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AN INTEGRATED APPROACH TOWARDS VULNERABILITY ASSESSMENT OF CLIMATE-CHANGE INDUCED SEA LEVEL RISE ALONG THE KENYAN COAST.

By

Valentine Ochanda Khasenye

A dissertation submitted to the Faculty of Engineering and Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

University of the Witwatersrand, October 2017

Declaration

I declare that this thesis is my own unaided work. It is being submitted for the degree of Doctor of Philosophy in University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university.

Part of this thesis has been presented at the Paris IPCC conference in 2015 under "Rethinking Coastal Design and Planning: Integrated SLR vulnerability assessments, the case of Mombasa and Lamu Islands". And the world climate research programme (CLIVAR) conference in Qingdao in 2016 being published under "Shoreline integrated SLR impact prediction in Mombasa and Lamu islands in Kenya".

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(Signature of candidate)

_____day of_____2017

Abstract

Currently, 48% and 71% of the infrastructure for Mombasa and Lamu respectively falls within the Low Elevation Coastal Zones (LECZ) of less than 10m thus highlighting their extreme vulnerability under the pessimistic sea-level-rise (SLR). Based on the primary objective of assessing the impacts of climate-change-induced SLR for the two island cities, this study finds that by the end of this century, close to 50% of Mombasa Island and almost 71% of Lamu Island fall under threat of inundation from SLR enhanced storm surges of a one storm surge in 100 years. The study objectives were to assess initial SLR vulnerability levels for the Kenyan coast, analyse status quo vulnerability perceptions and awareness, co-produce mitigation and adaptation policy options and produce an integrated vulnerability assessment atlas and manual for SLR along coastal cities, with participatory processes as a key component. SLR scenario modelling using GIS techniques (and guided by Intergovernmental Panel on Climate Change-IPCC) under two SLR scenarios of Regional Concentration Pathways (RCP 2.6 and RCP 8.5), was applied to estimate the spatial extent, population, and infrastructure under threat. Participatory Action Planning (PAR) based on a mini-charrette was used to analyse status quo perception and awareness of SLR and related impacts followed by co-creation of adaptation and mitigation strategies. Under RCP 2.6 (optimistic-scenario) the simulation findings indicate that exposure level to the 1:100 storm surge for Mombasa County at 4m elevation falls between 433,300 and 2.5 million people and over US$ 9.1 billion in assets exposed by 2090. Under RCP 8.5 (pessimistic-scenario) for Lamu, the exposure level of between 37,200 and 480,400 people and over US$ 648 million in infrastructure/assets is exposed by 2090. Under increased urbanization, vulnerability for both Mombasa and Lamu increases to over 2.6 million inhabitants and US$14.5 billion and US$ 1.2 billion respectively by 2090 under RCP 8.5. The participatory process showed improvement in the awareness of SLR impacts by participants in both islands and thus constituted the basis of co-production of adaptation and mitigation strategies as well as finalization of the vulnerability atlases of the island cities.

Keywords: Sea-level-rise, vulnerability assessment, climate change, Kenyan coast and coastal planning.

To my late Mom Sarah Imbande my sons Sifa Alakara and Amani Ejakait much respect. To the Triune my unfailing companion throughout the seasons.

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Acronyms and abbreviations.

A1F1 ..... Fossil intensive change in the energy system

AAP ..... Affirmative Action Plan

AGCMS ..... Atmospheric General Circulation Models

AOGCMs .... Atmospheric-Ocean General Circulation Models

AR4 ..... IPCC Fourth Assessment Report.

AR5 ..... IPCC Fifth Assessment Report.

CGSM ..... Coastal Geomorphic and Stability Mapping

CIESIN ..... Centre for International Earth Science information Network.

CLAMAL .... Climate Assessment for Mombasa and Lamu.

CM ..... Common Methodology.

CMAs ..... Cells for Monitoring and Analysis of Sea Level.

CMIP ..... Coupled Model Intercomparison Project.

CVAT ..... Community Vulnerability Assessment Tools

DEM ..... Digital Elevation Model.

DIVA-DINAS Dynamic Interactive Vulnerability Assessment

EACC ..... East African Coastal Current.

ECC ..... Equatorial Counter Current.

ECP ..... Extended Concentration Pathway.

ERA1/2 ..... Earth Remote Sensing.

FGDs ..... Focus Group Discussions

GCM ..... General Circulation Models.

GCMs ..... Global Climate Models.

GDP ..... Gross Domestic Product.

GIA ..... Glacial Isostatic Adjustments.

GIS ..... Geographic Information System.

GLOSS ..... Global Sea Level Observing System.

GNP ..... Gross National Product.

HAT ..... High Astronomical Tide

IKS ..... Indigenous Knowledge System.

IPCC ..... Intergovernmental Panel on Climate Change.

ISAs ..... Integrated Scientific Assessments.

KMFRI ..... Kenya Marine and Fisheries Research Institute.

KMD ..... Kenya Meteorological Department.

KPA ..... Kenya Ports Authority.

Kshs ..... Kenya Shillings

LAPSSET ... Lamu-Port-South Sudan-Ethiopia-Transport-Corridor.

LD ..... Lateral Direction.

LECZ ..... Low Elevation Coastal Zone.

LIDAR ..... Light Detection And Ranging.

LPG ..... Liquefied petroleum gas.

MARI ..... Mitigation and Adaptation Research Institute.

NASA ..... National Aeronautics and Space Administration.

NEMA ..... National Environmental Management Authority.

PAP ..... Participatory Action Planning.

PAR ..... Participatory Action Research.

PCMDI ..... Programme for Climate Model Diagnosis Intercomparison.

PDF ..... Probability Density Function.

PSMSL ..... Permanent Service for Mean Sea Level.

RCMRD ..... Regional Centre for Mapping Resources for Development.

RCPs ..... Regional Concentration Pathways.

RegMs ..... Regional based Climate Models.

SLE ..... Sea Level Equivalent.

SLIMCLIM .. Software limited to climate variability.

SLR ..... Sea Level Rise.

SLR-V ..... Sea Level Rise Vulnerability.

SREs ..... Special Report on Emission Scenarios.

SST ..... Sea Surface Temperatures.

STRM ..... Shuttle Radar Topography Mission.

SURVAS ..... Synthesis of SLR Vulnerability Assessment Studies

TEUs ..... Twenty-Foot Equivalent Units for cargo carrying capacity.

TUM ..... Technical University of Mombasa.

UNEP ..... United Nations Environmental Programme.

UNFCCC .... United Nations Framework Convention on Climate Change.

US$ ..... US Dollar.

USGS ..... The US Geological Survey.

WMO ..... World Meteorological Organization.

WWF ..... World Wildlife Fund.

Chapter 1

Introduction

1.1 Global overview and SLR models

1.1.1 Introduction to climate change and SLR

Global climate change and variability have been recognised as one of the priority challenges of the 20^{th} and 21^{st} centuries (**?**) as it poses significant threats for the developed and developing countries and most especially for their urban residents. According to World Meteorological Organization (WMO) (**?**), the world has experienced several impacts of climate extremes during the 2001-2010 decade with nine of the decade's years being the warmest on record.

In particular, the year 2014 recorded the warmest temperatures since 1850 "with a mean temperature anomaly estimated at 0.54°C above the 14.0°C baseline" (**?**, :4). The current decade is also the warmest on record (with 2015 identified as the warmest to date) for both land-only and ocean-only surface temperatures. Concerning related impacts, in the decade 2001-2010, most of the disasters reported around the globe had meteorological origins. These include the many devastating storms and hurricanes which accounted for the majority of natural disaster damage, mounting to more than US$502 billion annually. The climatological and hydrological disasters around the globe caused losses estimated at US$52 billion and US$23 billion respectively (**?**).

WMO posits that recent coastline storms and tsunamis that occurred in 2013 (especially in the Philippines, India as well as Britain), are being seen as the effects of gradual but ongoing sea level rise (SLR). SLR is, in turn, increasing the probability density functions (PDF) of these flooding events and thus impacting negatively on coastal settlements and residents. It was estimated that in 2004 more than 240,000 people lost their lives in 396 disasters, with over 225,000 of the deaths resulting from the Indian Ocean tsunami that hit 12 countries on 26th December 2004 (**??**).

? argue that since 2005 the value of flood losses in the major 136 coastal cities amounted to US$6 billion per year and it is expected to increase to almost US$52 billion by 2050. The projected SLR losses are expected to account for up to US$60-65 billion per year by 2050. Climate change affects the magnitude and probability of storm events and density (**?**), thus adding to the impacts caused by SLR due to the PDF of flooding events.

1.1.2 Regions and SLR models

Global SLR is one of the identified and commonly studied impacts of climate change. The Intergovernmental Panel on Climate Change **?**estimated that global sea levels would rise by about 1.8m by the end of 21st century. Research conducted by **?** in the Bay of Basque was able to relate SLR with inundation, environmental degradation and the flood risk of the Gulf of the northeast Atlantic. Other researchers have shown that rising sea levels will cause natural thresholds of coastal ecosystems to be exceeded more frequently. Consequently, this will escalate the PDF of impacts as a result of more frequent occurrences of tropical storms and waves.

However, it has emerged that global information directly derived from the global models, were extremely limited particularly concerning the horizontal resolution to allow for extrapolation to regional and local scale. For this study, high-resolution Atmospheric Global Climate Models Data (AGCMs) were used to complement the coupled Atmosphere-Ocean Global Climate Models (AOGCMs) to facilitate the generation of locally applicable data based on mathematical downscaling and modelling. This was also guided by similar studies conducted in Europe and America as cited in (**???**).

The steady global SLR along the coastal tidal range/zones has been associated with severe negative impacts on coastal systems and infrastructure, the permanent inundation of coastal islands and small island nations as well as with several other ecological, environmental and socio-economic impacts (**?**). The additional effects include increased flooding events associated with changes in patterns of tropical storms, hurricanes, typhoons and tsunamis which will recurrently lead to losses especially in the main coastal cities.

These storms mostly break seawalls, leading to floodwaters overtopping levees, and storm surges that wash and breach barriers, thus increasing mitigation costs for these regions (**????**). SLR changes and their related impacts vary from coast to coast. This hinges on the magnitude, their respective geographical characteristics and the topography of the Kenyan coast. Other factors include the natural and

anthropogenic activities within the shoreline which include massive engineering infrastructure and services along with such coastal and delta zones.

1.1.3 Contributing factors to global SLR

SLR studies have identified four key drivers of global sea level changes. The first one is, the average Antarctic ice sheets contribution to global SLR at an average rate of 0.45mm $\pm$ 0.14mmyr^{-1} since 2010 hence projected to contribute up to 0.45m increase in global SLR by the end of the 21st century (**?**). The shrinking ice sheets in the Antarctica, especially during summer, is expected to contribute to SLR by up to 1.2m/°C per century, (**?**), with the West Antarctica undergoing a marine ice sheet instability due to climate-change.

In a study using Earth Remote Sensing (ERS-1/2) satellite radar from 1992 to 2011, **?** and **?** suggest that there is a probability of a faster than anticipated melting and retreating off of the Greenland ice sheet as a second factor. This sheet also includes the West Antarctica due to the existence of deep inland submarine valleys, of up to 31kms under the ice sheet. The melting of these vast ice sheets is expected to increase the global SLR by a higher margin of up to 5m per century. The total contribution of glacier, ice cap, and ice sheet melt to the sea level rise is tending towards 4.5mm$\pm$ 0.14yr^{-1} for the period up to 2013 (**???**). The surface mass transfer from land ice to oceans contributes to the deformation of the earth and corresponding variations in the ocean floor height and gravity. This is referred to as glacial isostatic adjustment (GIA) and is reviewed in detail in Section 2.3.1 (**??**).

The third contributor to increased SLR is the thermal expansion of sea water due to increased ocean surface temperatures, contributing about 0.4m/°C per degree temperature increase. The current global mean sea level rate is about 3mm annually which is almost double the observed 20th-century trend of 1.6mm per year **?**. Although this has been the rate modelled and reported by the IPCC, other independent studies allude to a higher rate of up to 5m by the year 2030 on a century basis based on the anthropogenic climate forcing (**???**).

The fourth factor that causes SLR is the tectonic earth movements which lead to uplift and subsidence. The process is not associated with current temperature-related climate change. Some of these movements lead to changes that are significant enough to influence the interpretation of observational records and sea level projections at regional and global scales. Coastal zones that are prone to active vulcanicity and increased coastal engineering infrastructure are likely to experience changes in uplift and subsidence, thereby contributing to sea level changes.

1.1.4 Coastal sustainability, planning, and SLR

Due to the slow and gradual changes in SLR capturing and communicating its associated risks it remains a critical challenge globally, especially in the developing world. Part of this challenge stems from the fact that it is a long term, varying and gradual process which is hardly perceptible to ordinary human sensing and perception, with only a limited experience on the probability of high impact events.

Another challenge emanates from the lack of or limited awareness of the impacts of the gradual changes to the coastline among both spatial and economic planning professionals as well as the vulnerable communities. The advancing oceans pose the greatest threat to most small islands and island nations. This is through both direct inundation and increased frequency in coastal floods as well as the changing patterns in coastal tsunamis.

The consequences are often not immediately detected or observable. Although Mombasa and Lamu islands enjoy a vast coastal zone that is vital for tourism activities for the county as a whole, about one-fourth of this zone has a moderate to high physical sensitivity to sea-level rise impacts (**?**). Nevertheless only a limited number of studies have been conducted on coastal zone impacts and community perceptions and adaptations to such SLR climate change vulnerabilities. Existing Kenyan studies on SLR such as **?**, focussed on economic impacts assessment and evaluation, with the Island of Mombasa featuring in the study. However, this excluded the equally important Island of Lamu.

