CVI with an additional rank of low risk in this study. Therefore, sections of the coast were mapped as follows:

- The EM scenarios of SLR (300, 600 and 1 000mm) were mapped;
- Development between the shoreline and 100m HWM/300mm setback was identified.

Based on observations from the above mapping and subsequent analysis of the relative importance of the 300mm SLR erosion line and the 100m setback from the HWM, it was concluded that development situated within the 300mm SLR erosion line was at greatest and most immediate risk. Subsequently the 300mm line is roughly co-incident with the 100m setback from the HMW, and this is the zone of highest vulnerability. Since a setback line has not yet been formalised for KZN and the 100m setback from the HWM does not preclude development in the high-risk zone, the EM has considered adopting retreating to the 300mm line. This is to guarantee that development proposed in the future does not occur below this area due to the high risk and to create a broad zone of groundcover for vegetation to grow to help buffer against SLR impacts. This area needs to be afforded greater protection from SLR impacts in future. Therefore, vulnerability assessments were focused on this zone.

3.2.4 Risk assessment of sea level rise impacts on coastal ecosystem

Mather (2007) found a linear rise in sea level for Durban, rising at a rate by 2.7mm per year from the year 1970. These findings were established on tidal records of the South African Navy's tide gauge situated close to Durban's harbour. According to IPCC (2019) the GMSL is projected to rise between 43cm under RCP2.6 and 84cm under RCP8.5 by 2100. The projected rate of SLR under RCP8.5 will be 15mm per year in the year 2100 and could go beyond a number of cm per year in the 22^{nd} Century. The current rate of GMSL is 3.6mm per year over the period 2006 – 2015. These findings were derived from tide gauges and altimetry observations.

As part of the GIS analysis in this study, coastal infrastructure, properties, ecosystems and the EM SLR lines were overlaid, and the extent of intersection was measured. This was useful to determine how much overlap there was with the spatial layers, where the 1000mm line had much greater overlap than the 300mm line. This gave a comparison of the level of risk between the lines. A precautionary approach should be taken/considered to minimise future development SLR risks by staying out of the 1000mm overlaps.

The current SLR projection for Durban (2.7mm/annum) translates into a period of approximately 110 years of rising sea level until the 300mm level is reached. This however may be reduced under changing emission scenarios (i.e., RCP2.6 drifting to RCP8.5). Sea levels are not changing rapidly and while the model under RCP8.5 suggest much higher annual rates of SLR which while not improbable, they are highly unlikely given modelling issues/assumptions. Therefore, the 300mm scenario is the focus for this study. However, the 600 and 1 000mm scenarios were used to illustrate how far impacts may extend using these projections.

Classification of land use

Following from the spatial analyses from 3.2.3, the high vulnerability coastal strip falling within the 300mm SLR erosion line was then further assessed for land use type and relative value. Land use was categorised into (see Table 1):

- Natural areas, e.g., NFEPA (National Freshwater Ecosystem Priority Areas) and D'MOSS (Durban Metropolitan Open Space System);
- Developed areas and residences (out of NFEPA) and;
- Other protected areas (Protected Areas SANBI NBA, Protected Areas Database DEA, Ezemvelo Conservancies, Estuarine Functional Zones and Important Bird and Biodiversity Areas).

This was done to aid valuation of property at potential risk and, if possible, distinguish responsibility/ownership for damage costs from SLR impacts.

Identification of property at risk

Properties (residential houses and hotels and lodges) situated within the 300mm coastal stretch were digitised. Contiguous developments were recorded in a block-wise fashion (i.e., discrete polygons). The size of block was determined by any proportion of development (e.g., front wall of house, pool, garden) within the 300mm zone was considered for further analyses. The municipal total costs of damage to public infrastructure throughout the storm event in March 2007 was utilised to calculate cost of repair and a table was created in Microsoft Excel™. In addition, potential area loss was quantified by polygons created for the overlap between properties and the 300mm SLR erosion line and was tabulated in Microsoft Excel™. Properties were divided into areas (Westbrook, Umdloti, Umhlanga Rocks, Amanzimtoti and Umkomaas) within EM (refer to Figure 2). A central set of GPS coordinates for each block was recorded to allow easy facilitation when locating properties. Property value was ranked into five classes. Estimated value of properties were calculated using data from eThekwini Municipality's valuations roll. The total area of damage to properties was calculated on ArcGIS™.

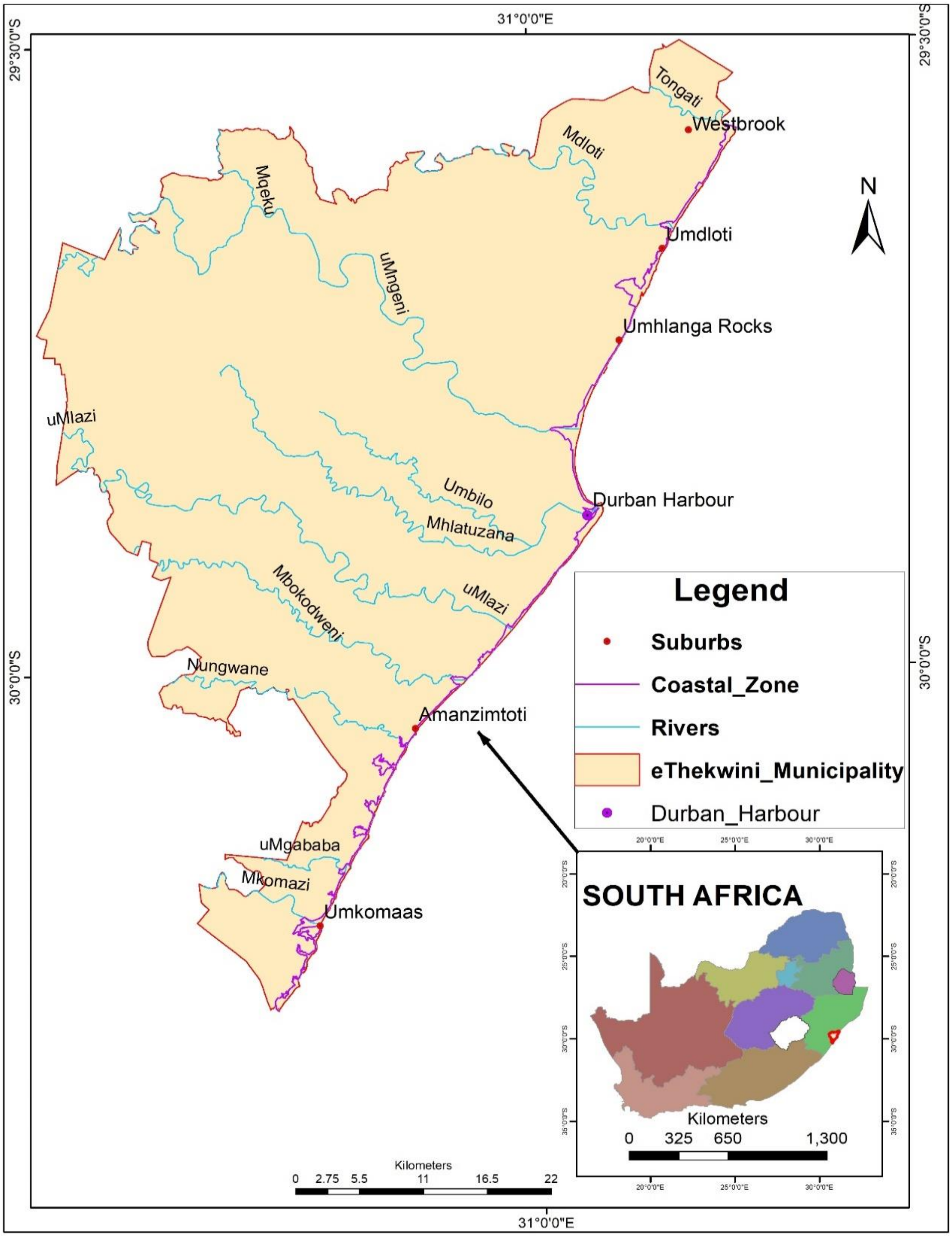

Figure 2: Location map of suburbs in eThekwini Municipality, KwaZulu-Natal, South Africa (drawn by Ballabh, 2020)

Identification of coastal ecosystems at risk

High risk zones

A second assessment of the maps produced were carried out focusing only on sections/areas along the shoreline which are in the high-risk zone, i.e., the 300mm SLR scenario. Here, the CVI was used (CoastKZN^{TM}) based on its principle of categorising risk, as well as GIS maps on municipal infrastructure from the EM asset register which records all municipal assets for management purposes. Municipal assets are essential as they support service delivery to local communities. The GIS maps were overlaid on the CVI map to identify which municipal infrastructure are within the high-risk zone.

To assess the vulnerability along the EM coastline, the coastlines at Sibaya Forest and Clansthal Beach, where field work was undertaken, were divided into 50m-by-50m cells drawn on ArcGIS^{TM}. Orthophotographs captured in 2019 supplied by the EM were added into ArcGIS^{TM} and were used to measure five physical parameters (beach width, dune width, percentage outcrop, distance of vegetation behind the back beach and distance to the 20m isobath) within each cell.

Point data were obtained between the low water mark and the back beach and the average measurement of parameters for each cell were recorded. The width of the beach was calculated directly from measuring the distance from the low water mark to the back beach, while the width of the dune was calculated from the front of the dunes to behind the dune. The distance to the 20m isobath was determined by measuring the distance from the back beach to the nearest point of the 20m isobath, using bathymetric data supplied by the EM. The percentage of outcrop was calculated by the area of rocky outcrop visible in each cell divided by the area of the cell (50m-by-50m) and multiplied by 100 to get a percentage. Lastly, the distance of vegetation behind the back beach was calculated by measuring the distance from the vegetation behind the back beach to the nearest point where the vegetation intersected with developments/infrastructure. All calculations were captured on ArcGIS^{TM}.

Parameters would have various levels of protecting or responding to the coastline depending on the scale of the impact (Palmer et al. 2011). Therefore, each of the parameters was weighted corresponding to its value and subsequent recognised degree of risk. The weighting (or categories) of the magnitude of individual parameters are extremely low (1), low (2), moderate (3) or high (4) depending on its value and range (Palmer et al. 2011).

Based on statistical analysis and expert feedback, it was determined that the width of the beach, the width of the dune and distance to the 20m isobath were the utmost crucial indicators when measuring coastal vulnerability (Palmer et al. 2011). Therefore, locations that scored high on all three indicators were at larger risk. An extra weighting of very high vulnerable locations was calculated. In other words, if these three indicators total to 4. In addition, cells that intersected with an estuarine area was also weighted by an extra factor of 4 (Palmer et al. 2011). This highlighted the possible increased risk for these portions of the coastline. Based on the scoring and weighting, each cell got a total relative vulnerability score:

$$\text{Relative CVI} = a + b + c + d + e + f + g$$

Where a – e is the vulnerability score of beach width (a), dune width (b), distance to 20m isobath (c), percentage outcrop (d) and distance of vegetation behind the back beach (e) respectively. The extra weighting includes sites in very high vulnerable areas, in other words if the width of the beach, width of the dune and distance to 20m isobath equals 4 (f) and if the cell overlaps an area that has an estuary herein (g) (Palmer et al. 2011).

Risk Assessment

Risk is the product of the frequency to a hazard and the impact. To visualise the risk, a risk matrix can be used. A risk matrix provides information about consequence and probability and can be utilised to establish the complete degree of risk. A risk matrix table measures the probability on the vertical axis and consequence on the horizontal axis rated from low to high. The mixture of probability and consequence, which is the total degree of risk, can be classified into low, medium and high. A high likelihood means that it is likely to occur in most conditions and a low likelihood means that it may only happen very seldom, such as once in 100 years. A high consequence may mean serious damage to property or infrastructure/total loss of ecosystem services and a low consequence may mean minor damage to property or infrastructure/little or no loss of ecosystem services. Generally, typical risk management presumes risks are foreseeable. ‘Black Swan’ events, however, focus on risk that is unforeseeable and unpredictable events, for example low probability events with catastrophic impacts (Mutumbo 2017).

Although risk matrices have their limitations such as subjectivity, inconsistent interpretation, and that time frames are not taken into consideration, they are a helpful and practical tool to categorise risk.

Risk matrix table

Based on the CVI by Palmer et al. (2011), this study created a risk matrix table rating vulnerability of coastal ecosystems along the EM coastline using ecological parameters from previous studies, namely Bindoff et al. (2019) and Rangel-Buitrago and Anfuso (2015).

For this study, areas prone to consequences such as major damage to property/public infrastructure and loss of coastal ecosystem services (i.e., protection services) would rate as high risk. This, in turn, would result in increased cost implications for both repairs on prime/elite properties, as well as dune rehabilitation within EM, respectively.

The risk matrix table was used to identify areas along the coast that have an overall rating equal to "High Risk" to determine the level of impact and cost implications. Different case scenarios, for example the presence of coastal dunes vs. absence of dunes at Dakota formal settlement were explored, among other scenarios, and were mapped. Dakota formal settlement, in Isipingo Beach (approximately 8km north-east along the coast from Amanzimtoti, Figure 2), was selected as a site because it falls within the high-risk zone; it is an informal settlement with a highly vulnerable population of residents, and its behaviour factors, namely dune degradation by settlement residents, increases risk of dune failure.

Field surveys

Site visits at Sibaya Forest and Clansthal beach (Mahlongwana River) were conducted coupled with ground truthing. The projected extent of *Mimusops caffra (M. caffra)* trees in each site was determined by subdividing the coastal stretch between transect lines into unit blocks and interpolating the number of trees within each block based on the number of trees occurring along 20m segments and including the 10m width band of each transect line. Transects, which were linear and starting from the front dunes to 100m inland, were spaced out at an equidistance of approximately 500m, therefore a total of four transects were carried out along a coastal stretch of about 2km at both sites.

3.3. Conclusion

This chapter outlines all of the methods used to gather data used in this study. Assessments of coastal vulnerability and land use classification maps, as well as identification of properties at risk provide the motivation for this study namely to inform decision-making within the EPCPD around the prioritisation of climate change adaptation actions for SLR within the Durban Climate Change Strategy. The analysed maps provide valuable information for municipal decision makers as to the extent of areas vulnerable to future SLR and associated extreme events along the EM coastline, as well as potential cost implications. This highlights coastal vulnerability and land use classification assessments, as well as identifying properties at risk, as essential. With reference to the study area, this suite of methods is considered as most effective in determining areas which are vulnerable to future SLR, the degree in which they are vulnerable and how to protect these areas along the EM coastline.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Introduction

This chapter focuses on the results obtained for the various assessments. The results presented in this chapter include a series of maps, data of recorded potential property loss, and a risk matrix for coastal ecosystems at risk, all in tabular format. Furthermore, this chapter focuses on the discussion of the above, particularly on the developments and coastal ecosystems identified to likely be impacted within the 300mm SLR setback line, as obtained from the map results. A comparison of vulnerability between this study and the CVI are discussed, as well as a comparison of SLR scenarios from past studies (Mather 2009) to IPCC projections. Moreover, the projected timeframe within which SLR will reach the 300mm setback under the current SLR rate is also discussed. In terms of the land use assessment, natural areas that are vulnerable to SLR impacts are presented as well as the implications (total area and cost) of properties vulnerable to SLR impacts and associated extreme weather events along with the type of protection required to prevent infrastructural damage and costs in future. The overall results presented provide holistic perspectives of the natural and anthropogenic impacts on the EM coastline.

4.2. Identifying and mapping high SLR risk areas

Following discussions with staff from EPCPD and the Coastal Policy department, the ‘at risk’ target areas identified for coastal dunes and forests at risk within the 300mm setback line were categorised as ‘Dune Thicket’, ‘Dune Forest’ and ‘Dune Thicket and Dune Forest’. The areas classified as Dune Thicket were Palmcliffe, Umkomaas, Danganya, Merewent and Kingsway. Areas classified as Dune Forest were Glenardle, Bushlands (Bluff), Umhlanga lagoon, Umhlanga Nature Reserve, Isipingo beach and the Embokwodeni Golf Course. Areas identified as having both Dune Thicket and Dune Forest were Westbrook, Umdloti and Atholton.

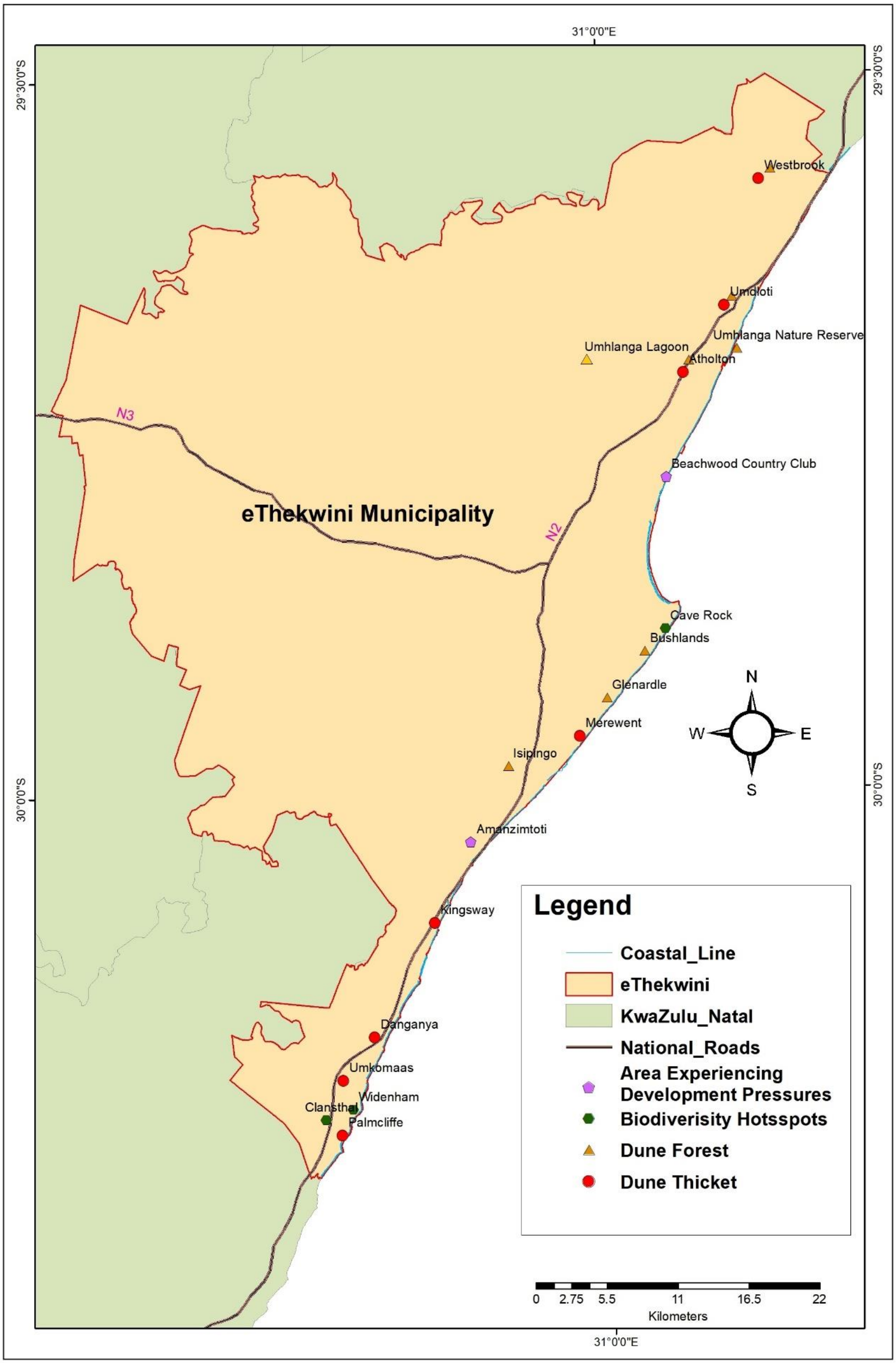

Figure 3: Map showing land classification along the eThekwini Municipality coastline (drawn by Ballabh, 2021)

Other important areas that were considered and noted for this study include biodiversity hotspots (Umkomaas, Widenham, Clansthal and Cave Rock at the Durban harbour entrance) and areas experiencing development pressures or impacts on coastal dunes and forests (Amanzimtoti, Isipingo, the Beachwood Country Club and Westbrook, in the vicinity of Beach Bums).

4.2.1. CVI and CoastKZN maps

CVI maps were created using CoastKZN™ (https://maps.coastkzn.co.za/CoastKZN/) which illustrated both coastal risk lines and vulnerable areas, and sections of the EM coastline were mapped. A sample section of the mapped CVI is presented in Figure 4 below. Since the coastline is extensive, it is not possible to present the entire EM coastline on a single map together with the requisite detail. Hence, the rest of the coastline is presented in a separate file (pdf format) in Appendix A. It is noted that this pdf document contains all appendices for this study.

Figure 4: Map showing coastal risk lines and vulnerable areas along Isipingo Beach, eThekwini Municipality. The light blue triangle indicates Dakota settlement and dunes (produced using the CoastKZN™ interactive mapping tool, 2020)

Coastal dunes at Isipingo Beach are at risk to future SLR impacts and associated extreme weather events (Figure 4). Moreover, the Dakota formal settlement is located herein which makes community members vulnerable. Poor communities are concentrated in dangerously vulnerable and hazardous locations, most often in informal settlements which are situated in areas characterised with have steep slopes or are low-lying, prone to floods, and have limited protection from extreme climatic events (Niekerk 2013). When hazards act together with one another they generate complex hybrid hazards, and as disaster risk increases daily, it weakens the resilience of communities (Niekerk 2013). Each subsequent event destroys a household's resources to deal with and recoup in time for the following shock, resulting in high vulnerability. Addressing disaster risk and vulnerability in urban areas is vital to ensure that people's lives and livelihoods are protected, including the infrastructure and development profit. Resilience presents a standpoint on lowering disasters and daily risks, including creating a more vigorous and adaptable society to variations and shocks (Niekerk 2013).

4.2.2. CVI Analysis

Figure 5 illustrates highly vulnerable areas along the EM coastline in the Umhlanga area. Built up areas situated within the coastline and 100m HWM (setback line) outlined in purple are the most vulnerable to SLR impacts. For the purpose of this study, the CVI maps concentrate on specific sections of the coast as it is too extensive to cover the entire coastline. Other areas vulnerable to future SLR impacts include:

Northern region - Westbrook, Umdloti, Virginia, Durban North

Central region - central Durban region, Blue Lagoon, Durban Port

Southern region - Bluff (Glenardle), Isipingo Beach, Amanzimtoti, Kingsburgh, Umkomaas, Clansthal.

However, there are no residential properties located within the central Durban region. The other maps covering the rest of the coastline are presented in the separate pdf file as Appendix B.

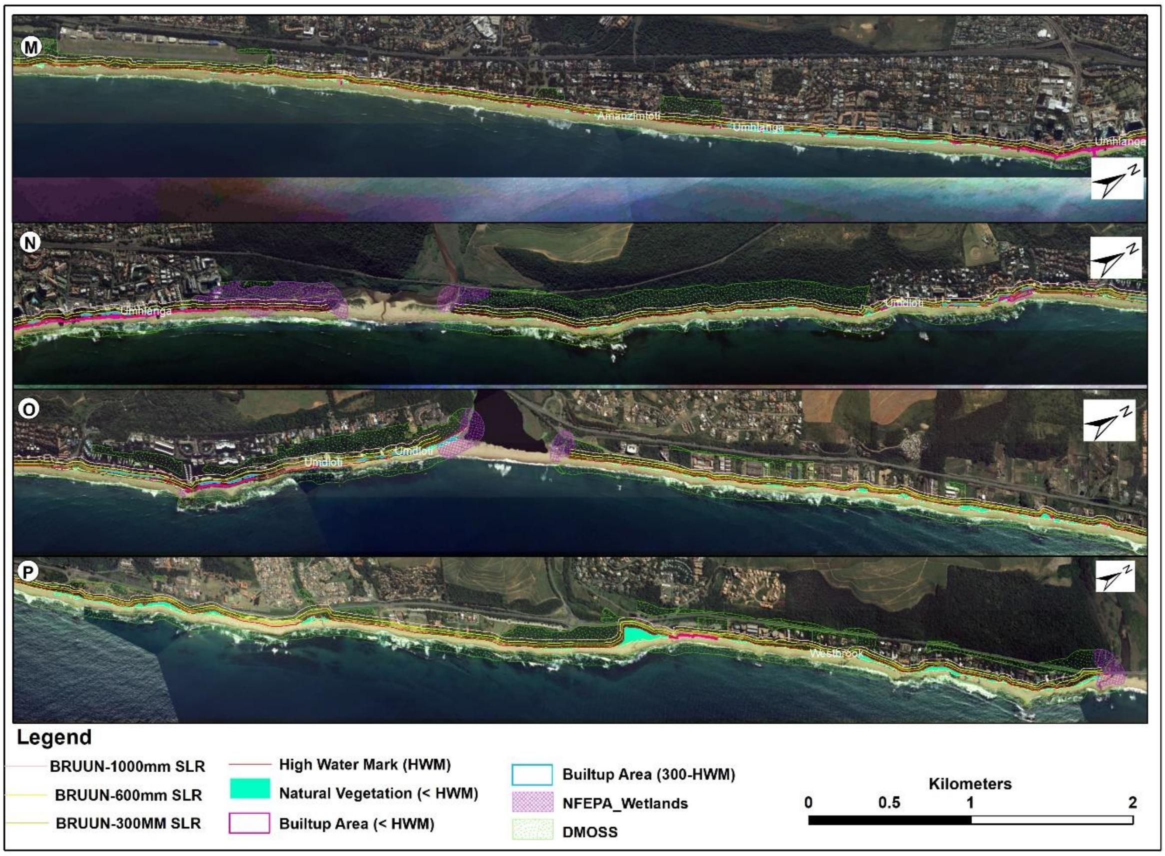

Figure 5: A continuum of map segments showing development and natural vegetation exposed to SLR impacts under the 100HWM in Umhlanga

Estimations from the CVI are not a complete indication of vulnerability, however they do deliver a comparative index (Palmer et al. 2011). In the past, the KZN coast has undergone significant erosion damage, and it is anticipated that these events will become more frequent. It is projected that the coastline will experience erosion events again and that the CVI locations ranked as "high" will be at greatest risk. Properties within 100m of the HWM and situated in neighbouring areas of exceptionally high CVI scores may potentially be at risk (Palmer et al. 2011). The nearness of these properties to the HWM is important to determining the level of comparative risk, with developments, including infrastructure, that are within 2m (vertical distance) of the HWM more probable to be impacted by SLR impacts and associated extreme weather events than structures further inland (Palmer et al. 2011).

Friedrich and Kretzinger (2012), for instance, conducted a study of the vulnerability of the wastewater infrastructure, both collection and disposal such as pipelines and manholes, pumping stations and wastewater treatment plants, to SLR in EM. The study found that regions at Amanzimtoti South and Isipingo Beach along with two regions of the CBD, namely the east and west regions and Maydon Wharf contained the most vulnerable manholes and pipelines. Based on the CVI analysis, there are no manholes in these areas that are within the high-risk zone but there are manholes found in Newsel Beach and Umhlanga where they are most vulnerable. Similarly, there are no pipelines in these areas that are within the high-risk zone. According to the CVI, Umhlanga, south of the Durban Harbour entrance (i.e., the whaling station), near Mlazi River mouth and Newsel Beach have sewer pipelines that are highly vulnerable. The Point Road pumping station is highly vulnerable because of its size, connectivity and underground parts. The CVI Analysis also indicates that this pumping station is in the high-risk zone, as well as a few more pumping stations located between the South and North Beach coastal strip. The wastewater treatment plant that is most vulnerable is the Central Wastewater Treatment Plant (WWTP) owing to its geographic location and sensitivity in the past. The CVI analysis also shows that the central sewer systems area is highly vulnerable, however the north and south also have sewer systems areas within the high-risk zone, particularly near the river mouth of most rivers along the coast. The researchers advised that these components have to be monitored, particularly for rises of influx, and ought to be prioritised for adaptive actions. In addition to the CVI analysis, the Umhlanga pier at McCausland Crescent, the pier at Sometseu Road Outfall, the Bay of Plenty pier at Patterson Groyne North and the North Beach pier at Patterson Groyne South, located along the EM coastline between 31^{o} 5’ 21’’ E; 29^{o} 43’ 36’’ S and from 31^{o} 2’ 14’’ E; 29^{o} 50’ 41’’ S to 31^{o} 2’ 20’’ E; 29^{o} 51’ 1’’ S are the most vulnerable as they are within the high-risk zone.