Moreover, the existing studies do not follow an integrated approach for assessing substantial risk exposure in addition to local attributes that could facilitate the ability of communities for adaptive responses to extreme events. This study thus provides a unique case that combines scientific findings on environmental change, especially SLR, with a community-based assessment of locally relevant elements of adaptive capacity in response to climate change on the island cities of Lamu and Mombasa. The study areas (as described in detail in section 3.2) were identified by the *Government of Kenya*, through Vision 2030 (**?**), as critical sectors towards the achievement of the country's vision of long-term development. Therefore, an understanding of threats due to SLR in these coastal islands would be instrumental in ensuring sustainable development of Kenya as a country and the East African region as a whole.

The third challenge arises from the fact that culturally, most choices and decisions by coastal planners and communities are anchored on an assumption of a stable coastline. This assumption can be attributed to a normalcy bias which is referenced to the mean high water mark and has been the basis for planning the

built environment and the socio-economic practices of the coastal zone. Given that most coastal households derive their sustenance from maritime-related activities such as trade, fishing industry and tourism, climate-change induced impacts to these coastal areas would affect not only livelihoods and the coastal infrastructures, but also national and regional economies especially if related risks are not adequately understood, and systematically mitigated (**?**).

The inclusion of the local communities within the study site is a significant step towards creating awareness for proactive intervention mechanisms. The significance of public participation in scientific assessment studies and practices in climate change and its impacts has been systematically highlighted since the 1992 Rio summit on sustainable development. The involvement of local communities in participatory and co-production of knowledge for adaptation purposes increases the awareness and improves perception in the process of exchange of knowledge between the researchers and the affected communities. Further, the co-production and participatory process allow real-time adaptation techniques as well for inclusive development of integrated mitigation interventions and strategies.

1.1.5 LECZ and urban settlements

The Low Elevation Coastal Zones (LECZ) settlements in developing countries are expanding rapidly. This is occasioned by increased urbanization which in turn contributes to growth in planned and unplanned infrastructures along such coastlines. Urbanization and related lifestyle choices have been some of the factors contributing to increased global greenhouse gas emission, which consequently contributes to the rise in sea water temperature and ultimately to SLR (**?**).

Overall, urbanization on coastal zones has led to the destabilization of the natural coastal processes which this has given birth to several impacts on coastal areas. Such impacts include increased salinity and salt water intrusion into the mainland and increased flooding. This escalates the socio-economic losses and disrupts the growth and abundance of flora and fauna as illustrated in **?**. In the developing world, the risk related to coastal impacts of SLR as a factor of coastal zone productivity is much higher than in the developed countries.

Many of the world's largest cities are located in low-lying coastal areas that thrive in related economic activities such as fishing, tourism and global trade logistics, especially based on infrastructure for ports and harbors. **?** and **?** allude to the grim realities of low elevation coastal zones around the globe which are now under threat from effects of climate change. Although coastal towns have always been more vulnerable to disasters such as flooding, extreme heat conditions and salt

water intrusion among other risks, the danger of increased cyclones and storms will probably complicate planning for these areas thus intensifying the need for adaptation and mitigative interventions (**?**).

As a result, the potential hazard facing coastal cities due to extreme weather patterns in the course of the 21^{st} century are increasingly severe, for example the impact on Mombasa island under the pessimistic scenario in 2090 losses may amount to over US$9.1 billion in assets (see chapter 4) . A growing number of related studies indicate that coastal cities in the developing world are ill-prepared to respond to the probable impacts arising from SLR changes and its related storm surges (**???**). African cities such as Port Harcourt and Victoria Island in Lagos (Nigeria), and Mombasa (Kenya) are already experiencing these impacts (**???**).

Urban business owners and residents in cities along Kenya's coast will become increasingly vulnerable to the risks of increasing SLR. According to **?**, the Southern and Eastern African coastlines (comprising the coasts of South Africa, Mozambique, Tanzania and Kenya) are poised to be affected by cyclonic and other significant weather changes and realities that pose risks related to large wave tides along this coast. The changes are predominantly due increased variability in ocean circulation and increased flooding episodes.

1.1.6 Overview of SLR in Mombasa and Lamu Islands

The coastal towns of Africa, including those in Kenya, continue to bear significant pressure from rural-urban migration and mushrooming of commercial enterprise. The recent dredging of Mombasa port and the opening of Berth 19 for example will help expand the port and position it to deal with bigger ships and enhanced cargo traffic. To the north of Mombasa, the Lamu-Port-South Sudan-Ethiopia-Transport-Corridor (LAPSSET) is a new development project involving eight east and central African countries. The project will actualise the development of a new Port and standard gauge railway (SGR) linking the coastal city of Lamu with South Sudan and Ethiopia through northern Kenya. These new infrastructure ventures will inevitably increase the attraction of these coastal towns, thus intensifying urbanization (expanding economic base and larger populations).

In addition to hosting large populations, the seaport cities of Dar er Salaam and Mombasa serve as major conduits of commerce and administration thus facilitating the flow of goods to the interior parts of the East and Central African region. Beach related tourism in and around these two cities accounts for a high proportion of each country's gross domestic product (GDP) (**?**). At 12% of the GDP, tourism was the third largest contributor to Kenya's economy in 2007. The tourism hospitality

and allied industries in Kenya are the main export earners and form an essential base of the country's economy after agriculture and forestry and the construction sector (**??**).

Mombasa Island plays a significant role in the national and regional economies by facilitating external trade for the landlocked countries of Uganda, Burundi, Southern Sudan, Congo, and Rwanda. Together with its peri-urban areas, the city, lies at an average altitude of about 5m above sea level, with an estimated area of 229.6 Km^2 of which, 65 Km^2 is water mass, 31 Km^2 is gazetted mangrove forests, 3 Km^2 is gazetted marine parks and 140.6 Km^2 is the peri-urban area (**?**). **?** reports recent discoveries of minerals such as oil, coal and natural gas which will attract new investment and further economic growth for the region. This will attract more people and development of new settlements which will, in turn, contribute further to the greenhouse gas emission challenge which is associated with global SLR.

1.2 Framing of the research issues and general approach

The Kenyan coast is home to upcoming large port and infrastructure developments such as LAPSSET, the upcoming English Point Marina (with exclusive residential and business premises), as well as numerous tourist beach hotels. Despite the importance of the coast to Kenya's economy, the country has not made a substantial investment in SLR vulnerability studies and research compared with countries such as South Africa (**?**) and Egypt (**?**). In essence, it is business-as-usual along the Kenyan coast where urban and capital development investment projects along the Kenyan coast continue without crucial SLR information and data for responsive and informed decision making.

This lack of information is escalating the development versus planning gap thus exposing many businesses and residents to extreme events within the life cycle of the planned investments and projects. Determining the spatial extent of gradual SLR impacts on coastal areas constitute one of the region's greatest challenges. The challenge is further exacerbated by the normalcy bias of a stable coastline by government entities, scientists, and planners (**????**).

Addressing this challenge, in turn, depends on reliable data concerning the extent and severity of the threat. Moreover, communicating effects of accelerated SLR on the natural environment (physical and ecological) to the stakeholders is essential in the quest to achieve adaptation. Knowledge sharing with all stakeholders, including public and private sector policy and decision makers as well as local communities

would facilitate a better understanding of the challenge at hand and intervention to facilitate resilience of the vulnerable communities and infrastructure. In recent times, the sustainability of the Kenyan coastal cities of Mombasa and Lamu has come under sharp focus as the continuing impacts of extreme events in the region continues to put an incredible strain on the tourism and transport businesses that constitute the main economic activity of especially the largest port city in the region.

1.2.1 Justification of the study

The economy of Mombasa and Lamu revolves around port/harbor activities and other coastal resources that facilitate tourism, fishing and trade. Whereas Mombasa attracts most of the tourists on the beaches and hotels, Lamu's tourism allure is based on its world-acclaimed cultural heritage status and largely appeals to tourists during the annual Lamu cultural festivals. With major support from their seaports (which is envisaged to become the largest ports on the East African coast), enhanced understanding of vulnerability to SLR is increasingly becoming a matter of urgency.

Studies on the general awareness and perceptions of the effects of climate change, have been growing steadily across developed and developing countries (**?**). Such research shows that perceptions and experiences of related disasters are important in facilitating community planning and response to extreme events. A society that is not meaningfully aware of the dangers and threats that they face may end up increasing its vulnerability primarily due to lack of knowledge to plan and adapt to climate-related impacts.

Several studies on national climate-change vulnerability for Kenya mainly dwell on vulnerability to drought, famine, and flooding with economic losses projected in GDP terms (**??**). However, very few studies touch on the slow effects of SLR and its coastal impacts regarding the change in storm frequency and patterns (PDF) and how this slow change can negatively impact on the Kenyan economy.

A more responsive vulnerability analysis needs to include the stakeholders in these areas and especially the low-income earners who depend on the coastal ecosystems for their livelihoods and survival. Participatory action planning enhances vulnerability assessment by creating an environment where discussions around a subject are allowed and the conclusions disseminated to the participating groups as well as the wider community to influence informed choices and decision making. Participatory action planning, also known as the mini-charette process is applied in this study, is deemed to be a critical research

dimension necessary to enhance public awareness and response to the effects of SLR.

This study incorporates awareness across the policy spectrum level, from counties to communities living in affected areas, with the aim of improving responsive action towards adaptation and mitigation strategies. The study thus addresses this need through an action-based research approach to SLR modelling and production of the vulnerability atlas based on a participatory process. The main focus of the study is the analysis of the vulnerability of coastal settlements and urban developments to the impact of climate change induced SLR.

The study mapped out the most vulnerable environments to SLR; appraised community perceptions of SLR risks and enhanced the awareness of the risk and vulnerability in these areas, with an orientation towards enhanced preparedness for adaptation and mitigation strategies. The co-production of the vulnerability atlas and perceptions analysis with the communities at risk facilitated a more innovative hybrid of qualitative and quantitative research approach. The vulnerability atlas will be published and availed to the participating communities as well as the county government offices for parties and organisation can access it.

1.2.2 Conceptual framework for SLR vulnerability atlas

Systemically delimited quantitative analysis has been the main approach to vulnerability assessment of climate change and SLR impacts globally. A lot of effort has also gone into the dissemination of the findings to the affected communities and governments in order to serve as inputs to adaptation measures in several fields such as agriculture and food security. The challenge to an extent has been the on- going inaccessibility of some of these findings by the local communities that may be affected as they might not fully comprehend the scientific perceptions used in conducting and reporting of such studies.

Since the 1992 Rio Summit, participatory processes have increasingly been hailed as an ideal method to enhance the uptake of adaptation and mitigation findings within vulnerable communities as well as for enhanced governance (**?**). The need for socio-ecological systems to be adaptive has highlighted the need for community management and co-production of knowledge for environmental and ecological resilience.

The processes of participatory action planning as applied in this study aimed at adaptation of co-learning and co-management towards the improvement of the methodologies used to analyse climate change related impacts, and especially SLR in this case. The feedback loops facilitated through such approaches facilitate for

the empowerment of such communities and individuals in identifying and mitigating attendant threats apparent to them. The participatory approach as applied in this study, facilitated new methodological tools for the co-production of suggested policy and adaptation techniques collaboratively and simultaneously with the affected communities.

The conceptual framework applied in this study relied on the guidelines by **?** and a survey conducted by **?** on participatory processes, as well as insights on participatory typologies as reported in **?** and the concept of empowerment through participatory processes, as seen in Figure 2.4). A key focus in the process was the co-learning and co-production of understanding about sea level changes and experiences with the communities in Lamu and Mombasa island cities.

Although the research processes were closely tailored towards participatory planning in general, the conceptual framework of this study emphasized on co-creation of knowledge and empowering stakeholders and communities about SLR. Social empowerment and learning was understood as relational and heavily dependent on cognitive changes that emerge from experiences of activity within group settings. The research therefore was geared towards the merging of social learning with individual learning in pursuit of transformational understanding.

The social and environmental awareness coalesced from the diverse perceptions during the mini-charrette process of the study. The various community members who participated in the mini-charrette are involved in diverse activities along the coast. The activities include fishing, conservation efforts through mangrove conservation systems, and the tourism-based stakeholders who were able to give accounts of the experienced effects of climate change on their specific livelihood activities. They acknowledged their varying dependence on environmental resources of the coastline in the provision of the ecosystem sustenance they desperately need, and how any disruption to their dependence due to advancing oceans would inevitably affect their social, economic and psychological wellbeing.

Following on **?**, the study prioritised relative changes based on how individuals related to the other actors and sectors in a planning setting within the two islands. The essence of the participatory process was to gauge the ability of the process to provoke cognitive changes, which is the acquisition of factual knowledge about climate change and SLR debate, especially in the planning for sustainability of islands and small islands nations. Participatory process is crucial in social learning and especially for empowerment to act on one's challenges and contexts (**?**).

Based on **?** and **?** as well as studies cited earlier, this study emphasized on the differentiation between single versus double-loop learning and referred to the

varying depth in learning. The double-loop learning process was preferred as it facilitated for a more fundamental shift in the related mental perception. Double-loop learning occurs when prevailing world views and community values/beliefs are radically challenged in order to open-up for integration into the specific needs of the emerging risks and vulnerabilities. The generated atlas and the manual will be published and sent to the county governments and the participating communities to allow for implementation.

1.2.3 The SLR vulnerability atlas and its production process

The challenges of participatory action planning (PAR) have been systematically appraised through several academic studies and professional consulting reports. The challenges stem from the diverse typologies of participation processes ranging from passive communication to active and meaningful participation through the full project process or cycle. The production of the vulnerability atlas includes both the discussion and the scientific methods of analysis as guided by the IPCC and the integration of the community contributions from those living in the islands at risk. The PAR process has a focus on inclusive information exchange and empowerment for adaptation by key actors within the communities. Through the merging of the two processes, it emerged that the communities had some awareness of climate change issues and its ongoing impacts on global ecosystems.

The identified SLR vulnerability levels for Mombasa under RCP 2.6, indicate that up to 1.4 Km^2 is low-lying and susceptible to ocean disturbances in the event of a severe coastal storm event. This exposes a population of almost 433,300 individuals under threat (seen Figure 4.9). The area translates to 10% of the land mass under threat from accelerated SLR. On the other hand under the same scenario Lamu Island has more of its land mass under threat from the effects of SLR (seen Figure 4.18).

By the year 2060 the most pessimistic scenario for Mombasa under RCP 8.5 places an enormous strain on the county as seen in Figure (4.12), with almost 20% of the land mass under threat from accelerated SLR. The case for Lamu Island is even more grim (see Figure 4.18) given that even under the optimistic scenario, island mass of 53% falls under threat from accelerated SLR by 2060 .

The analysis of participant perceptions demonstrated that climate changes are not news or speculation to them. Whereas they have had long histories of living with natural hazards their need to survive in the immediate apparently overrides the more remote imperative to adapt for long time survival. An important finding of the

study is that there are many inherent attributes within communities that, although seemingly unrelated to climate change responses, enhance the understanding and the adaptive capacity of coastal communities to deal with social and environmental stressors.

Among the attributes identified is the high social cohesion and related social capital which enhances community resilience to ecological and social disturbances. The understanding of the effects and the causes of sea level rise during the charrette process emerged to be more of a reinforcement for the community to deepen their "working together" with the local and county governments. The cohesion was seen as an important resource towards improving the adaptation strategies that are feasible in the event of a catastrophe especially through mitigation measures to protect the exposed communities as well as critical infrastructure and property.

The longer-term challenges shared with the communities were related to adapting to increasing climate change hazards and especially those due to SLR. Other challenges shared include high exposure to related environmental risks, exposed critical infrastructure, the risk of the limited provision of essential services and a lack of inclusion by the government agencies during similar adaptation and mitigation planning sessions.

As a result, the study developed significant insights on broader and integrated approaches to the assessment of vulnerability and adaptive capacity of social ecosystems. The approach considered both the social and natural coastal impacts due to climate change and related risks/vulnerability. The initial scope was significantly informed by community perception and the latter scope determined by conventional earth science research methods (such as inundation scenario modelling). The study therefore hinges on a hybrid multi-disciplinary approach with PAR as its most critical strategy.

1.2.4 Production of SLR vulnerability assessment manual

During the conceptualization of the combined methodology of SLR vulnerability assessment, emerging insights helped to identify a methodology gap which needed to be filled for ongoing refinement. In the production of the atlas based on the integrated approach, the lessons learned informed and inspired the production of a manual on integrated SLR vulnerability assessment for coastal islands. The process envisaged suggests using both scientific modelling methods and blue prints together with the social process of community and stakeholder participation. The manual is a product that can be adapted to guide studies in cities faced with similar vulnerabilities as those of Mombasa and Lamu, which served as the case studies for this study. A conceptual draft of the manual is included in Appendix B.

1.3 Overall understanding sought and research questions

The research aimed to develop SLR vulnerability atlas for the coastal region of Kenya and thus illustrate and disseminate its vulnerability levels. The application of a participatory approach to assessing vulnerability coupled with co-production of the atlas offered an opportunity towards raising awareness among the affected communities and other stakeholders concerning related risks/vulnerabilities and the need for enhancing adaptive strategies. The study then evaluated how this co-production process triggers adaptive and mitigative responses.

The study covers the physical modelling of environmental and socio-economic impacts based on GIS tools as one of the primary techniques to spatially map out land areas and related infrastructure under threat. However, the investigation of SLR impacts was not limited to the spatial effects. Additionally, a more inclusive, and comprehensive study of social perceptions and the responsive action to the SLR impacts was also conceptualized as a critical component of the study.

Since each approach is individually limited in its ability to explore the whole context of SLR and vulnerability, an integrated approach was hence conceptualized and applied to address the study objectives comprehensively. Effective climate-change mitigation and adaptation strategies should address impacts from an integrated system perspective as explored in this study through the tripartite perspective of the physical threats, unique awareness levels and creation of responsive action. This is a more holistic framework.

To effectively conduct this investigation, a multidisciplinary approach anchored in climate science, geography, urban design, and planning was therefore conceptualized and demonstrated. This study therefore, explores the potential for complementary forms of knowledge that take into account synergy and complexity to guide decision-making for mitigation of coastal cities at risk of SLR in order to enhance their urban resilience.

1.3.1 Research objectives

The study objectives were as follows:-

- Assess initial SLR vulnerability levels for the Kenyan coast based on scaled-down regional models guided by IPCC predictions
- Assess initial SLR vulnerability levels for the Kenyan coast especially the zones, assets, people, infrastructure and public services

- Appraise status quo vulnerability perceptions and awareness through a mini-charette in order to understand the prevailing adaptation and mitigation practices and coping strategies apparently in place (status quo awareness and preparedness)
- Share scaled down SLR findings with stakeholders and co-produce mitigation and adaptation interventions/policy options for their subsequent action and implementation (recommended for follow-up by various actors and stakeholders)
- Consolidate overall experience into a "how to" vulnerability evaluation and mitigation manual and atlas adapted for such assessment for similar coastal zones and cities or settlements

1.3.2 Research questions

Four research sub-questions were applied to guide the study as below:

- What is the nature and extent of infrastructure vulnerability to SLR in the coastal areas of Mombasa and Lamu?
- What is the level of awareness of the people living in these areas to the threat of SLR?
- To what extent could participatory approaches in vulnerability assessments contribute towards enhancing stakeholder preparedness and empowerment to act in adaptation and mitigation of the identified vulnerabilities?
- How could the insights from the stakeholders experience be incorporated into future climate change impact assessments and especially in SLR vulnerability assessments?

This study was therefore designed around gaining an understanding of both physical and social factors relating to coastal SLR and how various types of knowledge influence the way and manner in which the affected communities respond to ocean and sea related perturbations induced by climate change. Different approaches have been used to define how storms and other coastal disasters have affected a range of communities and the way such communities have responded to these hazards. The first research question was addressed through an initial analysis of the physical infrastructure and human activities at risk from the impacts of envisaged SLR.

This stage of the analysis was undertaken through physical, statistical and quantitative analysis of inundation incident data from annual climatic forecasts

and global inundation scenarios. The second and third sub questions involved the analysis of policy documents and reports, focus group discussions with diverse participants drawn from the affected stakeholder communities in conjunction with interviews with county planners and managers. The fourth sub question was investigated through a mini-charrette process and the production of the co-generated atlas itself. The results of these investigations were subsequently integrated towards derivation of the overall findings and thus addressing the primary objective of the research.

1.3.3 Working hypothesis

The working hypotheses used to guide the study was conceptualized as follows: A participatory approach to SLR vulnerability assessment and the co-production of the related atlas with affected stakeholders enhances their awareness including empowerment for adaptive and mitigative response at different levels. PAR can facilitate meaningful and effective stakeholder engagement towards such awareness of climate change induced SLR. PAR would also serve as an opportunity for stakeholder preparedness for adaptation and mitigation actions/interventions against such vulnerability to related impacts.

1.3.4 Research settings and outputs

The outputs of the study include the initial assessment of spatial extent, physical infrastructure and socio-economic assets (infrastructure and people within the coastal case study cities), susceptible to the effects of accelerated SLR. Through the integrated process, an initial draft of the vulnerability atlas to SLR for the case study cities of Mombasa and Lamu was created. In addition a vulnerability assessment manual for guiding related future research of coastal cities faced with similar vulnerabilities was developed thus concluding a synthesized assessment of the two cities in relation to vulnerability to SLR impacts.

The research then appraised the awareness of SLR impacts through a participatory process aimed at subsequently addressing limited awareness, empowerment levels and preparedness for responsive actions. The co-produced atlas was disseminated and shared with stakeholders for strategy and action options on integrated coastal zone management and mitigation of related threats and risks.

1.3.5 Scope and delimitation of study

The target area of this study is the Kenyan coast, with a focus on the two island cities of Lamu and Mombasa which serve as the empirical case study areas,

towards facilitating the approach of co-creation of knowledge as the core method of the study. Whereas Mombasa constitutes the smallest county in Kenya, it is the second largest city in the country after Nairobi and hosts the largest seaport in East Africa (**?**). Stakeholder-communities in the two cities were identified and approached to participate in the process of deriving the vulnerability atlas based on the mini-charrette method of participatory design. Participants from the selected stakeholder-communities were facilitated to give feedback on the importance of the vulnerability map for local adaptation measures together with inferences on the importance of the understanding of coastal threats due to the impacts of accelerated SLR.

The study also focussed on the generation of the vulnerability atlas for the islands of Lamu and Mombasa based on currently available modelling techniques. The generated atlas includes the description of the areas that may be under inundation threat due to accelerated SLR, and the number of people threatened as well as the assets exposed under each of the two scenarios. The vulnerability impact analysis mainly highlighted on the direct impacts of climate change induced SLR within the Kenyan coast but did not factor in the indirect or second-degree impacts across the coastal zone at a national or regional scale. Whereas the study offers new insight into areas that may need protection from climate-change-induced impacts, the study does not cover the engineering solutions required for mitigation interventions particularly for the Kenyan coast. An engineering-based assessment is therefore needed to complement/address vulnerability indicators reported in the Atlas.

The available GIS tools/techniques and mini-charrette models were used to supplement the information generation for vulnerability analysis. This was also facilitated by data from climate models on the SLR expected within the century. The indices used for the analysis excluded the SLR commitment that may be due to increasing polar and complete ice caps melt. The areas scoped within this study include the use of available models and equations that have been generated by independent researchers and IPCC with a new participatory concept as presented in the study.

1.3.6 Definition of terms

To achieve the objectives of this study, several key terms used in the study are defined in the following sub-sections.

Adaptation and adaptive capacity

As modified and adapted from **?**, adaptation is the positive adjustment in natural or human systems in response to current natural hazards such as actual or

expected climate change impacts. It also includes action taken to help communities and ecosystems moderate, cope with or benefit from actual or planned changes in weather and climatic conditions. On the other hand, adaptive capacity is the ability of a natural or human system to respond to climate change (including SLR and inundation) to moderate/mitigate the damages while taking advantage of available opportunities that help in coping with the consequential impacts.

Charrette and mini-charrette

A charrette is a consultative process, tool/strategy initially applied by planners and architects to intensely engage with a diverse range of projects within a brief but intensive engagement period of the project process. According to **?**, a full charrette process largely involves the use of participatory/workshop plus interactive exercises which take up to 4 days, while a mini-charrette usually takes 1 to 2 days but guided by the same principles of engagement. A charrette can transform a project from an unknown, complex problem to a successful plan with an enhanced sense of ownership and agency as the key benefits (**?**). While the delivery and *modus operandi* of charrettes vary (often depending on the project or research problem and the participants/stakeholders involved), they take place in multiple sessions in which a major group then divides into sub-groups for intensive deliberations (**?**).

Eustatic sea level changes

Eustatic sea level changes occur as a result of either a change in the volume of seawater or a change in the size of the ocean basin that contains it. Even in these large-scale cases, however, mean sea level can vary from place to place due to local tectonic and hydrographic effects.

Inundation

Inundation refers to the coastal zones of Mombasa and Lamu which will grow increasingly vulnerable to flooding and/or submergence as the ultimate consequence of the shifting coastline and related storm-surges due to the accelerated SLR as a result of climate change. According to **?**, inundation is the partial and persistent submergence of low-lying land due to a rise in sea level. A low-lying coastal area is expected to experience initially increased risk and frequency of coastal flooding before permanent inundation due to SLR. An account in **?** gives an illustration of how several coastal islands such as those in the Chesapeake Bay, have either been completely inundated or restructured since the last ice age, with a warning that there is a probable danger of similar experiences increasing in the 21st century.

(Isostasy) alternatively, Isostatic sea level change.

Isostatic sea level change is the response of the earth to the ongoing changes in the earth's surface loads. This reaction is elastic for a shorter period, especially in the earth-ocean response to changes in mountain glaciation, or can also be for a longer period as in viscoelastic, following the reaction to the last deglaciation (Last Glacial Maximum). Isostasy also refers to changes in the land surface load due to the deformation of the earth and its gravity as a response to the changes in ice and associated water loads also referred to as Glacial Isostatic Adjustment (GIA) (**?**).

Mitigation and adaptation

In climate change, mitigation refers to interventions aimed at reducing the emission of carbon dioxide and other harmful greenhouse gases as the main contributors to climate change. Currently, the Paris accord signed on the 18th of November 2015 sets a mitigative strategy aimed at keeping the global temperature rise to 1.5°C. On the other hand, adaptation refers to the preparedness and related interventions to the consequences and impacts of climate change. According to Mitigation and Adaptation Research Institute (MARI), adaptation to climate change and SLR impacts are actions that increase our preparedness to a broad range of SLR impacts and allow us to adapt to the changes if and as they happen.

Normalcy bias

Normalcy bias (also known as a normality bias) is a mental state people experience when faced with an unfortunate event or a disaster. It tends to reinforce complacency with the status quo as a norm which is highly unlikely to change. The assumption occasionally made in the case of the normalcy bias is that since the current pattern of behavior (action or inaction) has not been known to lead to a disaster. Normalcy bias may result in situations where planning agencies and individuals fail to prepare adequately and sufficiently for a disaster and on a larger scale, it results in the failure of planning bodies and governments to include the citizens in its disaster mitigation and adaptation measures. The opposite of normalcy bias would be an overreaction, or "worst-case thinking" bias, in which non-catastrophic deviations from the normal range are dealt with severely as if they are signaling an enormous catastrophe.