In addition, the wastewater infrastructure in EM will be capable to manage the early phases of SLR (i.e., when the water table along the coast is projected to increase, causing an enhanced entry and waterflows into pipes, pumping stations and wastewater treatment plants) as a result of the current, vacant facility in the most impacted pumping stations and wastewater treatment plants (Friedrich and Kretzinger 2012). Such a design provides resilience to the system, and is a great insurance policy in the instance of a few expected SLR impacts for the EM. During this time, the infrastructure may reach the end of its projected lifespan, which will require either refurbishment or provide the opportunity to move the infrastructure to a less vulnerable location.

Vulnerable zones can be recognised for future risk management (Palmer et al. 2011). Existing developments located close to the shore are at higher risk of being destroyed. Therefore, options of defend and retreat ought to be investigated. However, in urban zones where there is probably not much space for retreat/relocation or adaption under projected SLR scenarios, options may be more complicated. Consequently, management mediations need to be carefully planned using Coastal and Shoreline Management Plans (Palmer et al. 2011). Furthermore, new development should be setback sufficiently giving the coastline space to move up the shore as SLR is experienced. Alternatively, when developing new sites, one should consider doing so away from risk prone areas. Portions of the KZN coastline are vulnerable to coastal erosion, therefore public and financially critical infrastructure may be impacted if it is in very near proximity to the HWM. Current and future management decisions need to ascertain the most suitable management options, dependent upon the nature, value, life expectancy, and impacts of possible loss of developments.

The use of the CVI alone will not provide a conclusive understanding of development and/or properties lying within the projected 300mm SLR curve or the 100m setback from the HWM. Therefore, this study assessed SLR impacts on areas demarcated only between the 100m HWM and the predicted 300mm SLR, and thus will be more precise when analysing potential areas vulnerable to SLR.

4.3. Risk assessment of SLR impacts on coastal ecosystems (dunes and forests)

4.3.1. Classification of land use (NFEPA, D'MOSS, NPAs) assessment

Table 1 describes each of the land use types that were used for this study and the significance of each.

Table 1: A description of land use types and significance of each

Land use type	**Description**	**Significance**
Natural areas (e.g., NFEPA, D'MOSS)	The National Freshwater Ecosystem Priority Areas (NFEPA) is a project that was created to strategically and spatially prioritise conserving freshwater ecosystems in South Africa, known as Freshwater Ecosystem Priority Areas (FEPAs), and support the sustainable use of water resources (Nel et al. 2011).	The project aims to achieve national biodiversity goals for freshwater ecosystems by identifying FEPAs and conserving them, within the context of equitable social and economic development (Nel et al. 2011). Water bodies which fall under NFEPA are important ecosystems that have strategic importance regarding the supply of water or aquatic ecosystem support (Reimers 2017). Functions involve corridors for species to migrate as well as biodiversity management.
	The Durban Metropolitan Open Space System (D'MOSS) is an open space plan focusing on areas of high biodiversity value and natural areas in the eThekwini Municipal Area (EMA) (Davids et al. 2016). Approximately 95 000 hectares	D'MOSS is important for the protection of biodiversity hotspots and ecosystem services in EM. D'MOSS had been officially incorporated into the eThekwini Municipal Town Planning Schemes (Davids et al. 2016). This will

Land use type	Description	Significance
	within EM is demarcated as D'MOSS.	help control development taking place within the EMA.
Developed areas and residences	Developed land refers to structures built by man, including roads, residential homes, factories, parks, and golf courses (Palmer and van der Elst 2012).	Coastal development such as service industries, tourism, resort development and trade-related activities from ports is good for the economy. This is the case for the KZN coastline (Palmer and van der Elst 2012).
Other protected areas (e.g., Protected Areas SANBI NBA, Protected Areas Database DEA, Ezemvelo Conservancies, Estuarine Functional Zones and Important Bird and Biodiversity Areas)	Natural Protected Areas (NPAs) are areas designated or regulated by authorities that are managed in order to ensure that specific conservation objectives are achieved (Mulongoy and Chape 2004). KZN Wildlife is the responsible governmental organisation for biodiversity conservation in KZN. They manage 110 protected areas, which is approximately 7 127.9km^2 of land in KZN (Goodman 2003).	The role of NPAs is to safeguard biodiversity, and to conserve the ecological integrity of ecosystems, as they deliver important ecosystem services essential for sustainable livelihoods (Figueroa and Sánchez-Cordero 2008). The KZN province in South Africa is an important region in the world because it contains rich biodiversity and ecosystems, as well as diverse geology (Goodman 2003). Therefore, the conservation of biodiversity in KZN is important, not only for the environment but communities at large.

National Freshwater Ecosystem Priority Areas (NFEPA)

Water bodies within NFEPA are at high risk to future SLR impacts. In Figure 6, there are areas which fall under NFEPA that are vulnerable to future SLR impacts within 100m of the HWM. Thus, these areas require attention from the respective institutions and authorities to ensure protection and maintenance of these highly sensitive areas.

Figure 6: A continuum of map segments showing areas of NFEPA, D'MOSS and properties affected by the 300mm SLR impact on the eThekwini southern coastline (Umkomaas coastal suburb)

Durban has a global reputation for the strong emphasis it has placed on how valuable the natural resource base is in Durban and the role it plays in guaranteeing urban sustainability and meeting the basic needs of people (Anguelovski et al. 2011). Ecosystems such as wetlands and estuaries, which fall under NFEPA, may be severely impacted and degraded, if these areas are not protected from future SLR impacts and associated extreme weather events. Consequently, the supply of water for both consumption and for the service industries will be contaminated due to the impacts of salt intrusion (Mills et al. 2020).

Durban Metropolitan Open Space System (D'MOSS)

A majority of the EM coastline is demarcated as D'MOSS as illustrated in Figure 6. Both natural vegetation and properties situated within D'MOSS are at high risk to future SLR impacts within 100m from the HWM. Natural environments within this zone typically comprise of coastal forests and coastal dunes which are valuable ecosystems. As laid out in Chapter Two, *M. caffra* is a protected species found within the coastal forest and dunes along the coast support a high diversity of vertebrates. Therefore, protection of these natural areas is vital in order to maintain biodiversity.

The EMA faces many stresses on biodiversity and supplying ecosystem services. The largest of these are deemed to be the destruction of habitat, invasive alien species and pollution (Rouget et al. 2016). D'MOSS aims to safeguard the biodiversity assets and underlying ecological infrastructure in Durban and to achieve optimal ecosystem functionality and biodiversity conservation (Botes and Steenkamp 2020). D'MOSS is a formal policy, with a spatial planning layer of connecting open areas between the public, private and traditional authority land ownership that seek out to safeguard Durban's biodiversity and related ecosystem services for next generations (Botes and Steenkamp 2020). Since its formal adoption on 9 December 2021 by the EM council, D'MOSS has been incorporated into all municipal planning schemes as a control area or overlay layer.

Currently, only approximately 10% of the area demarcated as D'MOSS is safeguarded and 8.6% is managed out of suitable zoning of land for preservation, conservation servitudes and land procurement (Rouget et al. 2016). The D'MOSS areas that are not within areas that are managed formally go through an internal prioritisation process to identify areas that require protection on an ongoing basis. This process involves the management measures stated above, including stewardship programmes, which are utilised to secure open spaces for D'MOSS as a method of approval before establishing new developments (Rouget et al. 2016).

Zones of high biodiversity value and natural areas which fall under D'MOSS are managed by the relevant departments of EM for the protection of biota. Areas with properties which fall under D'MOSS, namely Umkomaas (refer to Figure 6), should consider co-managing to protect biodiversity. On the contrary, some properties in Umhlanga and Umdloti do not fall within D'MOSS land but may have natural areas which contain biodiversity. Therefore, the owners should take accountability to ensure that their properties, including natural areas, are well-managed through suitable adaptation measures. Nonetheless, Umhlanga and Umdloti are areas of high property value, therefore owners are likely to have the financial means/capacity to implement adaptive measures.

Developed areas (outside of NFEPA)

Increasing urbanisation is taking place in Durban, South Africa. There is, overwhelmingly, a relationship between urbanisation and deforestation, with deterioration, fragmentation and loss of the natural environment (Scheye and Pelser 2020). Amanzimtoti, Isipingo, Beachwood Country Club and Beach Bums in Westbrook are areas experiencing development pressures or impacts on coastal dunes and forests. Critical ecosystem services, for example the cleaning and storing of water, coastal protection, and lowering the air temperature of urban areas, could be compromised and exacerbated by negative impacts of climate change on the ecosystems in Durban (Botes and Steenkamp 2020). The protection of ecological infrastructure is vital to ensure that the natural functioning of coastal ecosystems is unhindered so that they can deliver valuable ecosystem services to people in Durban. In response to potential negative impacts, Durban seeks to adopt an integrated planning approach with placing controls on development to safeguard the integrity as well as increase the functionality and resilience of the biodiversity and natural capital in the city (Botes and Steenkamp 2020).

The main guiding document for the EM and its residents in responding to these issues is the Integrated Development Plan (IDP). The IDP acknowledges that the services which ecosystems provide are essential to reach the municipality's growth and development needs, including all its residents and visitors. EM recognises that the ecosystem services provided by its natural areas may deliver important protecting opportunities for local communities and infrastructure against the negative climate change impacts (Botes and Steenkamp 2020). The management and protection of healthy ecosystems also help to deliver on the Strategic Priorities expressed in the IDP.

Natural Protected Areas (NPAs)

There are nine NPAs under DFFE and seven NPAs under SANBI within EM. Three are situated along the coast, which comprise of one Marine Protected Area (south, between Scottburgh and Umkomaas) and two Nature Reserves (Beachwood and Umhlanga). The other NPAs are Nature Reserves and are situated inland (Figure 7 and Table 2). All NPAs under SANBI are Provincial Nature Reserves and are managed by Ezemvelo KZN Wildlife. The NPAs under DFFE are all Nature Reserves and are legally designated. The NPAs under DFFE and SANBI overlap as shown in the Figure 7 but are managed by different organisations. The map showing the NPAs were generated using the interactive tool available in the CoastKZN website.

Using the current SLR projections (Mather 2009), it is evident that the NPAs between Scottburgh and Umkomaas, Beachwood and Umhlanga, which are biodiversity hotspots, will be impacted. Consequently, species diversity and ecosystems will be affected, potentially negatively impacting on people's livelihoods through a loss of ecosystem services. Therefore, relevant authorities such as SANBI, DFFE, etc. will have to take cognizance of these potential impacts.

The South African National Biodiversity Institute (SANBI) heads up and coordinates research, and monitors and reports on the condition/level of biodiversity in South Africa, as well as offers services such as knowledge and information sharing, provides planning and policy advice and partners with stakeholders to pilot best-practice management models. The Department of Forestry, Fisheries and the Environment (DFFE) is in the forefront of providing guidance and direction in environmental management, utilisation, conservation and protection of ecological infrastructure in the hopes of achieving sustainability, which will be advantageous to both South African citizens and the community across the world. KZN Wildlife, the governmental organisation responsible for biodiversity conservation in KZN, together with SANBI and the DFFE, previously known as the Department of Environmental Affairs (DEA), will need to ensure that these areas are protected from SLR and extreme events and their associated impacts. For example, they work together on facilitating research focused on mitigating the negative impacts of climate change and SLR on coastal ecosystems and disseminate findings to the National Biodiversity Assessment (NBA).

Table 2: List of NPAs under DFFE and SANBI within EM

Name of NPA	**Reserve Type**	**Legal Status**	**Management Agent**	**Location**
Aliwal Shoal MPA	Marine Protected Area	Designated	Ezemvelo KZN Wildlife	Coastal
Beachwood Mangroves Nature Reserve	Nature Reserve/Provincial Nature Reserve	Designated	Ezemvelo KZN Wildlife	Coastal
Umhlanga Lagoon Nature Reserve	Nature Reserve/Provincial Nature Reserve	Designated	Ezemvelo KZN Wildlife	Coastal
Hawaan Forest Nature Reserve	Nature Reserve	Designated	Ezemvelo KZN Wildlife	Inland
Bluff Nature Reserve	Nature Reserve/Provincial Nature Reserve	Designated	Ezemvelo KZN Wildlife	Inland
Kenneth Stainbank Nature Reserve	Nature Reserve/Provincial Nature Reserve	Designated	Ezemvelo KZN Wildlife	Inland
North Park Nature Reserve	Nature Reserve/Provincial Nature Reserve	Designated	Ezemvelo KZN Wildlife	Inland
Krantzkloof Nature Reserve	Nature Reserve/Provincial Nature Reserve	Designated	Ezemvelo KZN Wildlife	Inland
Palmiet Nature Reserve	Nature Reserve	Designated	Ezemvelo KZN Wildlife	Inland

Establishing NPAs was recognised as a means to guarantee the preservation of biodiversity and protection of ecosystem services (Rouget et al. 2016). Managing NPAs effectively can enhance ecosystem services, along with high levels of biodiversity and is vital for either controlling procedures and purposes of ecosystem services or immediately supplying them (Rouget et al. 2016). In cities, there are reduced opportunities for overseeing biodiversity because of conflicting pressures for land. For example, in EM, there is a continuous increase in transformation and deterioration of the environment due to poverty and considerable social need. This exacerbates management of biodiversity and ecosystem services within an urban setting (Rouget et al. 2016).

In addition to the numerous pressures on ecosystem services in an urban framework, it is important to identify and manage ecosystem services in priority areas to guarantee the supply of these services are ongoing for human welfare and sustainable socio-economic development (Rouget et al. 2016). For EM, a valuation of ecosystem services/biodiversity hotspots linked to land ownership/management agent will be beneficial by providing an understanding into the possible opportunities and challenges for the protection and management of ecosystem services, which is essential to support human development. For ecosystem services and biodiversity to be managed successfully, a multidisciplinary method that includes a variety of stakeholders is required (Rouget et al. 2016).

EM is seeking an independent conservation strategy for ecosystem services which is related to safeguarding biodiversity (Rouget et al. 2016). This strategy aims to include procedures to guarantee that ecosystem services are considered during planning/development processes either through expanding NPAs, in evaluating applications for development, through suitable zoning of land, gaining land by management authorities and by applying stewardship programmes in areas owned jointly or privately. For joint management of biodiversity and ecosystem services, a process of priority in selecting areas (i.e., ecosystem service of important values with little biodiversity values, or important biodiversity values with little ecosystem service values) may be necessary, depending on what the management is aiming for (Rouget et al. 2016). Umkomaas, Widenham, Clansthal and Cave Rock at the harbour opening are biodiversity hotspots and, therefore these areas should be considered as priority areas for biodiversity conservation as these areas have high species richness, endemism and threat.

Figure 7: Map showing natural protected areas under SANBI and DEA in eThekwini Municipality, KZN (CoastKZN^{TM}, 2020)

Conservancies

Conservancies, which focus on community-based conservation, are a crucial constituent in the ecological systems of safeguarding and conservation of sites with high levels of biodiversity in a region (Hannan 2007). Conservancies found along the coastline and between rivers can be classified as 'coastal systems'. These conservancies should therefore be holistically managed, rather than disconnected ecosystem units with no interactions (Hannan 2007).

There are six Ezemvelo Conservancies within EM. Three conservancies, namely University of KwaZulu-Natal's Westville and Durban campuses and Mt Moreland are situated inland (CoastKZN 2022). The other three conservancies are found along the coast and are at risk to future SLR impacts. These are Renishaw (south, between Scottburgh and Umkomaas), Bluff Ridge (central Durban, near the Harbour opening) and Dolphin Coast (north) conservancies (Figure 8).

There is a large focus, globally, on the effects of climate change on biodiversity. Risks for ecosystems were assessed bearing in mind physical, structural, genetic, and biogeochemical aspects (IPCC 2019). Greater risks connected with multiple consequences of climate hazards consist of loss in habitat and biodiversity, the composition of species and dispersal ranges shifting, and impacts on ecosystem composition and operation. The anticipated SLR impacts on ecosystems within the coastal zone by 2100 include shrinkage of habitat, functionality and loss of biodiversity, and lateral and inland migration (IPCC 2019). Impacts will be intensified in circumstances where hard built barriers impede inland migration of certain ecosystems and reduce the accessibility and transfer of sand. Fauna and flora found along the coast in Renishaw, Bluff Ridge and Dolphin Coast are particularly vulnerable to CC impacts as these areas are at high risk of losing diversity and changes in ecosystem composition and operation (Bindoff et al. 2019). Therefore, conservation of these conservancies can aid in sustaining the various ecosystem services they support and help with climate change adaptation by way of enhancing vital habitats for biodiversity and protecting communities along the coast from sea storm events and SLR (IPCC 2019).

Figure 8: Map showing Ezemvelo Conservancies in eThekwini Municipality (CoastKZN^{TM})

Estuaries

There are 16 estuaries within the study area (Figure 9). There are 13 estuaries that are temporarily open/closed, two estuaries that are permanently open, namely uMkhomazi and uMngeni, and one estuarine bay (Durban Bay). All 16 estuaries are categorised as crucial biodiversity areas. A major consequence would be a rise in sea level, which lets additional saline water to enter these estuaries. The intrusion of saline water into fresh riverine water can further affect stratification in estuaries, causing an unbalance in the water column which will have a great impact on the biophysical aspects of estuaries (Mills et al. 2020). The projected SLR for EM is 300mm at a rate of 2.7mm per year, however sea level may increase at a much faster rate and could reach the 300mm (0.3m) mark way before 100 years. Most of the ocean surface (98%) has experienced significant SLR over the period 1993 – 2015. The GMSL in 2050 will rise between 0.1 – 0.4m higher than SLR in 1995 – 2014 under low and moderate emissions scenarios and under high emissions scenarios the sea level will rise between 0.1 – 0.6m more (Fox-Kemper et al. 2021). Consequently, estuaries will become more vulnerable to SLR impacts. Therefore, implementing adaptation initiatives, together with mitigating carbon emissions, can help slow down the rate of current SLR and projected extent in EM, therefore reducing the inflow of saltwater into estuaries and avoiding impacts on its physical properties.

Figure 9: Map showing estuarine functional zones in eThekwini Municipality (CoastKZN™)

4.4. Analysis of developments potentially impacted by future SLR

Table 3 presents the estimated value of properties along the EM coastline using data obtained from eThekwini Municipality's Valuation Roll focused on those properties deemed to be at risk. Properties deemed to be at risk of SLR impacts were those that are located within the 300mm SLR zone as per modelled SLR projections reported by Mather (2009). Following the mapping and delineation of properties (Figures 5 and 6), this study identified a total of 112 properties in this zone that may potentially be impacted by a 300mm rise in sea level (Table 3). The total estimated value of property loss is R629 282 000,00 and the total area of potential loss of properties is 34 428,97m^2.

Table 3: Total properties, estimated value of property loss and area of potential loss of properties impacted by 300mm SLR in suburbs along the EM coastline

Suburbs	**No. of properties**	**Market value of properties (R)**	**Area (m^2)**
Westbrook	1	R3 120 000	229,68
Umdloti	51	R153 540 000	12 558,12
Umhlanga Rocks	35	R403 080 000	7 322,21
Amanzimtoti	5	R9 990 000	3 180,21
Umkomaas	20	R59 552 000	11 138,75
Total	**112**	**R629 282 000**	**34 428,97**

Table 4 presents the estimated value of potential loss of properties in Amanzimtoti using data obtained from eThekwini Municipality's Valuation Roll. This was also done for Westbrook, Umdloti, Umhlanga and Umkomaas. However, for the Umhlanga suburb, there is an additional category for property value (> R20 million) as one of the properties at risk has a market value of R284 million. The total number of properties in Umdloti potentially impacted by a 300mm SLR is 51 properties, with most properties situated within blocks 14, 16, 17 and 18. Furthermore, the estimated cost of potential loss for these properties range between R1 - R10 million with a total estimated value of property loss amounting to R153.5 million. A total of 35 Umhlanga Rocks properties occurred within the 300mm SLR line, mostly within blocks 13 and 19. The estimated median property value of potential loss within Umhlanga Rocks is R 5.97 million and the total estimated property loss is R403 million. In Amanzimtoti, there are only five properties that may be impacted by a 300mm rise in sea level (Table 4). The estimated costs of property loss range between R 1 million and R 10 million and the total estimated cost for property loss in this area amounts to R9 990 000,00. On the eThekwini Municipality's Valuation Roll, there was data for only three out of five properties in Amanzimtoti and the total value for these three properties added up to R 9 990 000. Lastly, in Umkomaas 20 properties are at risk to a 300mm SLR. Most properties that will be affected are found in block 5. The estimated cost of individual property loss ranges between <

R 1 million and R 10 million, with a total loss calculated to R59.5 million. An abridged version of property evaluations is presented below and the other evaluations for the rest of the EM coastline are presented in the separate pdf file as Appendix C.

Table 4: Total properties and estimated property values impacted by 300mm SLR in Amanzimtoti, eThekwini Municipality

Location	**GPS co-ordinates**		**Property value**	**No. of properties**	**Estimated value of properties**
	Longitude	**Latitude**	< R 1 million		
Amanzimtoti			R 1 - 5 million		
Block 1	30º 53' 24.91" E	- 30º 03' 00.33" S	R 5 - 10 million		
			R 10 - 15 million		
			R 15 - 20 million		
				1	**No data**
Block 2	30º 53' 23.45" E	- 30º 03' 03.53" S	< R 1 million		
			R 1 - 5 million		
			R 5 - 10 million		
			R 10 - 15 million		
			R 15 - 20 million		
				1	**No data**
Block 3	30º 52' 22.49" E	- 30º 04' 29.96" S	< R 1 million		
			R 1 - 5 million	1	R1 060 000
			R 5 - 10 million		
			R 10 - 15 million		
			R 15 - 20 million		
Block 4	30º 52' 16.45" E	- 30º 04' 42.99" S	< R 1 million		
			R 1 - 5 million	1	R1 070 000
			R 5 - 10 million	1	R7 860 000
			R 10 - 15 million		
			R 15 - 20 million		
Total no. of properties				**5**	
Total value of properties					**R9 990 000**
Total Area (km^2)				**3180,21**	

The properties were delineated in sections or blocks and the area was calculated in ArcGIS. Table 5 presents the block identification in the first column, followed by the block length and area in successive columns. There is a mixture of both large size plots and small size plots of properties potentially at risk to future SLR impacts in almost all suburbs. However, the suburbs to receive the most potential loss of properties are Umdloti (12 558m^2) and Umkomaas (11 139m^2).

Table 5: Calculated area of properties impacted by 300mm SLR for each suburb along the eThekwini coastline

Name	Shape Length	Shape Area	Total Area (m^2)
Westbrook-1	0,000894649	229,68	
			229,68
Umdloti-1	0,001344242	474,84	
Umdloti-2	97,83551043	389,15	
Umdloti-3	0,000936806	388,30	
Umdloti-4	0,000621703	240,49	
Umdloti-5	0,000387341	79,03	
Umdloti-6	0,001270072	348,71	
Umdloti-7	0,000767301	280,93	
Umdloti-8	0,001772571	1009,81	
Umdloti-9	0,00176351	741,29	
Umdloti-10	0,001696249	658,91	
Umdloti-11	0,000779579	245,69	
Umdloti-12	0,001557179	695,04	
Umdloti-13	0,00170686	271,06	
Umdloti-14	0,005669214	1296,39	
Umdloti-15	0,001404107	608,56	
Umdloti-16	0,002778722	1163,60	
Umdloti-17	0,004154061	1333,40	
Umdloti-18	0,003241986	1419,44	
Umdloti-19	0,001082403	484,17	
Umdloti-20	0,001164369	429,33	
			12558,12
Umhlanga-1	0,000545405	161,84	
Umhlanga-2	0,000966265	223,50	
Umhlanga-3	0,000773862	109,24	
Umhlanga-4	0,000413225	65,00	

Name	Shape Length	Shape Area	Total Area (m²)
Umhlanga-5	0,00067731	222,97	
Umhlanga-6	0,002686191	1050,84	
Umhlanga-7	0,001279315	536,10	
Umhlanga-8	0,001269917	309,40	
Umhlanga-9	0,000328634	74,95	
Umhlanga-10	0,000356273	67,49	
Umhlanga-11	0,000429143	47,49	
Umhlanga-12	0,000560234	211,12	
Umhlanga-13	0,001727476	844,52	
Umhlanga-14	0,000776417	267,65	
Umhlanga-15	0,000603078	125,79	
Umhlanga-16	0,000848716	437,49	
Umhlanga-17	0,000892321	456,05	
Umhlanga-18	0,000500244	124,77	
Umhlanga-19	0,002980645	1601,98	
Umhlanga-20	0,000375085	87,34	
Umhlanga-21	0,000990259	296,67	
			7322,21
Amanzimtoti-1	0,000331004	76,36	
Amanzimtoti-2	0,002093177	553,29	
Amanzimtoti-3	0,001261753	510,93	
Amanzimtoti-4	0,001945467	2039,62	
			3180,21
Umkomaas-1	0,002361832	1366,57	
Umkomaas-2	0,001388828	637,85	
Umkomaas-3	0,000602009	157,35	
Umkomaas-4	0,000479666	131,89	
Umkomaas-5	0,004715148	2957,59	
Umkomaas-6	0,00376122	3250,70	
Umkomaas-7	0,000588597	228,17	
Umkomaas-8	0,000970547	381,02	
Umkomaas-9	0,001325536	1182,88	
Umkomaas-10	0,001652243	844,73	
			11138,75

Sea level is increasing and quickening over time, and it will remain to increase during the 21st century and beyond for centuries (Oppenheimer et al. 2019). Severe events of SLR that are previously uncommon, will turn out to be normal by the year 2100 under all emission scenarios, resulting in serious flooding without the use of any bold adaptation efforts (Oppenheimer et al. 2019). In both low and high emission scenarios, many low-lying coastal areas across many geographic regions will experience such events annually by 2050 (Oppenheimer et al. 2019). For the EM, based on current SLR estimations, the projected 300mm rise in sea level divided by the current rate of SLR for Durban (2.7 mm/yr) equates to 111.11 years, which implies that this is the time for sea level to reach the 300mm mark. However, latest science shows that the GMSL projections for the year 2050, across all emissions scenarios, are found between 100 and 400mm (Fox-Kemper et al. 2021). At the current rate of SLR, which is 1.38mm per year for the period 1901 to 1990, the 300mm setback in EM may not be conservative enough (Fox-Kemper et al. 2021). Therefore, this may not be appropriate to use for risk analysis of developments along the coastline. Understanding and utilising such information is useful for identifying those properties, situated in the 300mm area, which will be at risk to future SLR impacts and associated extreme events. For instance, in a scenario of an extreme storm event, wave height increases and may extend beyond the 300mm SLR mark. Those properties that were once categorised as moderate risk may have to be escalated to high risk. Therefore, calculating the number of years to reach a certain SLR scenario, as a risk factor, can help to identify property potentially at risk, and prevent future infrastructural damage as well as saving on costs to repair the damage and aid further projections with respect to extreme event impacts. In March 2007, the equinox storm caused about 100 million US Dollars in economic damages to private houses and public infrastructure along approximately 400km of the KZN coastline (Mather and Stretch 2012). Several houses were entirely lost or destroyed beyond financial repair and broken sewer network of pipes discharged raw sewage into the ocean for numerous months post-cyclonic event, following a prohibition on bathing along most common swimming beaches.

Ecosystem-based adaptation

Properties that are at potential risk to 300mm SLR impacts may be protected to some extent by vegetation which acts as a buffer. Ecosystem-based adaptation responses provide both protection and gains based on the sustainable management, preservation and rebuilding of ecosystems. Ecosystem-based adaptation measures protect the shoreline by attenuating waves and storm surges, by decreasing erosion rates through trapping and stabilising sediments on the coast, and creation of organic matter and detritus (Oppenheimer et al. 2019). The Durban beachfront has a dune rehabilitation programme where sand from the ocean floor is dredged to stabilise sand dunes. Also, fencing and timber boardwalks were erected, coupled with planting indigenous dune plants, which resulted in an extension of the frontal dune zone, thus enhancing coastal protection. Both private and public properties were found to be at risk to a 300mm rise in sea level within central Durban, as well as municipal infrastructure (e.g., piers) may be at risk.