One in 100 year flood clarification

A one-hundred-year flood is a flood event that has a 1% probability of occurring in any given year. The 100-year flood is also referred to as the 1% flood, since its annual exceedable probability is 1%. The clarification can also be based on 1

in 25 year or 1 in 50 years probability. For river systems, the 100-year flood is generally expressed as a flowrate. Based on the expected 100-year flood flow rate (clarification), the flood water level can be mapped as an area of inundation. The resulting floodplain map is referred to as the 100-year floodplain (**?**). The One in 100 year flood clarification is also known as the PDF (described below) and SLR and the coastal circulation changes is an important factor in determining flood events in a region.

Participatory action research (PAR)

Participation comes from the word"participate" which means to"share" or "take part" **?**. PAR (also known as Participatory Action Planning (PAP)) is a collaborative project/research process, used to gather information to use as feedback input towards a change in social or environmental systems. It involves the people who are concerned about or affected by an issue, SLR in this case, and their resilience such that as the affected communities they take a leading role in the production and utilization of the knowledge for subsequent responsive action.

Probability density function

In theory, Probability Density Function (PDF) is a mathematical model that describes the likelihood that a given variable in the model takes a specific value. The PDF allows for estimating the likelihood of the random variable falling within a particular range of values based on certain changes or alternatives. The PDF is non negative everywhere, and its integral over the entire space is equal to one. For the purpose of this research, PDF is considered in line with the influence of climate change in ocean circulation patterns along coastal areas and islands that are sure to lead to increased flooding or tsunamis events (**?**).

Representative concentration pathways (RCPs)

? notes that RCPs are the newly developed climate change scenarios including time series of emissions and concentrations of the full suite of greenhouse gases and aerosols and chemically active gases, as well as changes to land use/cover that affects the climate (**?**). The "representative" term signifies that each RCP provides only one of several scenarios that would result in the specific radiative forcing characteristics. The term "pathway emphasizes" that not only the long-term concentration levels are of interest, but also the trajectory taken to reach that outcome (**?**).

RCP 2.6 is the most optimistic scenario. It is a pathway where radiative forcing peaks at approximately $3\mathrm{Wm}^{-2}$ before 2100. RCP 4.5 and RCP 6.0 are the two

intermediate stabilization pathways in which radiative climatic forcing is stabilized at approximately 4.5Wm^{-2} and 6.0Wm^{-2} after 2100 (the corresponding ECPs assuming constant concentrations after 2150). RCP 8.5 is the most pessimistic scenario and is based on radiative forcing of greater than 8.5Wm^{-2} by 2100 and continues to rise further into the future (**??**)

Resilience

? defines resilience as the capacity of a social or natural system (such as a community) to pro-actively adapt to and recover from disturbances that are perceived to fall outside the range of expected or normal disturbances. In this case, the system, community, or society potentially exposed to hazards posed by such disturbances can adapt to negative impacts. The adaptation can be by changing to regain and maintain an acceptable level of normal functioning possible within a new/innovative structure or system.

Risk assessment

? define risk assessment as mainly a product of hazard probability times the vulnerability level(s) of the exposed assets times the value of the exposed assets. The risk is seen as the potential of harmful or undesirable outcome resulting from the occurrence of an incidence or an event. The risk is determined by the likelihood and associated losses which would include death and injury, loss of property and livelihood, environmental damage and socio-economic disruptions. Risks are mainly as a result of interactions between natural or human-induced hazards at various levels of vulnerability (**?**).

Sea level rise

Global SLR refers to increased changes in the volume of sea water which in turn causes the sea water to spread out further inland. The volume increase is as a result of changes in ocean circulation patterns due to increased sea temperatures. SLR is caused by thermal expansion of sea waters, impact of melting ice sheets due to atmospheric temperature increases and uplift/subsidence. Other studies define this as a relationship of landward intrusion of sea water as a result of increasing levels of water in the ocean.

Local SLR on the other hand mainly arises from the net balance of vertical land motion (uplift or subsidence) and the vertical motion of the sea surface (**???**).

In summary sea level changes both globally and locally are due to:

- Variations in the shape and form of the ocean basins.

- Changes in ocean volume as a result of a change in the mass of water in the sea
- Changes in ocean volume as a result of changes in ocean water density

Storm surge

Storm surge is the temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions especially low atmospheric pressure and/or strong winds. A storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place. A storm surge is a rise in sea level that occurs during tropical cyclones or intense storms also known as typhoons or hurricanes. Storm surges are often caused by strong winds that push ocean waters into the shore which often leads to flooding. This means that storm surges constitutes critical hazards for coastal regions, such as Mombasa and Lamu.

Tectonic sea level contributions

The tectonic sea level contributions can be by crustal movements which may be local or global. For example, tectonic activity along mid-ocean ridges will cause eustasy worldwide. However, locally, coastal areas may be raised or lowered to regional sea level by subsidence or uplift which could arise due to coastal drilling or engineering structures along coastlines. Tectonic global sea level contributions happen when the earth's plates facilitate the opening and closing of ocean basins. The process adds new crust/space along mid-ocean ridges which changes the continental/plate margins with subduction and isostatic adjustments by the new crustal material causing sea level contribution. Volcanic activity along the mid-ocean ridges also releases juvenile water that is ejected from the rock during extrusion thus effectively contributing to sea level changes.

Vulnerability assessment

For the purpose of this study, vulnerability is defined in line with recent IPCC definitions, where climate change vulnerability is the degree to which a system is susceptible to, (or unable to adapt to) the negative and adverse effects of climate change.The negative changes include climate variability and extremes (**?**). Vulnerability is therefore measured as a function of the magnitude, the rate of climate change, the extent to which a system is exposed, its sensitivity and its ability to adapt. A formal theoretical framework of vulnerability is a prerequisite for modelling approaches to its assessment. **??** note that for accurate vulnerability results, one must specify the following

- The entity that is vulnerable;
- The stimulus to which it is vulnerable
- The chosen criteria to analyse the related outcome of the interaction between stimulus and the entity

Vulnerability atlas

An atlas is defined as a collection of various maps of the earth or for a specific region of the earth. The maps in atlases show items like specific geographic features as well as the climatic, social, religious and economic representation of an area. The most common types of atlases are the reference or desk atlases. Desk atlases are hardcover, or they are made in a similar fashion as reference books while reference atlases are large and often include maps, tables, graphs or other images aimed at a more in-depth knowledge of an area. The atlas production process in this study is intended to incorporate the outputs of the impacts of SLR on the coast of Kenya. The final atlas thus integrates the concepts of a participatory process on climate change as a critical complementary process to the modelling for SLR.

1.4 Structure and outline of the thesis

The study is structured into six chapters as follows:

Chapter 1 provides the background and the research context of global climate change and SLR. The context includes the imminent threat SLR poses to communities and residents and the use of global and regional climate change research models to report on the projected climatic change scenarios. The chapter also includes an introduction to SLR vulnerability assessment which thus contextualizes the vulnerability assessment scope of the study. The research delimitations, objectives, the research questions, the working hypothesis as well as the justification and significance of the study. The chapter introduces the conceptual framework that guides the study, especially on the role of the community and community-based climate change information dissemination, awareness raising and climate-related perceptions. The vulnerability atlas production process is also outlined in the chapter. Finally, the chapter appraises the role of coastal planners and the relevant planning authorities in enhancing the sustainability of these islands in particular through mitigation of SLR vulnerabilities of their assets, infrastructure and communities.

Chapter 2 entails the appraisal of related literature starting with the definition of global climate change and SLR followed by the observed global and regional

changes and trends. The global climate change issues appraised includes global temperatures, changes in the precipitation patterns and land temperature changes. Others include sea-surface temperature changes and their influence on SLR and its associated impacts. The chapter then reviews related studies on regional climate trends including SLR vulnerability, the causes of SLR, and the scenarios used in the study. The chapter then concludes with a review of the scientific and spatial analysis of SLR using GIS, followed by an appraisal of studies on the current approaches to vulnerability assessments and their limitations, along with the methods that are deemed most suitable for the African continent.

Chapter 3 presents the overall research design and the methods employed in the field including how the PAR was incorporated in the one-day mini-charrette process in each of the cities. In particular, the chapter presents the methodology of PAR as implemented and the challenges identified in the two case studies and the approach used to mitigate these challenges. The chapter also presents the physical modelling processes used, where the analysis for Mombasa and Lamu islands is based on the IPCC 30 years starting from 2030 to 2100. This includes the process applied in defining and identifying the inundation areas in the field, the sources of data and the limitations associated with the tools and data sources used. The research design (description of the study sites, their population, geography and the individual oceanographic factors) are elaborated on in the chapter as well as the vulnerability assessment methodologies used in the SLR calculations.

Chapter 4 provides an overview of the data collected and analysed in order to derive the nature and extent of land and infrastructure vulnerability to SLR, for Mombasa and Lamu, thus addressing the first research question conjointly with the first and the second objectives of the study. The first research question (on the extent of vulnerability) and the second goal of the modelling using GIS-based tools are presented. The chapter further presents the simulated/modelled inundation areas along with the results regarding the extent of inundation based on the two most important Rapid Concentration Pathways (RCPs) which are the RCP 2.6 (the optimistic scenario) and RCP 8.5 (the pessimistic scenario).

Chapter 5 presents foremost, perceptions of participants before and after the mini-charrette process and how the perception and awareness changes generated dialogue on adaptation and mitigation techniques. The chapter also addresses the third and fourth research questions on the role of participation in scientific-based studies and the significance of participatory methods in changing perceptions or empowering the concerned stakeholders/communities to act on/towards responsive adaptation and mitigation strategies. The chapter also describes the

level of community understanding of SLR and the areas and activities that are important to the coastal community members and the changes they are currently experiencing possibly as a result of climate change.

Chapter 6 summarises climate change trends globally and regionally on the two islands, SLR trends and community perceptions. In addition the chapter also presents community steps towards SLR vulnerability adaptation and mitigation. Also included is a summary consolidation of the results followed by overall conclusions and recommendations of the study with reference to the main research question and the working hypothesis. It also presents the consolidation of findings derived from the vulnerability levels which are then applied towards the compilation of the vulnerability atlas. Findings on the significance of participatory methods toward influencing and empowering affected communities and stakeholders to changing perceptions and act pro-actively towards mitigation and adaptation are also appraised. The chapter thus coalesces and describes the research findings in response to the four research sub-questions and the key research objectives.

The final section of the thesis carries the list of references and the appendices. These include the Vulnerability Atlas, Vulnerability Assessments Manual, additional figures, examples of geographical characteristics of the two islands, different research data of the coastal zone.

Chapter 2

SLR, spatial vulnerability assessment and participatory action planning: A literature appraisal

"In the framework of co-science and co-production, virtue in science cannot be constituted any differently from virtue in the society; the two are inseparable, cut from the same polishing cloth, and seemed with the same ethical and political understandings" **?**, 237.

2.1 Introduction to literature reviewed

Previous studies in climate change, SLR studies and adaptation management in coastal environments has had a strongly technical and quantitative approach **?**. The studies either focused on the physical/spatial approach, such as beach response to effects of SLR using remote sensing, and an emphasis on socio-economic vulnerability focussed on disaster mitigation in response to natural hazards. **?** posits that much attention in vulnerability assessment is given to the physical forcing and impacts of climate change at the expense of integrating and examining the pre-existing social and community level of exposure and vulnerability. As a result community vulnerability-based research is under emphasized even as inland coastal inundation risk escalates especially where such communities eke a daily living along the vulnerable coastal zone (**?**).

Although this approach is necessary for effective adaptation strategies, it neglects the influence that social and governance systems have on the studied impacts and the management thereof (**?**). In most studies in this field, no single approach or technique can sufficiently explain or fulfil the requirements of the research objectives. Equally, the production of policy-relevant and usable knowledge is

rapidly becoming a critical factor necessitating the integration of science, policy, and related fields within a study.

In summary, several key limitations with previous approaches used to characterize coastal vulnerability to climate change were noted and explained. The results from the typically scientific driven impacts and vulnerability assessment approaches, are mainly narrow based with regards to the all round definitions of vulnerability. The issues of spatial extent and scale that control the distribution/type of impacts/attributes of adaptive capacity are emphasized. To date, there is no common, and consistent definition of vulnerability as applied to the assessment of climate change impacts. There is, therefore, need to follow a synthesizing approach to accommodate contributions from a range of disciplines that span across the urban social and natural sciences (**?**). A review of common research processes and definitions towards a more responsive and integrated approach as applied in this study is provided in subsequent sections.

2.2 Global climate change

? notes that several countries (150) ratified the UNFCCC, which gave key definitions of climate besides global climate change. In Article 1, the document defines climate change as,

> "*A change of climate which is directly or indirectly attributed to human-induced activity that changes the composition and characteristics of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods*"

As such, a distinction is drawn between natural climate variability and anthropogenic climate change induced by the socio-economic activities of the *homo sapien* species due to altered state of the earth's atmospheric composition. It also recognizes short-term climate variability and longer-term changes as essential components of climate changes. Longer-term climate changes are significant shifts in the mean state of climate elements that persist for decades or longer.

Climate variability is defined by shorter-term (seasonal to inter-annual) variations within average weather conditions. The changes include shifts in inter-annual means and/or standard deviations of climate elements on top of shifts in the frequency and/or magnitude of extreme events. Climate variability is experienced on various spatial scales (locally to regionally) and temporal scales typically longer than that of individual weather phenomena. Climatic variability and change may thus occur as a result of:

- Natural processes internal to the climate system (with example such as ocean-atmosphere heat exchanges)
- External climate forcing (for example changes in solar radiation inputs) and
- Human induced (anthropogenic) and persistent changes in the climate system (greenhouse gas emissions) as one driver of such change.

The IPCC defines a time horizon of up to 2100 over which future climate change scenarios, impacts and adaptation strategies could be conceptualized and developed. However, it is worth noting that climate change and trends will not necessarily stop by 2100. The date is merely a long-term planning horizon adopted as the consensus range for future scenarios modelling.