On the foreshore where there is a longshore drift feeding sand along the coast, and sufficient space between development and the HWM, a natural dune cordon system is the optimum erosion buffer to SLR impacts. These should be established in areas along the coastline where extra defence is required (Mather 2008). Homeowners ought to be encouraged to rebuild and restore the dune cordon systems between their houses and the ocean. However, if it is difficult to replicate the natural dune cordon, soft engineered methods, such as the use of synthetically vegetated dunes, can be considered (Mather 2008). Sand that is replaced can be collected within geo-fabric bags placed at an angle up the erosion gradient to prevent further loss of sand at the base of the dunes and letting some wave run-up over the slanting construction, thus decreasing the wave energy (Mather 2008). Moreover, properties within the 300mm SLR area are highly vulnerable to future SLR impacts but also play a role as a first line of defence for the row of houses behind them. Nevertheless, these houses beyond the 300mm mark are designated in this study to be at moderate risk. However, in abnormal conditions like the 2007 event, moderate risk is categorised as too low. The risk classification does not take into account extreme events (for example, 1/100 year floods/storms).

Municipal Infrastructure

The cost of damage to municipal infrastructure along the EM coastline following the 2007 storm was R47 840 000 (capital projects) and the total estimated cost of repairs was R2 190 000 (operational damages). The Saros equinox spring tide had been recognised in the beginning of September 2006 as a likely period of vulnerability for the coast at Durban, especially for properties along Eastmoor Crescent, La Lucia, located north of Durban (Mather 2008). However, the city was not ready for the full impact of this event. Existing international best practice on SLR is a managed coastal retreat which reduces the growing risk of erosion and destruction along the coastline due to SLR. The removal of structures and retreating inland to provide more space for the fluctuation of the coastline to take place will lower the risk of destroying infrastructure and will in the end avoid frequent continual loss of this infrastructure, thus emphasising the idea of sustainability (Mather 2008). However, parts of the coast which have been developed and make up of a portion of the financial and tourism resources of the municipality will require prudent assessment of the advantages and disadvantages of not retreating.

The challenges for future SLR and increased extreme events include high levels of uncertainty and limited data, which makes it almost impossible for insurance companies to determine and calculate insurance premiums, specifically risk, vulnerability and future losses for properties (Warren-Myers et al. 2018). As a result, how insurance companies respond to houses that are potentially at risk could be varied. The costs of insurance, rising premiums and the likelihood of absence of insurance for houses in specific locations could leave some properties uninsurable. This raises concerns regarding who pays for the damaged or destroyed property. In Queensland, Australia, both the government and taxpayers had to cover the costs of post-event damages, due to not having comprehensive insurance. This placed a burden on taxpayers who almost had to pay 5.6 billion Australian dollars for flood destruction in Queensland (Warren-Myers et al. 2018). There should be a shift on focusing on researching and applying adaptive measures to reduce the impacts.

There was no data for the apartments/hotels in all suburbs (except Westbrook) that were identified as being at risk. The total value of properties impacted by a 300mm SLR could, therefore, be greater than R629.2 million. The average value of properties in these suburbs are very wealthy and located very close to the sea. Wealthy people can afford to live here, even though the properties are located in areas vulnerable to SLR impacts. Following the 2007 storm event, insurance companies were ready to pay the expenses of renovating the broken features for private landowners. Nevertheless, the private landowners were stuck between the local government and the insurance companies if owners proceeded with renovations (Mather 2008). There was no promise that the local government would agree to the renovations, putting the landowners at risk of being subjected to instructions to get rid of the mediation. If this occurred, the insurance companies had made it apparent to the landowners that companies would not pay the expenses again (Mather 2008).

Planning adaptation action in Durban needs to fit in with eThekwini Municipality's resources, capacity, and adaptation timelines. The detrimental outcome from the 2007 storm is a reflection of the city not being ready to respond to the storm event. However, the city's preparedness to such events has increased based on what was recognised during and after the repercussions. The EM implemented both a retreat and a do-nothing response following the March 2007 event (Corbella and Stretch 2012b). Minor structures owned by the public were moved out of vulnerable regions in the wake of their collapse, without any public complaints. Privately owned natural spaces were not covered with municipal funds and many of these spaces recovered naturally (Corbella and Stretch 2012b). The local government department is not obligated to offer any coastal protection for private homeowners. Nevertheless, they have a responsibility of care to make sure that any development that is proposed is sustainable and that each homeowner is provided some support to create hybrid coastal protection methods (Mather 2008). Local government ought to promote a collaborative method by impacted homeowners. Private homeowners must stay compelled to sustain any coastal defence structure they create. Also, homeowners must be held responsible for any malfunction, especially where such malfunction may impact on other houses or people along the coastline (Mather 2008). Similarly, in the Knysna municipality, investments are being made in the constant maintenance of the sea wall at Leisure Island to ensure that the coastal road and coastal edge is protected (O'Donoghue et al. 2021). However, due to limited budget constraints, assistance from the municipality to private properties has been limited which resulted in rich landowners constructing seawalls to protect their properties as they could afford sea defence. However, these interventions were not approved by the municipality and often led to an increase in coastal erosion impacts, as the risk is moved to further along the coastline (e.g., in Milnerton, Cape Town). Coastal municipalities taking a strong lead in coastal planning and adaptation to CC is important. The Knysna municipality has initiated a means of guaranteeing that integrated coastal management and adaptation plans are included into the municipality's spatial development framework (O'Donoghue et al. 2021).

4.5. Risk assessment of coastal ecosystems

This study employed methods by the Palmer et al. (2011) study to assess vulnerability along the EM coastline. However, the physical parameters were measured on orthophotographs of 2019. The criteria for selecting areas of interest for this study are coastal ecosystems, namely dunes and forests, that 1) contain *M. caffra* trees (a protected species), 2) areas situated in the high-risk zone (as per the CVI), and 3) provides coastal protection to property and/or infrastructure (example of an ecosystem service). The final sites chosen for the risk assessment are the Sibaya Forest and the Clansthal Beach areas. Table 6 below contains the measurements of the CVI physical parameters for both sites. The CVI values were categorised into low, moderate and high vulnerability based on an equation to calculate the total relative CVI score, as highlighted in Chapter Three. In the Sibaya site (cells 1 to 42), transect one falls within the moderate risk zone, as per the CVI, and transects two to four are situated within the high-risk zone. In the Clansthal site, cells 43 to 59 fall within the moderate risk zone which contains all four transects; cells 60 to 80, however, are situated in the high-risk zone. The rating of physical parameters is in table 1 in Palmer et al. (2011).

Table 6: Measurements of CVI physical parameters for both Sibaya and Clansthal sites

Cell/block Number	Beach width	Dune width	Distance to 20m isobath	Distance of vegetation behind the back beach	Percentage outcrop	CVI score	Risk level
1	46m	46m	1km	130m	$(199m^2/2500m^2)$ x100=8%	21	High
2	43m	30m	0,99km	129m	$(70m^2/2500m^2)$ x100=3%	22	High
3	44m	26m	0,98km	136m	$(141m^2/2500m^2)$ x100=6%	22	High
4	47m	20m	0,96km	133m	$(243m^2/2500m^2)$ x100=10%	22	High
5	50m	37m	0,95km	125m	$(126m^2/2500m^2)$ x100=5%	21	High

Cell/block Number	**Beach width**	**Dune width**	**Distance to 20m isobath**	**Distance of vegetation behind the back beach**	**Percentage outcrop**	**CVI score**	**Risk level**
6	54m	32m	0,94km	121m	0%	21	High
7	56m	27m	0,92km	129m	0%	21	High
8	51m	26m	0,9km	121m	0%	21	High
9	48m	35m	0,86km	135m	($230m^2/2500m^2$) x100=9%	22	High
10	45m	25m	0,84km	168m	($629m^2/2500m^2$) x100=25%	20	High
11	45m	26m	0,81km	175m	($403m^2/2500m^2$) x100=16%	21	High
12	48m	21m	0,79km	194m	($609m^2/2500m^2$) x100=24%	21	High
13	47m	21m	0,76km	17m	($957m^2/2500m^2$) x100=38%	22	High
14	57m	24m	0,76km	66m	($629m^2/2500m^2$) x100=25%	21	High
15	43m	30m	0,74km	179m	($531m^2/2500m^2$) x100=21%	20	High
16	46m	39m	0,76km	146m	($398m^2/2500m^2$) x100=16%	21	High
17	52m	31m	0,77km	152m	($366m^2/2500m^2$) x100=15%	20	High
18	50m	31m	0,77km	150m	0%	21	High
19	50m	27m	0,76km	131m	0%	21	High
20	48m	43m	0,76km	160m	($59m^2/2500m^2$) x100=2%	22	High
21	46m	26m	0,76km	171m	0%	22	High
22	46m	39m	0,76km	168m	0%	22	High
23	45m	26m	0,77km	192m	0%	22	High
24	48m	27m	0,78km	202m	0%	21	High
25	51m	24m	0,75km	208m	0%	21	High
26	48m	34m	0,77km	217m	0%	21	High
27	43m	31m	0,8km	226m	0%	21	High

Cell/block Number	**Beach width**	**Dune width**	**Distance to 20m isobath**	**Distance of vegetation behind the back beach**	**Percentage outcrop**	**CVI score**	**Risk level**
28	45m	25m	0,83km	243m	0%	21	High
29	50m	36m	0,83km	247m	0%	20	High
30	53m	28m	0,81km	271m	0%	20	High
31	45m	32m	0,81km	305m	0%	21	High
32	43m	30m	0,79km	332m	0%	21	High
33	46m	25m	0,8km	354m	0%	21	High
34	46m	30m	0,79km	386m	0%	21	High
35	50m	39m	0,8km	396m	0%	20	High
36	51m	18m	0,81km	356m	0%	21	High
37	49m	8km	0,8km	368m	0%	22	High
38	43m	20m	0,77km	363m	0%	22	High
39	39m	21m	0,77km	375m	$(8m^2/2500m^2)$ x100=0.3%	22	High
40	40m	32m	0,75km	373m	$(5m^2/2500m^2)$ x100=0.2%	21	High
41	36m	45m	0,74km	373m	$(150m^2/2500m^2)$ x100=6%	21	High
42	46m	38m	0,72km	391m	$(354m^2/2500m^2)$ x100=14%	20	High
43	56m	47m	1,72km	111m	$(506m^2/2500m^2)$ x100=20%	19	High
44	60m	56m	1,77km	45m	$(812m^2/2500m^2)$ x100=32%	18	Moderate
45	71m	49m	1,84km	119m	$(960m^2/2500m^2)$ x100=38%	18	Moderate
46	80m	41m	1,83km	86m	$(769m^2/2500m^2)$ x100=31%	19	High
47	81m	43m	1,76km	104m	$(468m^2/2500m^2)$ x100=19%	19	High
48	79m	47m	1,8km	97m	0%	21	High
49	81m	51m	1,83km	27m	0%	20	High
50	84m	48m	1,83km	86m	0%	21	High

Cell/block Number	Beach width	Dune width	Distance to 20m isobath	Distance of vegetation behind the back beach	Percentage outcrop	CVI score	Risk level
51	83m	45m	1,82km	89m	0%	21	High
52	81m	42m	1,83km	92m	0%	21	High
53	75m	44m	1,83km	95m	0%	21	High
54	69m	43m	1,8km	102m	0%	20	High
55	66m	43m	1,78km	104m	0%	20	High
56	69m	38m	1,75km	110m	0%	20	High
57	60m	49m	1,73km	112m	0%	20	High
58	60m	47m	1,7km	41m	0%	21	High
59	63m	47m	1,67km	18m	0%	21	High
60	60m	21m	1,55km	20m	0%	22	High
61	56m	24m	1,57km	30m	0%	22	High
62	45m	14m	1,6km	18m	0%	23	Very high
63	47m	9m	1,62km	42m	0%	23	Very high
64	48m	8m	1,61km	31m	0%	23	Very high
65	53m	5m	1,65km	28m	0%	22	High
66	49m	4m	1,68km	34m	0%	23	Very high
67	45m	10m	1,69km	46m	0%	23	Very high
68	47m	8m	1,7km	19m	0%	23	Very high
69	60m	25m	1,71km	29m	0%	21	High
70	55m	54m	1,73km	10m	0%	20	High
71	70m	43m	1,75km	110m	0%	20	High
72	77m	33m	1,77km	101m	$(61m^2/2500m^2)$ x100=2%	20	High
73	53m	27m	1,78km	96m	$(163m^2/2500m^2)$ x100=7%	21	High
74	61m	33m	1,77km	88m	$(956m^2/2500m^2)$ x100=38%	19	High
75	48m	40m	1,74km	83m	$(1685m^2/2500m^2)$ x100=67%	19	High
76	47m	46m	1,75km	77m	$(1014m^2/2500m^2)$ x100=41%	20	High

Cell/block Number	Beach width	Dune width	Distance to 20m isobath	Distance of vegetation behind the back beach	Percentage outcrop	CVI score	Risk level
77	51m	37m	1,75km	71m	($1147m^2/2500m^2$) x100=46%	19	High
78	43m	52m	1,76km	55m	($1730m^2/2500m^2$) x100=69%	18	Moderate
79	40m	103m	1,71km	48m	($1043m^2/2500m^2$) x100=42%	19	High
80	36m	167m	1,68km	36m	($1198m^2/2500m^2$) x100=48%	18	Moderate

In Sibaya, cells 1 to 6 are within the moderate risk zone (refer to Figure 10). However, the beach width, distance to 20m isobath and percentage outcrop rank high as per the CVI rating of physical parameters. On the contrary, cells within the high-risk zone (cells 7 to 42), the vulnerability index values mainly fall within the high range except for distance of vegetation behind the back beach and the percentage of outcrop (cells 10 to 17, 42). In Clansthal, cells 43 to 59 are within the moderate risk zone and the vulnerability index values mainly fall within the moderate range except percentage outcrop for cells 48 to 59 which rank as high as per the CVI rating of physical parameters (refer to Figure 11). In addition, a few cells for distance of vegetation behind the back beach rank high because of the obstruction of property. The remaining cells (60 to 80) are within the high-risk zone. The vulnerability index values mainly fall within the high range except for distance to 20m isobath and percentage outcrop in cells 74 to 80. Moreover, there are areas where the beach width and dune width rank moderate as per the CVI rating of physical parameters.