2.2.1 Global climate scenarios

Several sets of consensus scenarios have been standardized and used as a basis for climate change impacts and costs assessment as well as associated mitigation interventions globally. These scenarios thus constitute the commonly used approach/framework of the Special Report on Emission Scenarios (SREs) (**?**). The scientific community did an update of these SREs scenarios aimed at facilitating current and integrated analysis of climate change across different scientific communities (**?**). During the update of the SREs scenarios, members of IPCC and the larger scientific community were commissioned to redevelop the current set of scenarios (**?**).

The revision facilitated for the conceptualization of Representative Concentration Pathways (RCPs) according to harmonised radiative forcing up to 2100 level as published by various scientific groups. The aggregate radiative forcing estimates are based on the forcing of greenhouse gases and other change agents but does not include direct impacts of land use and land use change (albedo) or the forcing of mineral dust. The redeveloped climate change scenarios are classified and identified as follows: The RCP 2.6 is the lowest and the most optimistic emission and radiative forcing scenario represented by an increase in mitigation measures aiming to limit the global mean temperature increase to 2 °C.

The RCP 4.5 is the stabilization scenario where the total radiative forcing is stabilized and managed before 2100 by the employment of a range of technologies and strategies aimed at reducing greenhouse gas emissions stabilized at approximately 4.5 Wm^{-2}. The AIM modeling team developed the RCP 6.0 at the National Institute for Environmental Studies (NIES) of Japan. It is mainly stabilized scenario where total radiative forcing is stabilized at 6.0 Wm^{-2} after

2100 without overshooting the target and based on the employment of a range of current sustainable technologies and strategies for reducing greenhouse gas emissions.

The pessimistic climate forcing scenario is the RCP 8.5 which is considered a high emission, high energy-intensive scenario. The MESSAGE group developed this scenario, and its mainly driven by increased population growth coupled with a lower rate of technology development. According to **?** and **?**, the scenario is characterized by high greenhouse gas emission levels over time on an upper pathway under which the earth radiative forcing reaches above 8.5 Wm^{-2} by 2100 and continues to rise for some amount of time (**?**).

The study concentrated on the two final RCP 2.6 and RCP 8.5 as summarised in Table 2.1. The two scenarios were selected to explore the effects under the pessimistic and optimistic scenarios as the extreme conditions, especially given that the updated RCPs scenarios have not been systematically downscaled to the local/regional levels within the case study area.

2.2.2 Observed global changes and trends

Based on the continuous data capture and reporting by the IPCC, there are several changes already being observed in both short term and long term climate changes. The variabilities noted to date are reviewed in the sub-sections below.

Temperature changes

In the technical summary of the AR5 IPCC climate report, **?** confirm that Global Mean Surface Temperature (GMST) in Africa has increased since the late 19th-century as demonstrated in Figure 2.1. Equally, based on the altimetry measurements, the earth surface temperatures for each of the past three decades has been warmer than previous decades with the 2000 decade being the warmest.

The globally averaged combined land and ocean temperature data as calculated by a linear trend, show a warming rate of 0.85 °C over the period 1880 and 2012, and about 0.89 °C over the period 1901 and 2012. In Africa, projected temperature increases fall within an increase of 1.6 °C range under the RCP 2.6 (optimistic scenario) and a high of between 3 °C and 5 °C under the pessimistic scenario of RCP 8.5 (see Figure 2.1).

According to the IPCC, the surface temperature change by the end of the 21st century is likely to be more than 1.5 °C for all RCP scenarios except the most optimistic scenario which is RCP2.6. It is expected to exceed 2 °C for RCP6.0 and the most pessimistic scenario of RCP8.5, but expected not to exceed 2 °C for

the median scenario of RCP4.5. In summary, warming will continue beyond 2100 under all RCP scenarios except RCP2.6 (**??**).

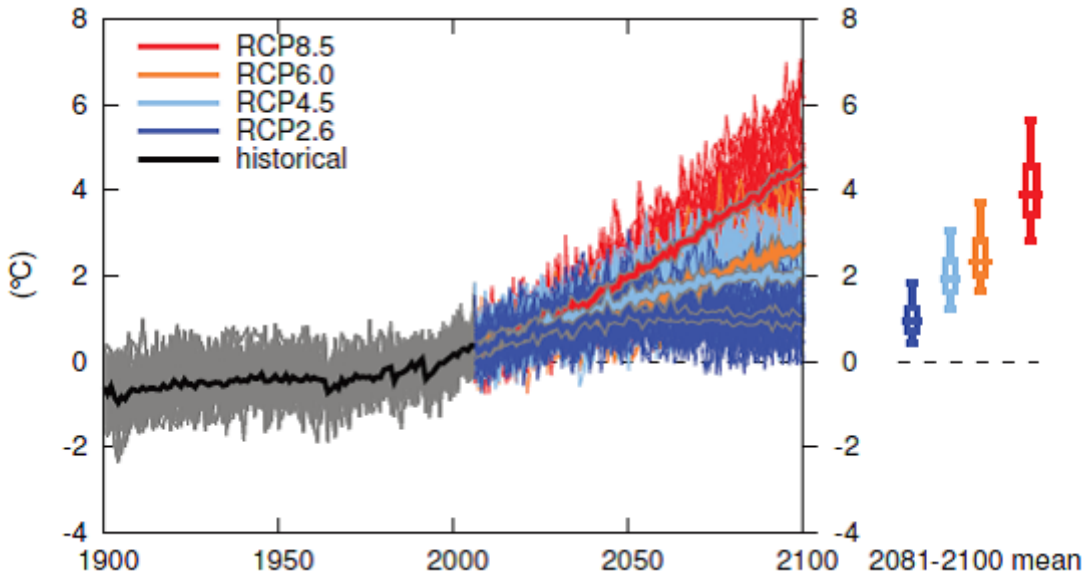


Figure 2.1: Temperature changes in East Africa between December and February. Source:(**?**).

Land and sea surface temperatures

? note that land and sea surface temperatures have already been on the rise over recent and previous decades. The upper ocean temperatures for zones that are from 700m ocean depth have increased from 1971 to 2010. Sea surface warming is causally associated with the thermal expansion of the ocean waters thus leading to increased SLR. However, there is less certainty about changes before 1971 due to relatively sparse sampling in earlier time periods.

On the global scale, the ocean warming is largest near the surface of the ocean, the upper 75m has warmed by 0.11 °C per decade over the period 1971 to 2010 (**?**). The confidence in the values of ocean warming has improved due to the improved instruments and tools for ocean monitoring since the IPCC Fourth Assessment Report (AR4) of 2007. The inclusion of better assessment instruments have led to accurate temperature recording and in the measuring of the upper-ocean temperature thus reducing the uncertainty and increasing confidence in the sea surface temperature measurement trends and trajectories.

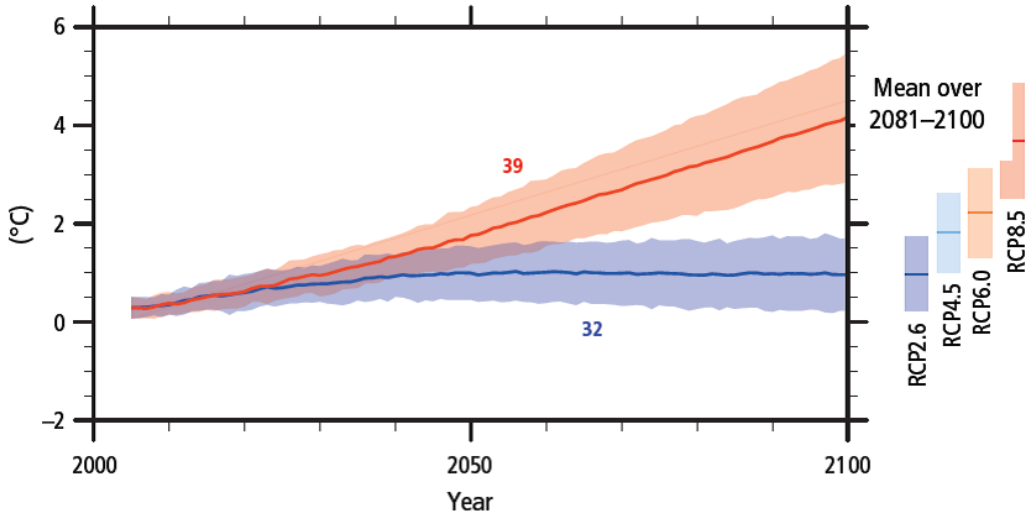


Figure 2.2: Global average surface temperature change (1986-2005). Source: (**?**).

2.3 Sea level rise

Whereas sea level has been rising slowly over the last century, the rate of rise is set to escalate by the end of this century. It is also projected that SLR will continue beyond the year 2100 unless the current global mean temperature trend is reversed. Sea level change is mainly influenced by three key drivers which are eustatic forces, isostatic and tectonic contributions.

Although SLR over the last century has been dominated by the thermal expansion of ocean waters and the loss of glaciers, past records and related research (see for example **?** and **?**) indicate that significant contributions are expected from the melting of the Greenland and Antarctic Ice Sheets. The IPCC report states that the mean rate of global sea level rise between 1901 and 2020 is 1.7mm yr^{-1}, 2.0mm yr^{-1} between 1971 and 2010,
and 3.2mm yr^{-1} between 1993 and 2010.

The combined glacial mass loss and ocean thermal expansion due to warming since the 1970s explain for close to about 75% of the observed global mean SLR. For the period between 1993 to 2010, the global mean SLR has been consistent with the observed contributions of 1.8mm yr^{-1}. These contributions are from ocean thermal expansion accounting to 1.1 mm yr^{-1} and glacial melting and changes accounting to an SLR of 0.76mm yr^{-1} (**?**)

The other anticipated contributions are from the Greenland ice sheet amounting to 0.33 mm yr^{-1}, Antarctic ice sheet contributing up to 0.27mm yr^{-1}, and land

water storage (a factor of uplift and subsidence) contributing to 0.38mm yr^{-1}. The total sum of these contributions is 2.8mm yr^{-1}. There is also a consensus that the maximum global mean SLR during the last ice age (between 129,000 and 116,000 years ago) was up to 5m higher than the present rate, but not beyond 10 m above the current sea levels (**?**).

During the same ice age period, the Greenland ice sheet is believed to have contributed between 1.4m and 4.3m towards increasing the global mean sea level, thus indicating that the Antarctic ice sheet equally made a significant contribution. The change in sea level is believed to have been driven by a temperature of about 2 °C (**??**).

2.3.1 Drivers of SLR

Changes in local sea level are a factor of several drivers that include the weather and climatic factors, land subsidence, sand compaction, sedimentation and changes in water storage, vertical land motion due to earthquakes and isostatic rebound including ocean circulation patterns. Studies on these drivers are appraised in the subsequent sub-sections.

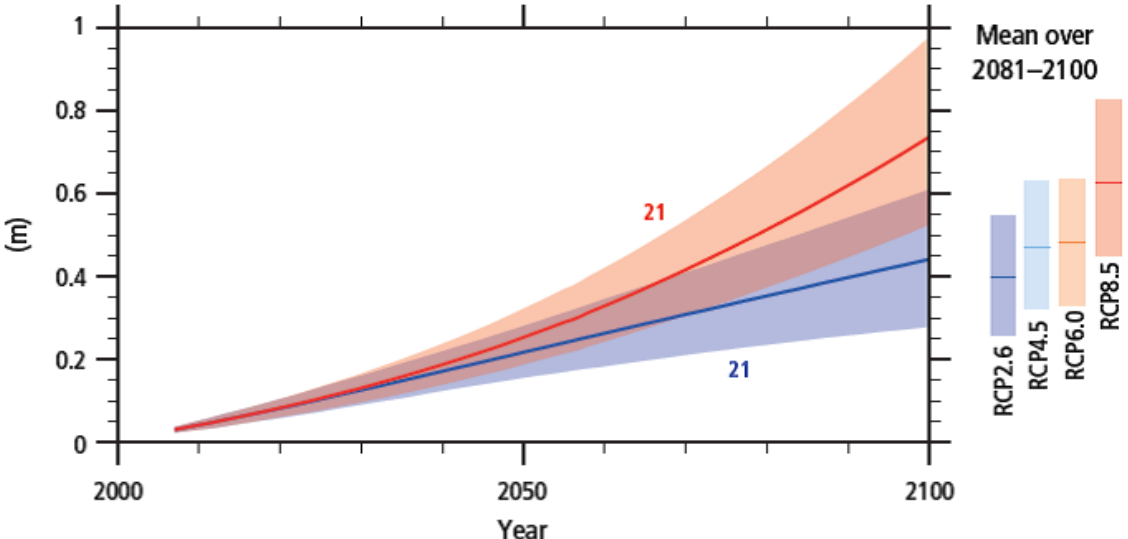


Figure 2.3: Global mean SLR relative to 1986-2005.
Source: (**???**)

Ocean heat uptake and thermal expansion

As indicated earlier, due to advances in ocean surface temperature measuring techniques, it has been observed that increased ocean temperature directly links to ocean thermal expansion. The warming has led to increase in the rate SLR by

the second half of the 20th century. Thermal expansion of ocean waters accounts for about 38% of the observed SLR since 1960 and about 50% from 1993 to 2003; thus depicting a massive increase in the rate of SLR in the past two decades. The contribution of thermal expansion of ocean waters to the global mean sea level is currently estimated at 38%. The 38% means that thermal expansion of the ocean could be causing an SLR forcing of up to 1.1mm yr^{-1} (**??**)

Melting of ice sheets

Melting of ice sheets due to the atmospheric and surface temperature changes is the eustatic component of sea level changes. The eustatic changes are due to an increase in the ocean volume as the great ice sheets of the late Pleistocene age melt and release large volumes of their water into the oceans. The SLR contribution from the Greenland Ice Sheet is on average 0.18m yr^{-1} for up to 1 °C of warming and 0.34m/yr^{-1} between 2 °C and 4 °C of warming. The melting is a factor of a 10% melted ice sheet per year to an essentially ice-free state. This means a reduction of ice volume of approximately 10% of the current volume.