Beach width

The width of the beach affects coastal vulnerability by playing a role as a barrier, reducing wave energy (Musekiwa et al. 2015). The wider the beach, the larger the capability of the beach to reduce wave energy as well as the impacts of SLR and associated severe weather events. Also, the width of the beach is a substitute for the slope of the beach, as places with narrower beach widths are always steeper and have a lower capability to refract wave energy (Palmer et al. 2011). In both Sibaya and Clansthal sites, areas within “high” vulnerability have narrow beaches (i.e., a beach width of less than 50m). Subsequently, the capacity of these beaches to dissipate wave energy is reduced, therefore making these areas more vulnerable to SLR impacts and extreme weather conditions. In the Durban bight, beach widths currently ranging from 15m up to 90m offer little or not much buffer against several of the erosion predictions (Rautenbach and Theron 2018). Therefore, earlier sand nourishment is required in these areas if such progressive erosional trends are observed.

Dune width

The width of a dune provides an indication of coastal protection and gives an approximation of sediment available to buffer erosion and accommodate leeward deposition of materials originating from the sea (Palmer et al. 2011). In the high-risk zone, both Sibaya and Clansthal sites have narrow dunes. In Sibaya, there is little to no development, whereas Clansthal has properties situated on top of dunes near the shoreline.

Distance of vegetation behind the back beach

In Sibaya, the area within the high-risk zone has both moderate and low CVI values for distance of vegetation behind the back beach. In Clansthal, both the moderate and high-risk zones have high CVI values for distance of vegetation behind the back beach. There is a railway line, as well as properties, behind the back beach which may impede the movement of dunes landward (refer to Figure 13e). The high CVI values linked to natural physical parameters, for instance narrow beaches and dunes, however other values are immediately attributable to development and other human-induced adjustments to the coastal environment (Palmer et al. 2011). For example, developments existing in near proximity to the HWM may hinder the natural movement of dunes and beaches landward, thus decreasing their influence in avoiding structures herein being susceptible to risk.

Distance to the 20m isobath

The offshore distance to the 20m isobath relates to subtidal bedform and wave energy (Palmer et al. 2011). In terms of coastal vulnerability, the larger the distance from the shoreline to the 20m isobaths, the greater the refraction of wave energy and hence the larger the decline of erosive energy. Subsequently, a decrease in wave energy approaching the shoreline means there will be lower vulnerability to the impacts of extreme weather circumstances (Musekiwa et al. 2015). In Sibaya, the area demarcated as “high” vulnerability, including the area within the “moderate” zone have a distance to 20m isobath less than 1km. This indicates that this area along the shoreline is extremely vulnerable to SLR impacts and associated extreme weather events due to less wave energy being dissipated and reaching the shoreline. In Clansthal, on the other hand, areas demarcated as “high” have a distance to 20m isobath ranging between 1 – 2km. Therefore, wave energy approaching the shoreline can be reduced, thus ensuring lower vulnerability to SLR impacts and extreme weather events (e.g., sea storms). However, it should be noted that areas that have an offshore distance to the 20m isobath between 1 – 2km, but beach width less than 50m and dune width less than 25m may still categorise that area as having “high” vulnerability.

Percentage outcrop

The percentage of outcrop was established on the percentage of rocky outcrop visible along each transect (Palmer et al. 2011). In Sibaya, cells 1 to 6 are within the moderate risk zone. However, the percentage outcrop ranks high as per the CVI rating of physical parameters. On the contrary, cells within the high-risk zone (cells 7 to 42), the vulnerability index values mainly fall within the high range except for percentage outcrop (cells 10 to 17, 42). In Clansthal, cells 43 to 59 are within the moderate risk zone and the vulnerability index values mainly fall within the moderate range except percentage outcrop for cells 48 to 59 which rank as high as per the CVI rating of physical parameters. The remaining cells (60 to 80) are within the high-risk zone. The vulnerability index values largely fall within the high range except for percentage outcrop in cells 74 to 80. Beaches that have rocks and cliffs are resistant to erosion and SLR compared to muddy and sandy beaches, which are vulnerable to SLR (Hereher 2015).

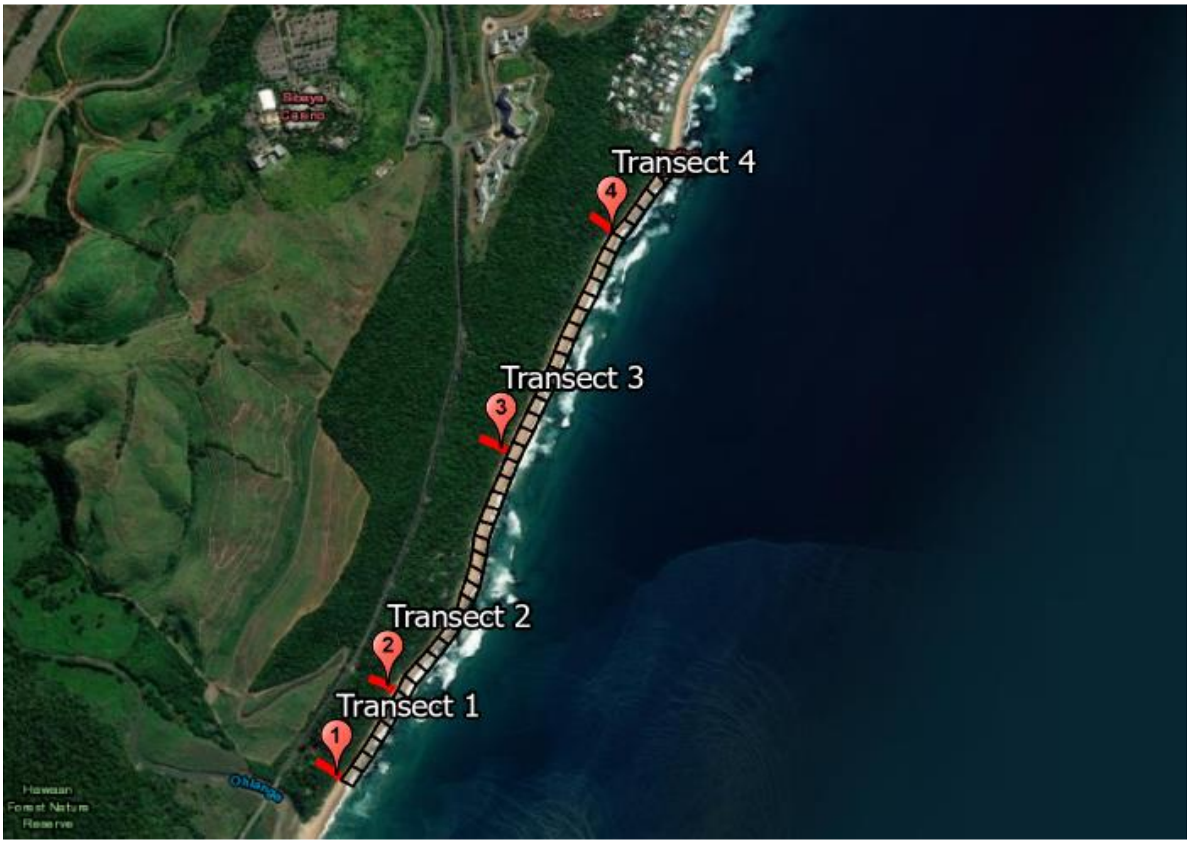

Figure 10: Map of the location of cells 1-42 as well as transects along a coastal strip at Sibaya Forest

Figure 11: Map of the location of cells 43-80 as well as transects along a coastal strip at Clansthal Beach (Mahlongwana River)

Climate Impacts on Coastal Ecosystems

The impacts of climate on the biodiversity, composition and operation of coastal ecosystems and the degrees of risk under different future circumstances of global warming have been assessed elsewhere, for example Bindoff et al. (2019). Coral reefs, seagrasses meadows, kelp forests and rocky shores are coastal ecosystems that are projected to be at incredibly high risk under RCP8.5 (Bindoff et al. 2019). The adaptive capacity of these ecosystems range between low to moderate due to them being extremely sensitive to ocean warming, marine heat waves and acidification. On the contrary, mangrove forests, estuaries and sandy beaches, and salt marshes are coastal ecosystems that will be at moderate to high risk under high emission scenarios (Bindoff et al. 2019). Estuaries and sandy beaches, in particular, will be at risk if global temperature rises to between 2.3ºC to 3.0ºC. Erosion in sandy beach ecosystems will persist with global warming, increasing sea level and more extreme and frequent storm surges and marine heat waves (Bindoff et al. 2019). The risk of habitat loss for vegetation and animals is likely to increase to high degree of risk under RCP8.5 by the end of the 21st century.

The rates of erosion are highest in areas with steep inclines, scant plant cover and areas with high population (UNESCO/IOC 2020). Human activity could be the main cause of degradation; nevertheless, natural erosion processes continue to be the leading cause in the ongoing degradation of the environment. Extremely flat/gentle slopes are easily flooded by sea intrusions, which is projected to worsen due to the forthcoming global SLR. Flooding along the coast from saltwater intrusion causes ecological stress through the loss of wetlands, flooding and erosion (UNESCO/IOC 2020). A study by Rangel-Buitrago and Anfuso (2015) calculated a coastal erosion risk index.

Coastal ecosystems at risk in EM

KZN had previously mapped the shore types (Harris et al. 2019). The vegetation types identified for the KZN coast are Dune-Scrub dune, Dune-Fore dune, Dune-Forest dune (Milkwood vegetation), Rocks, Sand, Development, and Other (Harris et al. 2012).

From the information above, a vegetation index for coastal ecosystems at risk for EM will be established in this study (Table 7). In addition to the CVI, this vegetation index can be used for assessing ecosystems at risk and will give a better sense of the resilience of ecosystems to coastal storm events. The parameters of this index are generalised so that it can be applied to most parts of the world.

Table 7: CVI rating of ecological parameters

Ecological Parameter	**Extremely Low (1)**	**Low (2)**	**Moderate (3)**	**High (4)**	**Very High (5)**
Vegetation type (ecosystems) (Bindoff et al. 2019)	X	X	Mangrove forests, estuaries and sandy beaches	Salt marshes, rocky shores	Coral reefs, seagrass meadows, kelp forests
Vegetation cover (Rangel-Buitrago and Anfuso 2015)	Unvegetated area	X	Bushes, stubble, grassland, bare rocks	X	Strategic ecosystems: salt marsh, marine seaweed, coral reef, lagoons
Beach slope (Rangel-Buitrago and Anfuso 2015)	Dissipative ($\tan \beta \leq 0.02$)	X	Intermediate ($0.02 < \tan \beta < 0.08$)	X	Reflective ($\tan \beta \geq 0.08$)

Protected species at risk: *Mimusops caffra*

In this study, the susceptibility of an important protected species, *Mimusops caffra* (*M. caffra*), to indirect SLR impacts, namely salt spray was assessed.

Observations from the survey on assessing the impact of salt spray on Milkwood between an area of open space and an area that is sheltered along the EM coastline found that there is deterioration evident for *M. caffra*, notably the front row of trees in Sibaya Forest, and no evidence of deterioration for trees situated further inland. However, in Clansthal there is little to no deterioration evident for *M. caffra*. A recent study by Jami et al. (2018) discovered that Botryosphaeriales (Dothideomycetes), one of the most widespread and cosmopolitan groups of fungi, is the possible cause of dieback on *M. caffra* trees growing on the east coast of South Africa. Based on a sample survey of the occurrence of chlorine-ions in leaf saps, the study concluded that the accumulation of chlorine-ions in plant saps depends more on the plant's metabolism than on environmental conditions (Meidner 1963). However, *M. caffra* situated closest to the ocean in Sibaya Forest are growing tilting towards the land, which may show that they are not tolerant to exposure of strong winds. However, there are some trees growing fairly straight in Clansthal. Lastly, *M. caffra* may not be resilient to coastal development as their occurrence is very low within developed areas (i.e., where trees are removed for coastal development). Trees are found growing in abundance near the sea, where there is very little disturbance (i.e., no developments), particularly in Clansthal.

Maps were drawn to show the transects carried out in Sibaya Forest (as illustrated in Figure 10) and Clansthal Beach (as shown in Figure 11) to determine the current extent of *M. caffra* trees along the eThekwini Municipality coastline. The Sibaya Forest has a steep dune face continuing into a relatively steep slope and becomes gradually flat before the M4 road. The vegetation is less dense and easily accessible to walk through. There is a general southerly wind direction with an average wind speed of 9 knots (https://www.windfinder.com/forecast/durban).

Clansthal beach has a flat plateau extending inland towards a railway line which posed as a barrier to carry out a complete transect (100m in length). Parts of the beach have a rocky outcrop. The majority of the coastal strip has very dense vegetation and some areas were not accessible to walk through the vegetation. This may be influenced by the proximity to an estuary. Presumably, there is more organic material in the soil closer to an estuary, and if so, this may be more favourable to seedling germination and establishment. Typically, organic material helps to hold water and nutrients. However, this would need to be tested to confirm if this is correct. This can be done through assessing soil organic material and testing germination rates of *M. caffra* in different soil types. There is a general southerly wind direction with an average wind speed of 10 knots (https://www.windfinder.com/forecast/durban).

Abundance, size, and dieback of *M. caffra*

For each site, an analysis of *M. caffra* trees was conducted across all transects, looking at abundance of species, tree height, dieback, and tree growth in 20m intervals (refer to Figures 10 and 11). In addition, the projected extent of *M. caffra* trees for each site was calculated.

In both the Sibaya Forest and Clansthal beach sites, within 20m along the transect line, including the 10m width band, there is an abundance of *M. caffra* trees throughout all transects, particularly transects one and two in Clansthal beach. At 40m along the transect line, the number of *M. caffra* trees declines sharply, with almost all transects not having any *M. caffra* trees (except transect two in Sibaya Forest and transect three in Clansthal). Between 60 – 80m, there are no *M. caffra* trees in both sites, except transect three in Clansthal which has one tree. However, at 100m, the end of the transect, the numbers of *M. caffra* trees slightly increases, particularly in transects one and three in Sibaya Forest, but no trees were recorded in all transects in Clansthal beach.

In both sites, within 10m along the transect, the *M. caffra* trees are short (approximately between 1 – 1.5m). In Clansthal beach, the shoreward side is dominated by young *M. caffra* trees and are growing in clumps/bushes (e.g., transect four). From 10 – 30m, the trees are taller (approximately between 2 – 6m) and are more mature in age. In transect three in Sibaya Forest, the trees look roughly to be over 100 years old. In transect three in Clansthal beach, there are two trees flowering. At 50m along the transect line, the *M. caffra* trees are larger in size and the height significantly increases (approximately between 10 – 20m). In Clansthal, the trees are in fairly good condition in all transects throughout the 100m transect line and within the 10m width band, but in Sibaya Forest only from 50 – 100m are the trees in healthy condition (refer to Figure 12a). In Sibaya Forest in transect two, the first tree has fallen at roughly 27m along the transect line.

Within 30m along the transect line, in transects three and four in Sibaya Forest, as well as transect three in Clansthal, the *M. caffra* trees show significant dieback (e.g., top of branches). Sibaya Forest is located south of Umdloti and Ballito. Smith et al. (2007) studied the impact of the March 2007 storm at Ballito, north of the Sibaya Forest. The impacts at Ballito were significant due to the low coastal profile (between 0 – 15m a.m.s.l.) directly exposed to maximum force of large swells, which resulted in minimal refraction and dissipation of wave energy. Furthermore, the beach which contains a mixture of rock and sand was severely impacted due to the presence of rock shelf located higher than the scour depth, therefore the breaking of wave energy was dissipated downwards as scouring and in the process enhanced coastal erosion (Smith et al. 2007).

An increase in sea level, storm surge, changes in sand supply and abnormal wave and tide conditions can cause shorelines to change, as illustrated in Figure 13d. The new line of vegetation in (d) was probably created by the 2007 storm or in the season after when there were no sandbars protecting the shoreline. The Bruun's rule is the common model used to measure a shoreline profile's response to SLR (Alvarez-Cuesta et al. 2021).

On the KZN coast north of the Tugela River mouth, sediment availability controlled by shoreline erosion significantly influences the width and volume of the beach, as well as dune behaviour (Olivier and Garland 2003). Foredunes retreat inland as a result of erosion of the dune's offshore edge and deposition on its sheltered side by wind. However, this pattern of sediment movement is more complex. The sea level off the coast of Durban is increasing by 2.7mm annually (Mather and Stretch 2012). International trends indicate that the rate of SLR is quickening and thus it could be likely that the rate of SLR for KZN will also accelerate. The amount of projected retreat for KZN in response to SLR is biggest for the area in the north (Harris 2008). However, this area is able to respond naturally to SLR as there is no development hindering movement of dunes.

Intense storms, such as the March 2007 storm in KZN, can erode beaches down to their bedrock, if no dunes are present, which was observed at Thompson's Bay in Ballito (Harris 2008). Consequently, the sandy beach, previously, became entirely empty of sand and was a rocky outcrop for a period of time post-storm until the sand returned. On the contrary, beaches that have a high resilience, for example at Sardinia Bay, are supported mainly by large sand dunes and the presence of a nearshore reef helps to dissipate a large amount of the wave energy before the waves get to the intertidal beach (Harris 2008).

The impact of storms will be felt the greatest where they are expansively superimposed over zones of lots of development, mainly beaches that are protected with hard engineering structures like seawalls (Harris 2008). From the March 2007 storm, observations demonstrated that erosion and alleged impact on the beach was much greater in the regions of intensive development compared to undeveloped regions. The increased frequency of intense sea storms impacting the coast is another great concern (Harris 2008). The majority of the disasters at the coast recorded each year are as a consequence of extreme weather events, and this is expected to increase. In KZN, many of the beaches are at risk of being starved from sand as a consequence of human activities, such as damming rivers and mining sand, occurring in catchments/rivers that decrease the movement of sediment through the system (Harris 2008). This may implicate the beach morphodynamic type as both the grading of sediment at local sites and offshore beach profiles may have changed. As a result, the combined action of SLR and storm surges has the potential to affect changes in sandy shorelines.

The low coastal profile at Sibaya Forest could also have been exposed to similar conditions which may have resulted in the severity of dieback in the *M. caffra* trees. However, there is no literature on the susceptibility of *M. caffra* to intrusion or damage during extreme events.

On the contrary, transects one and two in Clansthal, the *M. caffra* trees have limited to no dieback. This may be due to the presence of rocks offshore, in or beyond the intertidal zone which would have the effect of reducing the energy of the waves, and thus resulting in less salt spray and less erosion. Sandy and rocky coastal sections generally withstand the impacts from sea storms (Smith et al. 2007). However, this would need to be tested to confirm if it is correct. This can be done through assessing the number/extent of rocks present in and beyond the surf-zone in both sites, as well as assessing salt spray and wave energy. Beyond 30m up until the end of the transect (100m), there is no dieback in trees. The severity of dieback is significant in trees closest to the ocean and is less severe in trees further inland (refer to Figure 12c). Furthermore, the row of trees growing within 30m serve as a barrier against sea salt spray.

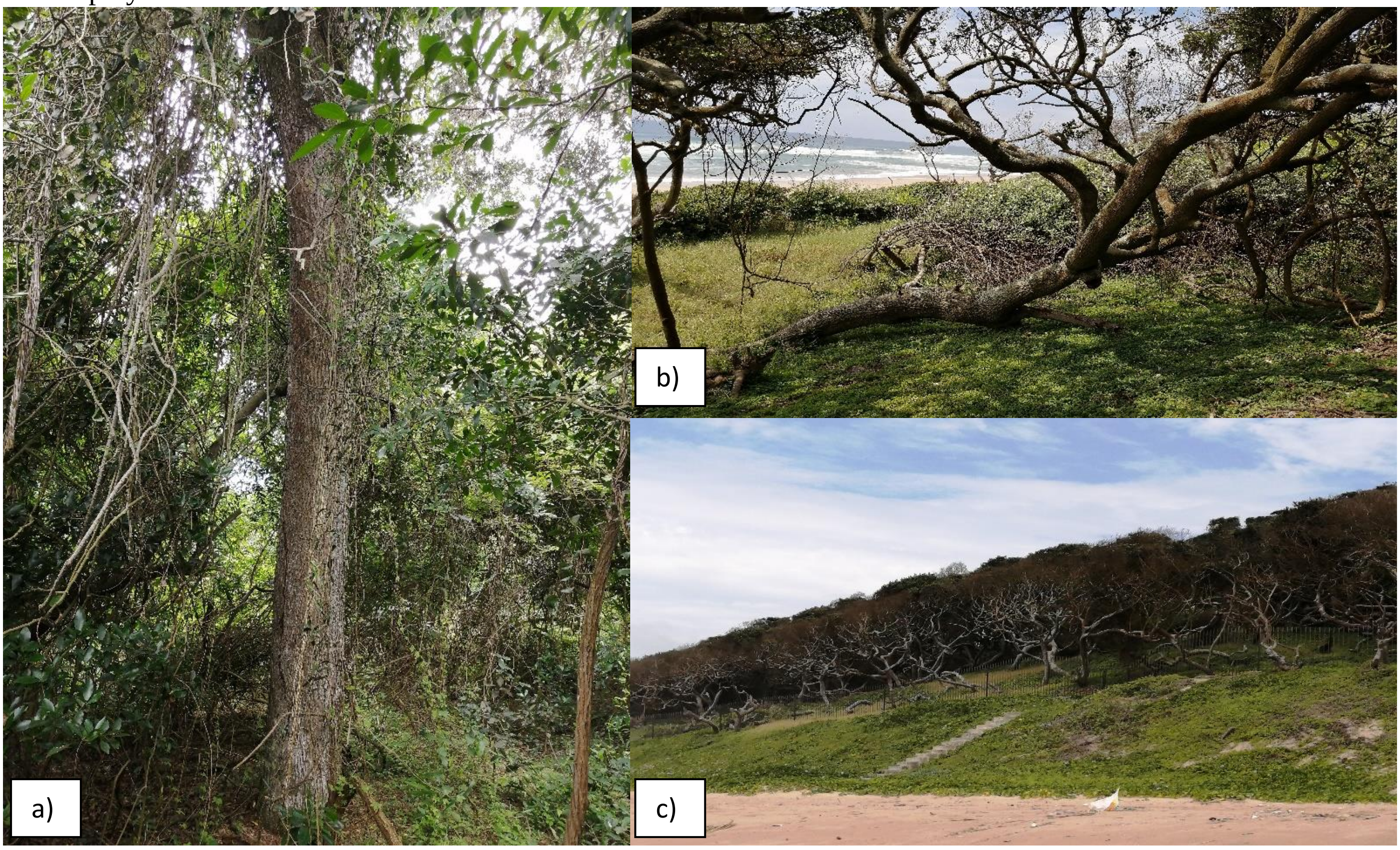

Figure 12: a) healthy *M. caffra* tree, no significant impact; b) tilting *M. caffra* tree growing landward; c) row of *M. caffra* trees along coast at Sibaya Forest showing significant dieback

In both sites, within 30m along the transect line and within the 10m width band, majority of *M. caffra* trees are tilting/bending landward (refer to Figure 12b) in all transects, except transects one and four in Clansthal. The trees herein have a slight bent on the treetop and growing fairly straight respectively. Wind shear may have impacted on the direction in which the trees grow, especially trees growing on the windward side and in the open (i.e., fully exposed and not sheltered). However, there is no scientific literature that can support this. This is evident in transect one in Sibaya Forest. The *M. caffra* trees in transect one in both Sibaya Forest and Clansthal beach have no significant impact to wind. The density in vegetation may have shielded/protected the trees from wind shear (refer to Figure 13f). Towards the end of the transect (100m), there is no significant impact by wind on trees except transect three in Sibaya Forest where there is one *M. caffra* tree tilting seaward.

The projected extent of *M. caffra* trees was calculated for each site. A visual inspection of the bush did not reveal any significant changes in vegetation morphology, therefore provides a rough estimate of projected extent of *M. caffra* in both sites. In Sibaya Forest, within 20m and between transects one and two, there is an average of five trees and the distance between transects one and two is roughly 350m, therefore a total of 35 10m blocks, which gives a rough estimate of 175 trees. Between transects two and three there is an estimated 350 trees and between transects three and four 880 trees. Within 20 – 40m between transects one and two, there is an estimated 280 trees and between transects two and three 704 trees. Lastly, within 80 – 100m between transects one and two, there is an estimated 105 trees; between transects two and three 88 trees and between transects three and four 80 trees.

At Clansthal beach, within 20m and between transects one and two there is an estimated 160 trees; between transects two and three 675 trees and between transects three and four 198 trees. However, there is an abundance of *M. caffra* trees growing in clumps/bushes in transect one and within the 10m width band in transect two, therefore the total projected number of trees may be more. Within 20 – 40m between transects two and three, there is an estimated 45 trees and between transects three and four 18 trees. The same number of trees is predicted for within 60 – 80m between transects two and three and transects three and four respectively. Rocky shorelines are fairly stable and do not experience erosion to the magnitude that sandy shorelines do. The key impacts of future SLR will be the rise in wave run-up levels causing vegetation loss at these locations (Mather and Stretch 2012). This is evident in Clansthal beach (refer to Figure 13d) where trees that were growing on the beach are now dying.

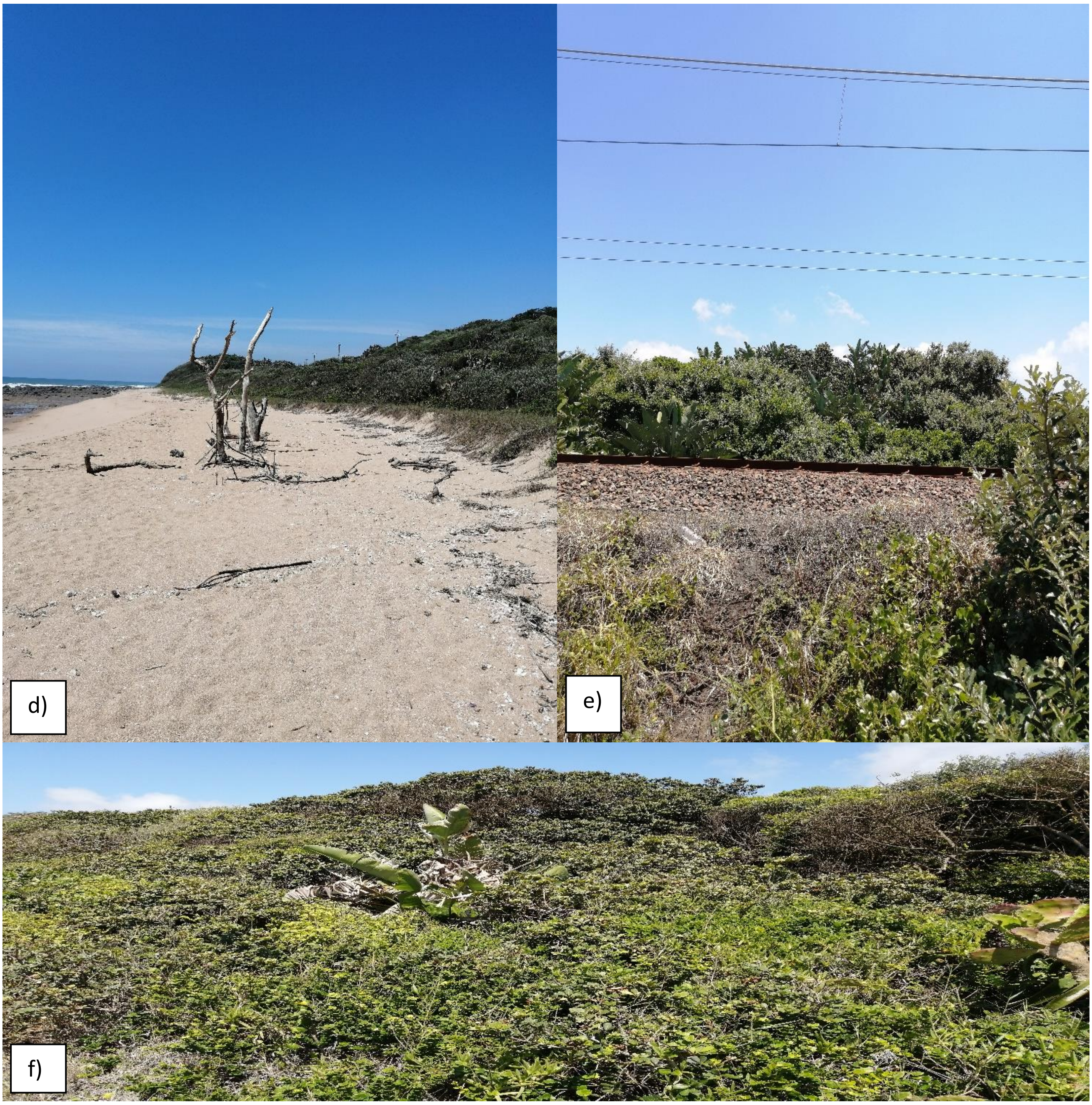

Figure 13: d) trees on the shore are at high risk to future sea level rise; e) a caveat in undertaking the transect (railway line barrier); f) dense vegetation along the coast

4.6. Conclusion

CVI analysis, classification of land use, developments impacted by a 300mm analysis, and the risk assessment of coastal ecosystems conclude that future SLR impacts will pose a threat to highly vulnerable areas along the eThekwini coastline in the next ±111 years if the current rate of SLR for Durban (2.74 mm/yr) remains constant. Affluent high costing properties that will be affected by a 300mm rise in sea level may have the capacity to implement adaptive measures to protect their property from SLR impacts. Land demarcated under D'MOSS and NFEPA, as well as protected areas, are accounted for by authorities to protect sensitive areas from SLR impacts. In summary, government and affected landowners should cooperate in efforts to ensure the safety and protection of both built-up and natural environments.