In the unlikely circumstance of a complete meltdown of the Greenland ice sheet it would correspond to a SLR contribution of more than 6m. According to **??**, the outlet glaciers covering Greenland and its ice sheet are becoming more vulnerable to deep ocean thermal forcing, and peripheral thinning than previously estimated. The melting of glaciers is creating profound and widespread glacial valleys around Greenland thus implying that the outlet glaciers and the Greenland ice sheet as a whole are also melting due to the warmer ocean forcing and are therefore retreating faster and farther inland (self-reinforcing feedback effect). The melting of glaciers is mainly during the hot summers while the disintegration of ice sheets is due to the eustasy.

Melting of the glaciers

The resulting sensitivity of sea level contribution decreases for increasing temperatures from 0.21m/°C at pre-industrial temperature levels to 0.04m at 4 °C of warming. The decline in sensitivity to higher temperatures is to a large extent explained by the loss/depletion of small glacier. Although melting glaciers and thermal expansion of the ocean have contributed approximately equally to the SLR of the last 40years, the sea level commitment due to glaciers is relatively small compared to the contribution from thermal expansion. Continuing the trends reported in AR5, the Arctic Sea ice extent (annual, multi-year and perennial) has decreased over the period of 1979 to 2012 (**?**).

The rate of the annual ice decrease was between 3.5 and 4.1% per decade which

translates to a range of 0.45 to 0.51 million km^2 decrease in ice mass due to melting per decade. The average reduction in the decadal extent of annual Arctic Sea ice has been most rapid in summer and autumn, but the extent has declined in every season, and in every successive decade since 1979. The melting of the Arctic multi-year period led to the ice decreasing between 1979 and 2012 at a higher rate of 11.5% which is an equivalent of 0.73 to 1.07 million km^2 per decade. During summer, the sea ice extent is minimum at 13.5 % per decade for multi-year ice. Global glaciers have been shown to be persistently shrinking as revealed by the time series of the measured changes in glacier length, area, volume, and mass.

Confidence levels in these measurements have increased substantially since the IPCC Fourth Assessment Report of 2007. During the last decade, the largest global glacier ice loss was from the Canadian Arctic, the glaciers in Alaska, the Greenland ice sheet, the Southern Andes and the Asian mountains (**?**). These melting ice sheets together account for more than 80% of the global total ice loss. The total mass of glacial loss in the world, excluding those on the periphery, was committing up to 0.62mm yr^{-1} in the period between 1971 and 2009, 0.76mm yr^{-1} in the period 1993 and 2009 and 0.83mm yr^{-1} between 2005 and 2009.

Uplift and subsidence

There are other processes which affect sea level but not directly associated with current global warming and climate change. Some of these result in changes that are significant enough to influence the interpretation of observational records and sea level projections at regional and global scales. In particular, the surface mass transfer from land ice to oceans during the last de-glaciation contributed significantly to current sea level change. The change has been facilitated by the ongoing visco-elastic deformation of the earth and the corresponding variations in the ocean floor height and gravity (referred to as Glacial Isostatic Adjustment, (GIA) **??**.

Ice sheets are also known to have long response times to warming and so they continue to respond to past climate especially temperature change. Sea levels have fluctuated throughout time and in the process, there has been the encroaching or retreating of coast lines and coastal plains. Variations in the natural positions of sea and land surfaces are a good indicator of vertical earth movements, caused by changes in ocean volume, or in most cases, by both driving factors. Moreover, most of these movements are associated with geological processes that include plate tectonic changes in the geology of the ocean basins.

During the last four decades, the dominant contribution to sea level change was the exchange of mass between melting ice sheets and oceans receiving the additional

water. The evidence for past sea level change occurs in the form of uplifted or submerged shorelines. These are often reflected in fossil coral reefs above their present growth positions or submerged below the former position. In situ tree stumps also give a clear indication of coastal changes. According to **?**, the increase in the ocean volume contribution comprises of two components:

- The vertical movements arising from any active plate tectonics, e.g., areas that have active volcanic activity (Asian plate)
- The vertical isostatic movements associated with any changes in the relative surface loads of ice and water.

These processes are non-climate-related but could still be anthropogenic related processes. For example ground subsidence could partly be due to groundwater and oil extraction, or reduced sediment supply to river deltas due to hard engineering structures such as dam building or sea walls. These factors often amplify local vulnerability associated with climate-related SLR. In the analysis of the coastline of Mombasa and Lamu it was noted they are not tectonically active and therefore a standard natural subsidence and uplift variation of 0.1mm yr^{-1} was applied for this study.

2.3.2 Measurements of global SLR and related challenges

The increased discussion on SLR and its effects has been informed by the availability of tide gauge data which have been used extensively to assess SLR around stations where such facilities existed. In most cases, however, the global coverage of tide gauge stations is patchy and incremental and in most countries and coastlines hardly available, or rarely maintained and left to decay. Although the coverage has considerably improved, especially in the second half of the 20th century, several locations around the globe are not covered and especially in Africa (**?**). Surprisingly data from tide gauges is seen as a critical component to the analysis of local SLR fluctuations.
Since the inception of discussions on climate change and SLR, most measurements were based on tide gauges, which as stated earlier are not evenly distributed around the globe. Besides the limited distributions of the tide gauge data, research by **?** suggests that the tide gauge records used to estimate SLR are underestimating the values, especially when including ice melt print further away from the melt source as in the case of Africa. This challenge has resulted in the inclusion of more data analysis techniques to provide an important corroboration of predictions by climate models as well as reduce the bias, which is mainly done through satellite altimetry. Satellite altimetry radar measurements are being combined with spacecraft orbits

to measure sea level on a global basis with unprecedented accuracy. These satellite missions started with TOPEX/Poseidon (T/P) in 1992, Jason-1 (20012013) and Jason-2 (2008present) which are managed by NOAA are gradually improving the estimation of global mean sea level every ten days.

2.4 Spatial SLR analysis based on global models

2.4.1 Introduction

Understanding the spatial extent of vulnerability is as important as understanding the social impacts of the vulnerable population/people. The approach of this study was based on a combined method focussing on of socio-spatial impacts of accelerated SLR. The study argues that, in addition to the unforeseen and anticipated physical hazards, there are several complex interactions between local communities living in these vulnerable areas, which in turn influences levels of exposure and vulnerability. The interactions are mainly affected by the ability of the various levels of governments to handle infrastructure/service delivery, and the communities' ability to respond to SLR related threats and hazards. These factors again are affected by available disposable resources, socialisation of risks (through health insurance for example), information dissemination, protection of the old and the young during harsh conditions, education as well as the history and preparedness levels gained from previous similar hazard events.

The global-scale climate models from IPCC were applied as the reference data in ascertaining the extent of SLR on the case study areas. The horizontal resolution of such global information directly obtained from global models was often found to be too imprecise to be extrapolated on a regional scale. Available data from the high-resolution Atmospheric Global Climate Models (AGCMs), were used to complement the coupled Atmosphere-Ocean Global Climate Models (AOGCMs), to facilitate the generation of Mombasa region-specific climate information for the RCPs (**?**). The comprehensive and detailed method is presented in Chapter 3.

2.4.2 Historical perspectives

Advanced and up to date global climate change models have been developed to estimate the impacts of climate-change related hazards to both social and ecological systems, at different spatial scales. Models on SLR and inundation of coastal regions use computer simulation and projection, with local downscaling protocols mainly used to relate findings to local scenarios (**?**). Data from such climate model simulations have increased greatly in complexity and scale.

These projections and simulations, particularly those run with common experimental frameworks, began in the mid-90s. They have gradually developed in magnitude, starting with outputs from the early Global Atmosphere-Ocean General Circulation Models (AOGCMs), into Regional based climate models (RegMs) as indicated by **???**. The models have led to increased research, and are central to the analysis of overall global impacts and changes including a comparison across several countries or regions. Also, global modeling for climate-related adaptation and mitigation has developed along the RCPs scenarios as seen in Table (2.1) section 2.4.2. Under the modelling future temperature changes are used to extrapolate diverse effects on rainfall patterns, temperature regimes as well as SLR trends.

Specific countries have taken their initiatives to model out SLR effects within their national boundaries/regions. The process has led to increased regional based modelling (RegMs), in alignment with global based climate modelling. The scaling down to regions has enabled scientists to predict regional patterns of climate changes at a more local scale. For example, Germany has adopted a 1m SLR increase by 2100 while Netherlands and Australia have a planning index of 2m SLR within the century (**??**).

2.4.3 Climate scenarios and projections for Africa

Regional research in related fields such as SLR where the baseline for the research is referenced to findings from the global trend studies has greatly improved. However regional model approaches vary from one study to the other, but most of them have provided a good basis for national planning in different fields. In this regard, Kenya has not developed its own regional or national scientific climate modelling studies or related data. The failure is mainly because of cost implications and the technology required for conducting a validly convincing analysis. However, several other research organizations and institutions have tried to model Kenya's response to climate change (see for example **?**). Results from these global models have been used, though with caution, in the development of planning schedules for the Kenyan government.

The greenhouse gas emission scenarios and story lines developed by IPCC in 1992 were used in the AR4 IPCC report (see Table 2.2 adjusted and updated as seen in Table 2.1). They have provided input for the reassessment of climatic and environmental consequences of future greenhouse gas emissions based on the key drivers under each scenario. **??** illustrates how independent researchers have used some of these scenarios, to estimate future outcomes, with regards to climate change and especially adaptation strategies to accelerated SLR.

Table 2.1: AR4 2007 climate scenarios: Adapted from **?**, 4-5.

Storyline	**Family**	**Description**	**Groups**
A1	A1	Future world of very rapid economic growth, global population peaks in mid-century and declines after that, and rapid introduction of new and more efficient technologies	A1F1-Fossil fuel intensive. A1T-Non fossil fuel energy. A1B-balanced energy use
A2	A2	Different world, with self-reliance and continuously increasing global population. Economic development is regionally based, and economic growth and technological change are more fragmented and slower	Balanced globe
B1	B1	Global population peaks in mid-century and declines after that, rapid changes in economic structures toward a service economy. More of information economy, introduction of clean and resource-efficient technologies. Global solutions to social, economic as well as environmental sustainability are emphasized	Clean energy and balanced
B2	B2	Continuous population increase lower than A2, intermediate levels of economic development, greater and less rapid technological change than in the B1 and A1 storylines. Oriented toward environmental protection and social equity, though on local and regional levels	Positive environmental protection

The importance of the development of the story lines (as shown in Table 2.1), is in guiding the estimation of the effects on SLR levels based on a given climate scenario. These can either be described in business as usual scenario, (A1 and A2) or a more adaptive scenario of, for example balanced and clean energy use (B1 scenario). These story lines were developed to anchor the relationships between emissions, their driving forces, evolution and the context under which the scenario can be quantified. Each storyline represents different mix in the demographic, social, economic, technological, and environmental development path (**?**).

As discussed earlier, the SRESs emission scenarios have been replaced with the RCPs that are outlined in Table 2.2 and compared with the SREs later in this section. Apart from the IPCC estimates, various studies have used a variety of different factors, tools and methods to estimate future sea level change. The use of global climate change models as reported by **?**, a temperature/SLR relationship study by **?**, ice melt-yield analysis of SLR by **??** and quadratic equation projections from tide records as reported in the **?** are a few of the methods used to date for SLR analysis. Although predictions of rates and magnitude of future global SLR are still hotly debated, there is strong agreement that sea levels will rise, and several countries have adopted SLR scenarios for their national planning based on the work of the IPCC

Table 2.2: AR5 2013 revised climate scenarios: Adapted from **?**.

Concentration pathway	**Family**	**Description**	**Groups**
RCP2.6	2.6	The lowest emission and radiative forcing scenario the representative of mitigation measures aiming to limit the increase of global mean temperature to 2 °C	Non fossil fuel
RCP4.5	4.5	Stabilization scenario where total radiative forcing is stabilized before 2100 by use of technologies for reducing greenhouse gas emissions	Balanced
RCP6.0	6.0	The total radiative forcing in the scenario is stabilized after 2100 without high effects by employment of a range of technologies for reducing greenhouse gas emissions	Balanced and technology intensive
RCP8.5	8.5	Considered a high emission, high energy-intensive scenario due to high population growth and lower adaptation to technology advancement	Fossil fuel intensive

Whereas vulnerability assessment in coastal areas is not a new phenomenon, especially given the ever-present risk of sea related impacts, contemporary assessments have emphasized the need for understanding escalation in exposure due to climate change induced hazards, such as additional sea water intrusion, storm surge or floods. The National Assessment of Coastal Vulnerability to future SLR (see **?**), alluded to the fact that determining the physical response of the coastlines to SLR constitutes a significant problem, in coastal environmental studies today (**???**). However, this can be better facilitated when participatory and multi-disciplinary research approaches are engaged. Consequently, studies have used various SLR scenarios to explore the socio-economic, physical, and ecological impacts on coastal zones throughout the world.

2.4.4 Tools employed in SLR vulnerability assessments

Several methodologies for assessing coastal SLR vulnerability have been promoted in key documents and reports such as **?**. These include the common methodology (CM) vulnerability assessment approach which was conceptualised by the IPCC, and is presently the most frequently used framework for coastal vulnerability. The method mainly focuses on monetary valuations of affected assets in vulnerable areas and uses a cost-benefit analysis to assess the best response options. However, the framework has been argued to entail several weaknesses. For instance, it is argued that the biophysical framework is inadequate to support the engineering and cost-benefit stages of the process. There is also concern, about its data intensity and its simplified approach to bio-geophysical and socio-economic system response (**???**).

As a result of the several criticisms of weaknesses of CM, several other methodologies have emerged. They include the UNEP Handbook on Methods for Climate Change Impact Assessments and Adaptation Strategies in coastal vulnerability assessments, the Bruun Rule, DIVA, and DINAS-COAST, SURVAS, SimClim and CVAT among others. **?** proposed four key stages on conceptualizing alternative methodologies towards the improvement of the eight steps of the CM. The Kay methodology was in turn criticized as ineffective in identifying base values and the inadequate link with policy development (**?**).

Smartline SLR analysis approach

An alternative method is the smart line approach, which entails the capturing of geographical data using a Geographical Information System (GIS). According to **?**, the model has been tested through a similar approach to a study of the coastal zone in the Australian state of Tasmania. The method allows for the extraction of data from different existing geomorphic maps, followed by analysis and data manipulation to score vulnerable areas that are then translated into

a single, nationally consistent classification regarding vulnerability index. The approach emphasises on the identification of shores sensitive to physical change or instability due to climate change and SLR.

A significant advantage of the model is its flexibility and ability to accommodate and rapidly handle a broad range of information for the coastal zone at different levels of detail. It thus allows for the efficient integration of several types of data within the analysis process. Whereas the approach still needs validation to ascertain its level of effectiveness in the presentation of SLR values from coastal regions, it has been hailed as an ideal approach for first pass assessments of coastal vulnerability. Since this study is the first line assessment for the Kenyan coast, the research intends to build on the knowledge of the Smartline as well as participatory methods to foster integrated SLR vulnerability atlas development (**?**).

The Smartline data model captures geographical data in a segmented GIS vector polyline with multiple attribute fields attached to each segment. The various attributes attached to each line segments not only record information about features which coincide with the line, but also about other elements or processes which relate to the line segment in some simple way but are not necessarily spatially co-incident with it.

The substantially linear nature of coastal areas are their most visible feature and are reflected in terms such as "shoreline" and "coastline". Line format mapping is, therefore, an intuitively obvious method of mapping coastal attributes, using GIS and has been previously utilised by a variety of coastal scholars to represent coastal landforms (see examples such as **??**). The earliest known use of a line format map to record multiple coastal geomorphic attributes was a paper map of coastal landforms of the world prepared by McGill (1958), even though this pre-GIS map had limited capacity to record multiple attributes of given coastal segments.

Nonetheless **?**, 404 noted that

> "*What is believed to be a cartographic innovation on a world map, is the use of the coastal outline itself to indicate the distribution of the major classes of coastal landforms (plains, plateaus, hills, mountains).*"

The smart line format for GIS coastal geomorphic mapping as developed during the Australian Coastal Geomorphic and Stability Mapping (CGSM) project, has built on and refined some methods and classifications used in earlier line-format. The line coastal mapping (see for example **?**) allows the principles, constraints and appropriate applications for this mapping approach to be more clearly defined than previously done.

To draw attention to the conceptual maturing of this mapping style, the term "Smartline" was coined during CGSM project. Although a Smartline coastal map has certain limitations compared to polygon mapping (e.g., it does not delineate the landwards platform and extent of geomorphic features), it compensates for this with the capacity to record arbitrarily detailed spatial data alongshore direction (through line segmentation or division).

The smartline approach provides considerable efficiencies in both data capture, which is essentially (information from a diversity of data sources, that can be attributed to line segments more rapidly than the same information could be re-mapped into a consistent polygon format). It is therefore relatively simple to extract a broad range of information from the multiple attributes attached to each line segment through GIS queries.

In this study, the Smartline method was used to create a map of coastal landforms, where the actual GIS line to which information is attached may directly represent the Mean High Water Mark (or some other convenient assigned coastal line). The attributes attached to the line may record information about landforms occurring both landwards and seawards of the line, as well as information about other environmental parameters directly relating to each segment of coastal zone, such as the exposure of that coastal portion to wave energy.

The GIS line is simply a repository for information about features and processes that need not necessarily coincide with the precise position of the line. Hence any existing mapped line which is located conveniently within the coastal area can be used (for example in many coastal environments). However, albeit in macro-tidal environments some decision may be needed as to which of these lines is most convenient.

The Bruun rule of coastal shore analysis

The Bruun rule is the most widely used model relating shoreline retreat as one of the impacts of local SLR. Introduced in **?**, it helps to model the response of the shore profile to SLR. By empirical data on cross-shore profiles in Denmark and California, an equilibrium profile beach shape was expressed by the formula:

$$h = \frac{Ay^2}{3}, \tag{2.4.1}$$

where, h is water depth, y is the distance offshore, A is a scaling parameter based on sediment characteristics.

According to **?**, the Bruun rule approach assumes that the marginal rate of retreat equates to 50 to 100 times the rate of SLR. Although applied with some success

in the US (see examples such as **??**), there has been criticism of several aspects of the rule as a "one model fits all" solution (**?**), which is not practical given the dynamic and diverse nature of coastal areas. Based on the uncertainties of the Bruun rule, it failed to provide replicable results of coastal recession which in turn led to the contradiction of results. **?** and **?** came up with detailed formula to calculate coastal inundation and recession. The formula was based on the level of climate change and individual coastal features and characteristics that include but not limited to uplift and subsidence.

Table 2.3: Overview of tools and methods for vulnerability assessment of coastal areas: Adapted from (**??**)

Method	Description	category	strengths	weaknesses
IPCC CM	7-Step approach using monetary valuations to estimate national coastal vulnerability to future SLR	Mainly Semi-Quantitative	Appropriate for global and regional scale analysis	Not appropriate to support engineering cost benefit stage. Not applicable to remote coastal areas
UNEP Handbook	Generic framework for responding to the problems of SLR and climate change	Semi-Quantitative/ First generation.	Accessible, straight forward approach for regional/national scale to future modelling	Largely used before being updated.
Bruun Rule	Estimate of the shoreline profile response to estimated SLR . Applied widely around the globe and underlies many studies published to date	Quantitative/First generation, forms the basis of many current tools	Applicable for sandy beaches	Controversy over equilibrium profile, alternatives suggested
DIVA	Analyses a range of mitigation and adaptation scenarios to predict the global impact on the coastal zone for the next 100 years. Involves a range of mitigation and adaptation scenarios	Quantitative/New generation	Gives a reasonable overview of socio-economic and climatic scenarios and adaptation policies on regional and global scales	Not appropriate at a national scale in assessing vulnerability of the coast to climate change (large scale)
Smartline	GIS based framework for first possible mapping at large scale. Its more detailed and based on a site-specific scale	Semi quantitative/new generation	Cheap, quick, easy analysis of coastal sensitivity	Its adaptation to local site-specific environment requires further testing

The formula gives an indication of the degree of recession then provides values that can be input in either a GIS system, to analyse the impact of sea level rise, especially on coastal port cities and nations. Several studies such as **?** are based on the equation and formula. Studies based on this approach purely focus on the quantitative and scientific analysis and thus ignores community participants. In the initial processes of this study, the smartline approach together with spatial analysis was used to show the extent of SLR and its effects on the selected portions of the coastline. In this case, the entity and asset that is vulnerable are confined to the spatial extent, which is identified through land use and maps thus reflecting areas/zones at threat from SLR related hazards and impacts.

2.4.5 Nicholls' formulae of storm surge validation

This methodology (see **?** and **?**), has been used together with the GIS methodology to ascertain the areas under threat from inundation. Such events occur in cases where the high water tide meets a storm surge, caused by changing ocean patterns, which can then intersect with increased sea level, effectively broadening inundation zones. Based on an elevation (STRM) derived from Geographic Information Systems (GIS) data set, the analysis is used to assess the number of people and associated economic assets, within the low-elevation coastal zone, and could thus be exposed to extreme water levels and inundation. **?** calculated extreme coastal water levels from a combination of storm surge, sea level rise, the natural subsidence and human-induced subsidence.

The focus of the analysis based on Nicholls idea is the exposure rather than 'residual risk' of the entity under investigation, (which includes defenses and other adaptation techniques). This methodology depends on determining the number of people and the area that would be exposed to extreme water levels as illustrated in Figure 2.4. The potential risk is then related to the potential economic assets exposed within the city. During the estimation of the risk, standards of flood protection are often assumed to be economically excellent. This assumption creates a bias, and in most cases the method tend to overestimate protection standards in comparison to reality, especially in many developing countries. This equation or format of modelling again excludes the role of the vulnerable stakeholders and communities in the assessment of coastal residual flood risk.

The metric of exposure of a city to a 1 in a 100-year flood event can reveal much about the risks faced in each city. First and foremost, people in the flood plain will be reliant on formal or informal coastal flood defense systems. Principally, they will be at some level of risk even in the best defended coastal cities. The potential hazard could be as a result of the failure of these flood defenses due to breaching or

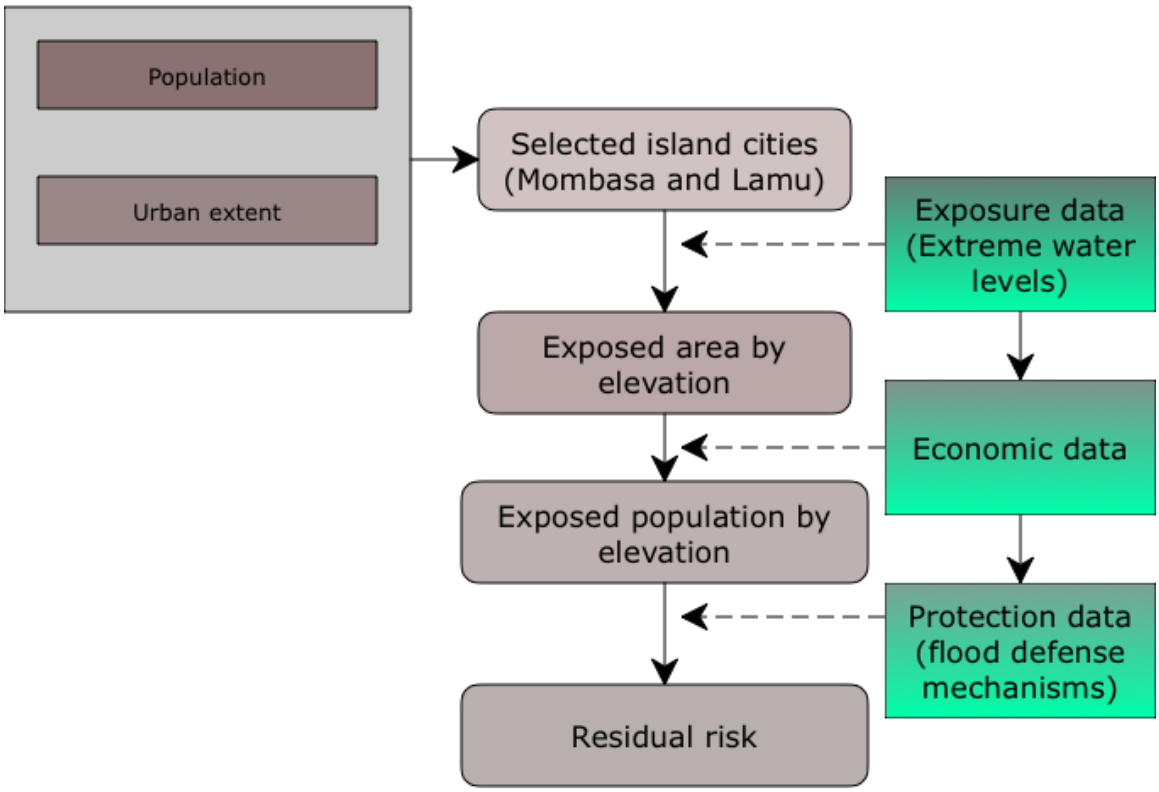


Figure 2.4: Flow diagram on methodology adapted for the study.
Source:adapted from **?**, 13.

over top surges which will become, a common phenomenon with climate change and PDF. In the case of Mombasa and Lamu, there are no flood protection measures within the cities. Instead vulnerable businesses and communities are trying to put up their own defense mechanisms haphazardly.

The exposure metric, therefore, is viewed as a worst-case scenario in the event of a storm surge, this translates into major losses during these extreme events. This exposure measure is particularly relevant when considering long time scales, as there is the added uncertainty around what appropriate defense levels will be adequate. In this study, the exposure index is calculated for a 1 in a 100-year coastal flood event with a 75% probability of occurrence (see Equation 3.3.1).

In their research , **?** considered factors that are important in SLR and storm surge impacts in coastal regions. They include;

- Population, level of economic growth and development;
- Natural subsidence/uplift;
- Global (and regional) sea-level rise;
- More intense storms and higher storm surges;

- Potential human-induced subsidence

Exposure to extreme sea levels

To analyse the land area and population exposed to inundation, current extreme water levels are obtained from the DIVA database. The water levels for each RCP scenario within each city is calculated as illustrated in the formula which combined the relative SLR, natural uplift and subsidence and the 1:100 year return period of extreme water level. The analysis also includes the storm enhancement factor, showing the probability of increased water levels due to more intense storms. Lastly the anthropogenic subsidence is also included in the analysis where appropriate. For tropical storms, a 10% increase in extreme water levels is assumed, with no expansion in the affected areas. For anthropogenic subsidence, a consistent 0.5mm is used in the analysis especially for volcanically active and highly developed cities.

Thus, according to Nichols, the change in extreme water level is variable from roughly 0.5mm to 1.5mm in the towns affected by global SLR, increased coastal storms as well as human-induced subsidence. The analysed areas of inundation are then overlaid with the population density maps, to estimate the number of exposed people and the value of exposed infrastructure and assets located at an elevation below the 1:100-year extreme water level. The result is the population and property that would be impacted by the 1:100-year event, in the absence of any flood defenses and indicates the scale of the implications in a flood event when the defenses fail. The formula uses the national wealth (GDP) as an indicator of the foreseen losses and the subsequent adaptive capacity for appropriate disaster response.