Coastal ecosystems are valuable assets in terms of providing protection for developments and municipal infrastructure, such as stormwater pipes and manholes against SLR impacts and sea storms. Implementing ecosystem-based adaptation solutions are economical options to lower climate risks and restore biodiversity. This, in turn, can help enhance resilience as well as safeguard vulnerable coastal communities (e.g., Dakota formal settlement) from these risks, including rising sea levels and fiercer storms. Coastal risk assessments can offer a better understanding of the resilience of ecosystems to coastal storm events. It can also be utilised to reduce coastal vulnerability, as well as assist coastal managers in making appropriate decisions for long-term planning.

CHAPTER FIVE: RECOMMENDATIONS AND CONCLUSION

5.1.Introduction

There is a widespread and growing concern that coastal cities will face a forthcoming and even more serious crisis with future SLR impacts as a consequence of climate change. Many stakeholders have made tremendous efforts in preparation for worst-case scenarios, including safeguarding vulnerable groups, such as coastal residents and natural areas. However, there still seems to be insufficient data for the South African coastline as well as historically poor data used when conducting vulnerability assessments (Palmer et al. 2011).

The CVI offers coastal managers with guidance on preparation and early warning perception for potential impacts (Palmer et al. 2011). Developments occurring along the coast in the CVI sites ranked as "high" are at high risk to future SLR impacts. In terms of future management, governmental agencies must make sure that developments near the HWM are not accepted. However, if there is a need for development to be built within the high-risk zone, careful consideration needs to be taken for the associated negative impacts that may occur (e.g., damage of property and infrastructure, as well as potential high maintenance costs). This will also have to be subject to the environmental impact assessment processes as legislated and must be formally authorised by the relevant governmental agencies for example the Department of Forestry, Fisheries and the Environment. In instances where developments already exist, but have been destroyed, building again in the same place ought to be evaluated or instead, the developments should be relocated to areas of lower risk (Palmer et al. 2011). Regarding the DDOP, a complex interactive system such as port infrastructure needs an adaptive approach based on actions which requires holistic implementation under adaptation measures (i.e., technology, management and policy) (Mutumbo 2017). In the face of future SLR, methods based on risk should include Black Swan events and to broaden the range of standard probabilistic evaluation which is evident in common procedure these days.

Regarding the estimated value of property loss impacted by 300mm SLR, the Umhlanga suburb has one property at risk with a market value of R284 million, which is 1/3 of the total value of properties (i.e., R629 282 000), therefore substantially skewing the data. Moreover, Umhlanga and Umdloti have the highest estimated value of property loss as well as contain the most properties at risk to a 300mm SLR. In this instance, public bodies are precluded from protecting private property in the coastal zone. No individual, possessor or inhabitant of land neighbouring the coastline or other public property within the coastal zone who may be affected by erosion or accretion may involve any national government body or any other individual to take actions to avoid coastal erosion or accretion or such other public property in the coastal zone, or of land neighbouring public property in the coastal zone, except when these coastal processes is triggered by a planned act or act of error by that State government body or other individual (SA 2009). Furthermore, no individual may build, preserve or expand any construction, or do other actions on public property in the coastal zone to avoid or support erosion or accretion of the coastline with the exception of those required for in the ICM Act. Societal understanding of the allocation and equity repercussions of SLR impacts and adaptation actions in coastal communities across the world is still limited (Martinich et al. 2013). On an international scale it is recognised that big investments will be required over the remainder of the 21st century for adapting to the impacts of SLR, as well as identifying the most vulnerable populations which have the least ability to adapt. This is still one of the biggest issues of dialogue amongst nations participating in global discussions to develop a climate pact. In addition, many studies have researched the need and benefits of guaranteeing fair access to resources that lessen vulnerabilities to a changing climate and enhance adaptive capacity (Martinich et al. 2013). However, at local and global scales, there is still uncertainty in regard to prioritising areas for resource investment, and how environmental justice (EJ) matters will be dealt with in the decision-making procedure. The balance between EJ considerations and economic efficiency matters, either in public sector or private adaptation investment decision-making, has not been achieved in policy on climate change. However, facilitating concerns of EJ is the beginning of generating a dataset to characterise socially vulnerable populations in relation to CC and SLR risks that can be reduced as a result of policy action (Martinich et al. 2013).

When identifying vulnerable areas to protect against SLR impacts, the approach chosen should not interrupt coastal sand flows and shift problems elsewhere along the coastline. Moreover, local government should have some influence on activities within the coast along with future planning and expansion in the coastal zone. Developing bylaws for coastal management that are aligned with the national ICM Act (Act 24, 2008) while considering setback lines proposed by the respective government institution can enable this. As a result, ad hoc practices implemented by landowners to adapt to climate change will be limited because of the increased interventions by government, thus reducing transfers of risk to other properties and public space along the coastline (O'Donoghue et al. 2021).

The question of how risk to extreme events is handled is a difficult one to answer, especially where it is unclear who the responsible actor is. For example, does a property owner carry the risk or private insurance companies? Regarding the ICM Act, local governments are obligated to establish coastal setback lines to safeguard both coastal public and private properties and to ensure the safety of the citizens. In cases where the HWM moves beyond a land unit's boundary line because of coastal erosion, SLR or other sources, and stays inland of that frontier line for a duration of three years, the landowner of that piece of land loses possession of the section of land that is below the HWM; and is not eligible to reimbursement from National government for that loss of possession, except where the cause of the HWM moving was a planned or neglectful act or error by a State government body and was a rationally predictable result of that action or error (SA 2009).

The value of coastal ecosystems in terms of protecting the coastline was explored in this study. For example, the steepness of the Bluff area makes it vulnerable to SLR impacts, however the coastal forest can counteract the effects of SLR as the ecosystem is in, or near, a pristine/undisturbed condition. In terms of the CVI, the condition of the ecosystem (i.e., transformed, pristine, mixed) would be an important variable, as well as the steepness/gradient within the ecosystems (i.e., undercutting may be enhanced indirectly as a consequence of SLR which is a driver of wave erosion further inland, therefore makes ecosystems vulnerable). For this study, the parameters in determining risk were adapted by looking at:

1. the type of ecosystem,
2. condition of ecosystems, and
3. slope of the landscape adjacent to the beach for both Sibaya forest and Clansthal beach.

The underlying geology of the terrain was presented. Using the risk analysis on ecosystems can help establish a model of the risk assessment that addresses the way in which ecosystems respond to SLR impacts and improve the resilience of the EM coastline to SLR.

The results of the land use classification and developments impacted by a 300mm SLR analysis shows that both natural protected areas and properties situated between the 100m HWM and 300mm setback line have highly vulnerable areas that may be negatively impacted by SLR in the future. Moreover, properties found behind the first row of development have a lower risk, as well as those properties that have natural vegetation in front which acts as a barrier to protect developments against future SLR impacts and associated extreme weather events.

There is a clear indication from research that future SLR impacts as a result of climate change along the EM coastline and associated extreme events is not only reoccurring but will probably be more frequent over the years due to increased anthropogenic activities/human-induced climate change. This causes some areas to be highly vulnerable to future SLR impacts which is evident in the CVI maps as well as the maps for NFEPA and D'MOSS.

It is therefore of utmost importance that the local government and the respective local authorities and institutions manage the coastline to ensure continued sufficient protection of coastal ecosystems and development/infrastructure so that people's livelihoods are sustainably met. From a coastal management viewpoint, integrating the ICM Act with the appropriate soft solution methods will ensure that the EM coastline is protected and preserved for future generation, however this process of change can only be implemented effectively once all recommendations have been met.

5.2. Recommendations

The EM coastline has been experiencing destructive conditions due to severe weather events and potential SLR impacts owing to climate change. This has played a primary role in the deterioration of the coastline. As a result, the following recommendations can be made:

- Adaptation measures must be considered in areas identified as "high" risk for the protection of development from future SLR impacts, as well as maintaining natural areas where biophysical functionality is unhindered.
- Regarding future management, governmental agencies must safeguard natural areas where biophysical functionality is unhindered are preserved and that new development near to the HWM are not authorized, unless the requirement for such development against the related negative effects that may occur are considered. This will also have to be subject to the environmental impact assessment processes as legislated and must be formally authorised by the relevant governmental agencies (e.g., the DFFE). In instances where developments already occur, but have been destroyed, building again in the same site ought to be assessed or otherwise repositioned leeward that is beyond the 300mm SLR setback which is out of the restricted zone (Palmer et al. 2011).
- From the CVI and CoastKZN™ maps, in order to protect the natural areas with coastal dunes, which fall within the high-risk zone, geofabric sandbags should be considered to establish a berm. Bags can be covered with sand and vegetation (i.e., suitable dune species which were already existing in the original natural zones). Although this approach will involve ongoing maintenance, it is considered effective in enhancing the stability of a slope, dissipating wave energy, and providing for the continuance of natural procedures along the coast and beach facilities (Breetzke and Mather 2013).
- Furthermore, for the vulnerable communities located within the high-risk zones, such as the Dakota informal settlement, an ecosystem-based adaptation approach should be considered, specifically a dune rehabilitation programme employing community members, in partnership with EM and/or UKZN and facilitated by the latter. Jobs can be created for community members through efforts on managing, conserving, and restoring ecosystems (i.e., coastal dunes) located in front of their settlement. Such an approach can provide coastal protection by attenuating waves and storm surges, by decreasing rates of erosion through entrapping and stabilising sediments along the coast, and building resilience by developing organic matter and detritus (Oppenheimer et al. 2019).
- The areas identified as "high" risk are put forward for consideration when setback lines are developed by the City (or at least, consideration is given to whether the areas identified are consistent with the Coastal Management Line produced by KZN, which effectively becomes EM's setback line).

- From the CVI analysis, the regions which contain developments (i.e., private property) within the 100m HWM, both local government and homeowners should consider working together when installing geofabric sandbags to avoid increasing the effects of coastal erosion, as risks can be relocated elsewhere along the EM coast if individual action is not coordinated.
- Moreover, the listed municipal infrastructure within the 100m HWM, as per the CVI analysis, in terms of future planning on existing municipal infrastructure in the face of SLR impacts along the EM coastline, the EM modelled SLR projections for three scenarios (300, 600 and 1000mm) should be taken into consideration during the decision-making procedure to help guide efforts on relocating infrastructure currently located within the high-risk zone, as per the CVI, to areas of low risk (i.e., beyond 1000mm setback line) where appropriate. This, in turn, will prevent municipal infrastructure from being damaged by SLR and associated extreme events in future.
- Future research on how risk to extreme events is handled is necessary to better understand who takes onus of repair costs (i.e., private property owners vs. private insurance companies).
- Beach nourishment should also be implemented in areas identified as high risk and have narrow beaches, as per the CVI, to widen beaches (i.e., contain more sand) and can therefore reduce the impact of coastal erosion (Theron et al. 2008). Consequently, the cost on damages to infrastructure and property value located within these areas, if any, will be reduced.
- To not develop within a corridor (i.e., natural area linked between the HWM/300mm SLR and natural open spaces inland) that can accommodate future expected SLR.
- Take action on parts of the coastline identified as “high” risk which might be required more urgently (e.g., controlling development along the northern coastline at the Beachwood Country Club and Westbrook, in the vicinity of Beach Bums to allow for dune migration upshore).
- From the classification of land use assessment, all areas within the respective land use that fall within the high-risk zone, the EM setback lines in conjunction with ecosystem-based adaptation should be implemented in order to protect these areas and ensure the functions of each land use is not unhindered.
- From the analysis of developments potentially impacted by future SLR, the total amount of estimated value of property loss within the given suburbs can assist coastal managers with deciding how money should be spent on defending properties and will yield the most protection from future SLR impacts along the EM coastline (i.e., a cost-analysis approach).
- From the risk assessment of coastal ecosystems, future research on applying the vegetation index to certain parts of the EM coastline is necessary to get a better understanding of how vulnerable coastal ecosystems are to SLR impacts in Durban.
- Based on observations, damage on *M. caffra* near the start of transects used in this study may have been caused by either or both of salt spray and/or wind. However, there is limited research

that has investigated/tested this, and the cause is still uncertain. Meidner (1963) found that it is the plant's metabolism rather than environmental conditions that causes dieback in *M. caffra*. Recent research by Jami et al. (2018) state that the likely cause is fungal-related. Therefore, further investigation is required on milkwood to better understand the dieback observed in this study (i.e., due to fungus, or natural cause), especially as they are a protected species.

5.3.Future studies

Future research on applying the vegetation index to certain parts of the EM coastline is necessary to get a better understanding of how vulnerable coastal ecosystems are to SLR impacts in Durban. It would be useful if the CVI could be applied outside eThekwini to neighbouring municipalities.

As an extension of this study, future research will include integrating estimating the value of coastal ecosystem services, particularly coastal protection. Coastal dunes will be the main focus as there is little knowledge of the degree of protection discussed by this coastal ecosystem. Furthermore, a comparison of dune restoration costs against ecosystem services would be useful by providing adaptation recommendations for some of the areas identified as "high" risk.

Future research on milkwood is essential to get a better understanding of the cause of dieback on this tree. A conclusive approach will have to incorporate multi-year observations, and ideally an experimental component in order to test the hypothesis of assessing the impact of salt spray on milkwood.

As an extension of this study, future research will include more detail on the mapping of coastal floodable areas, as well as the property value section. For the property value assessment, a conclusive approach will have to incorporate multi-year observations, and ideally an experimental component.

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