The generated calculation of Future Storm Surge (FSS) formula from the study and applied in this research is described as follows

$$\text{FSS} = \text{S100} + \text{SLR} + \left(\frac{\text{UPLIFT} * 100\text{yrs}}{1000}\right) + \text{SUB} + (S100 * x), \tag{2.4.2}$$

Where

- FSS= $S100$=1-in-100 years surge height(m),
- SLR=sea-level rise (based on the IPCC Prediction),
- UPLIFT=continental uplift/subsidence in $mm/year$,
- SUB=$0.5mm$ (applies to deltas only),
- x=0.1, or increase of 10% applied only in coastal areas currently prone to tsunamis and tropical cyclones.

The X factor

For the future exposure scenarios, S100 was used to illustrate the effect of potential changes in tropical and extra-tropical storm intensity and frequency (PDF) under climate change. The X factor, or "storm enhancement factor", is described based on the individual tropical and extra-tropical cyclone ratings for individual cities. For towns exposed to tropical cyclone hazard, S100 is assumed to increase by 10% equivalent to x=0.1. This scale factor is defined based on a current scientific understanding of the influence of climate change on the intensity of tropical cyclones. **?** presuppose that "based on several models there is greater than the two-thirds probability that future tropical cyclones (typhoons and hurricanes) will increase in intensity, with larger peak wind speeds and more heavy precipitation. Higher resolution models (as used by **?** for example), suggest that wind speeds could increase by approximately 6% and 14%, by the end of the century (under RCP 4.0 and RCP 6.5 emissions scenarios). These changes vary widely across different regions. In this study, a 10% intensity increase is assumed, which is consistent with intensity projections given by IPCC.

2.5 SLR and coastal protection methods

As earlier indicated, coastal areas are attractive to development and urbanisation, which in turn leads to increased population as a direct result of their attractiveness. These practices stretch back to the ancient times where coastal areas attracted settlement for food, tourism and entertainment almost exclusively provided by these regions, and especially where sea-trade was the primary driver of long distance logistics/transport. Global climate change and especially SLR, poses critical challenges to the sustainability of these coastal areas. Equally, people have engaged constant effort to use and protect available coastal resources, including the protection of their investments from negative coastal impacts as a result of increased SLR and ocean/salt water intrusion.

The various ways that beaches respond to changes in sea level complicate assessments of the impact of SLR on natural systems. Consequently, the perspective of the observed response to SLR, and/or our interpretation of a measured response to SLR, changes as a function of the different timescales. For example, barrier islands can migrate landward for tens to hundreds of kilometres over timescales that span 103-104 years. In several identified cases, SLR causes the shoreline to move landward during inundation. The movement leads to a stable or subsiding terrestrial land surface if the sediment supply rate cannot keep pace with the SLR rate (**?**).

Geologic evidence shows that during the Holocene era, coastal barriers, bays, marshes, and wetlands have all experienced dramatic changes that included overstepping and continuous rolling over. At the other end of the temporal spectrum, the daily physical forces associated with SLR do not appear to contribute to the net coastal sediment transport regime.

During decadal to centennial-scale time periods (over 100-years), processes such as El Nino, affected coastal sediment movements. Other factors influencing the coastline movements also include storm surges, tidal inlet processes, seasonal wave climate variations, or human-sea interaction. This interaction can either be synergistically or episodically based on a given event, or periodically overwhelm and impact coastline as a factor of geological processes interactions with the ocean and SLR to produce beach morphological responses as studied in San Diego by (**?**). Moreover, the global effects of SLR on coastal regions will vary spatially depending on the unique features and dynamics induced by the given coastal zones/strips.

2.5.1 Engineering protection techniques

Due to the continuous effects of coastal storms and disturbances, some coastal scientists have advocated analyzing and protecting coastal areas from further destruction due to the effects of climate change. Several methods have emerged, ranging from the traditional engineering coastal protection measures to the eco-system and spatial based coastal protection measures. The protection is mainly motivated on the basis of increased tourism and the need to keep coastal areas as natural as possible as well as protection of the coastal resources from the effects of flooding and inundation. The main engineering or hard methodologies of coastal protection include Shoreline Protection Works (bulkheads, seawalls, revetments) (**?**). Other protection techniques include;

- Flood control works (dykes, channels, retaining ponds)
- Sand trapping structures (groins, jetties)
- Sand moving programs (beach nourishment, beach scraping

Groynes, revetments, breakwaters or dams are built with the aim of mitigating the threats of flooding and erosion. Groynes are mainly perpendicular or almost perpendicular to the shoreline targeting the interruption of sediment transportation and typically set to resolve a problem, at a specific scale. As Groynes (both permeable and impermeable) stabilize, they form accretion (and a

beach) on the updrift side. In most cases, these structures are not helpful in the event of a steep beach.

On the other hand, revetments are implemented to mitigate small scale (both spatial and temporal) erosion. Revetments are designed sloping and placed on banks or cliffs in such a way as to absorb the energy of incoming wave or water. They aim to reduce the speed of sediment washout substantially. These structures are in a sloped form thus offering the security of an area from external ocean interference on adjoining land. Coastal revetments are built with the aim of protecting the existing beaches including the uses of the shoreline and the slope as a defense against erosion and inundation.

Revetments also include aspects of the sea wall as an improved method of hard coastal protection. The seawalls are constructed where further seaside erosion is about to make drastic changes to coastal infrastructures such as roads and railway tracks. They are the defining line of demarcation between the land and sea. The walls are mostly stable and structurally sound. However, irregular or unregulated building of sea walls has been associated with erosion and severe effects on coastlines.

In some cases, as has been regularly experienced, besides putting sea walls structures under immense pressure, high sea waves can create opposite effects on coastal areas not protected by the structures. The high water pressure caused by increased coastal storminess and climate changes has sometimes led to ocean waters overtopping the sea walls causing destruction along coastal areas. Other engineering structures against coastal threats include the dams, which are a barricade across a river to limit the flow of water downstream. Dykes, such as the Delta Works in the Netherlands, which are applied to provide protection on large spatial and temporal scales against the threat of coastal flooding and inundation aid to prevent water from entering a specific location (**??**).

2.5.2 Spatial methods of coastal protection

Whereas the spatial and close to natural coastal protection methods are not new concepts, they are too oftenly overlooked or ignored. Complete floodplain management program must include all activities necessary to reduce future flood hazards (preventive) while correcting past mistakes (remedial). These actions include land use controls, the planning, design, construction and naturally maintaining the flood control facilities (**?**).

As the agencies usually responsible for providing remedial flood control facilities, local governments are increasingly squeezed between tightening revenues and the

growing demand for services due to increased urbanisation. The public wants relief from flooding problems while also looking for more amenities, including recreational facilities. Flood control facilities, while necessary and useful, are dry most of the time; and are therefore available for other public purposes (such as recreation and open space) which are compatible with the flood hazard function (**?**).

Such spatial and natural protection techniques include floodplain regulation requirements, coastal hotels land dedication requirements, storm water detention facilities, open spaces or mangrove forests as part of beach landscaping requirement. These elements are essential and considered natural coastal protection systems that reduce the risk of storm surges and coastal flooding. Both public agencies and private developers can look to the spatial protection concept of multiple uses and provide needed facilities and desirable amenities which improve the quality of life, as well as protect coastal regions.

Shared land, shared facilities, and shared construction and maintenance responsibilities can all help meet the needs of society at a reasonable cost. Proper planning can assure multiple uses. Weak planning results in loss of opportunity for multiple uses at lower costs. Public parks can be set up at intervals along coastal areas prone to coastal flooding, and these parks can be used by the local community members during the dry seasons. These small parks can consist of playground equipment, benches, picnic tables and beach plots, bicycle racks, exercise stations, drinking fountains, trash receptacles, among others which can be used transiently.

Besides such facilities, other natural structures can be enhanced. They include channels, boat launching areas and lagoons providing access to the ocean banks, a parking lot with sports facilities, or a play structure that acts as a barrier between coastal communities and coastal influences. The desired areas or free spaces are a service that not only provides the flood protection required but also functions as a natural park for the residents. Retention centres can also be used as spatial coastal protection areas where every type of facility from major engineering structures and flood control projects to the smallest of “on-site” ponds, are designed to offer monitoring and remedy during an extreme event (**?**).

2.6 SLR and coastal vulnerability assessment in Africa

2.6.1 Introduction

Africa's coastline is vast and has a fast growing coastal population, especially in her major coastal cities. There are 33 countries in Africa with coastlines, and seven neighbouring coastal Island nations and territories. The coastline stretch is estimated to be more than 38,000 km long, inclusive of the 7,000 km of the neighbouring small island countries and territories (**??**).

The coastal zone (low elevation land at up to 10m above sea level), varies in width from a few hundred meters to more than 100km around the Nile and Niger deltas. It includes swamps, socio-economic and ecosystem features such as residential areas, three and five star rated hotels, mangrove forests, coral reefs, cliffs, sandy beaches and mudflats, tidal marshes, as well as urban settlements. **?** notes that there are around 320 coastal cities in Africa (home to more than 100,000 people each) and nearly 72 million inhabitants (by 2012 estimates), who are living at low elevation coastal zones. Many of these coastal cities are also key and important ports for national and regional trade as well as imports and exports within their regions.

2.6.2 Vulnerability of assessed cities in Africa

Africa (excluding South Africa) and the least developed nations globally are viewed to be the most vulnerable to the effects of climate change. These least developed countries are the least contributors to the greenhouse gases now contributing to climate changes **?**. Their lower contributions to GHG emissions is mainly due to lower energy use (overall and per capita) and lower consumption of fossil fuels that are the key contributors to GHG-emissions. The severity of future climate change impacts is predicted to escalate current vulnerabilities and further reduce existing adaptive capacities especially in the main urban areas of Africa (**??**).

It is, therefore, a primary concern that very few coastal cities in Africa have undertaken studies on potential impacts of SLR and detailed vulnerability assessments. The few existing studies cover the coast of Durban and Cape Town (**??**). Based on tide gauge records and a simplified version of GIS for spatial extent, the study by Mather Andrew (2008) documented sections of the services and areas under threat from the effects of accelerated SLR in the eThekwini municipality (the greater metropolitan area of Durban).

Based on the seven-step standard methodology as envisaged by IPCC (see Table 2.2) **?** assessed the vulnerability of the Nile Delta in Egypt to the impacts of SLR.

However, although the study covered economic and social implications it did not entail an integrated approach as with the objective of raising inclusion of raising stakeholders awareness and preparedness for adaptive and mitigative action as undertaken in this study. Vulnerability assessment for the Mediterranean eastern coast of Morocco was done as reported in **?**. The study combined the IPCC seven step common methodology, the UNEP Handbook process, and a GIS-based analysis to document the impacts of sea level rise and inundation.

As in most cases, the study by **?** in Durban South Africa, applied the Bruun Rule as reviewed in Table 2.2 as well as the Carter roll over model to calculate the inundation levels. For the Durban case, the results suggested that for the sampled locations and assuming intact primary dunes, the predicted shoreline retreat using Carter's roll over model was less than the coastline retreat caused by the advancing oceans using Bruun rule. However, at sites where the main dune had been removed or did not exist in the first place, the results from both models concurred.

In the studies identified in the African continent and globally, the various methodologies used did not consider stakeholder approach to vulnerability assessment within the case study sites. The analysis of the socio-economic implications was largely done without the participation of the local residents/ stakeholders' participation. In many of the studies, analyses of the perceptions towards the consequences of impacts of SLR were not covered.

The primary objective of the participatory and integrated vulnerability assessment approach was to identify levels of awareness and coping strategies that would be practical, and feasible for local government and communities. The participatory approach also facilitates towards analysing and identification of the related impacts. The general rule is that when we consider climate research with other local factors, the environmental and social stresses should be identified and effectively communicated.

2.6.3 SLR assessment for the Kenyan coast

On the East African coastline, portions of Mombasa and Lamu islands lie on low elevation zones with Lamu being more so than Mombasa, thus rendering Lamu more vulnerable to the associated risks of escalating SLR. The land use and infrastructure, socio-economic activities, people and spaces (design and planning) of the islands will be negatively impacted by SLR. The susceptibility of the two islands, including the related coastline losses, will require a rethinking of small island and coastal cities design and planning, especially with regards to SLR.

A previous vulnerability study of Mombasa Island in Kenya (**?**) focused on the

socio-economic and value of assets that are under threat from the effects of SLR. Using the method suggested by **?** and the DIVA tool, the assessment for Mombasa estimated/derived the potential economic losses associated with SLR of up to US$ 15 billion in assets by 2080, the analysis was based on GDP loss factor of 5, which was later downgraded to 2.8 as explained in section 3.2.3. The island of Lamu, as well as other smaller towns along the Kenya's coastline (for example, Mtwapa, Kilifi, and Malindi) have not been similarly assessed. Equally, no such studies of the coast have been conducted using an integrated approach to stakeholder participation and awareness creation as undertaken in this study. This study combines both the Nicholls' formulae with new integrated insights into the Mombasa analysis and thus building on **?** as well as initiating an original assessment for Lamu island.

2.7 Community awareness perception and PAR on SLR

Climate-change induced impacts within a community are influenced by social and political contexts, and cannot be accounted for purely by physical quantification of the hazard/phenomena alone. The understanding of the integrated approach to climate change risk and impact analysis especially SLR is crucial in coastal vulnerability assessment. Such an approach significantly enhances the possibility of initiating effective adaptation and thus promoting higher levels of resilience to impacts of accelerated SLR.

2.7.1 Community context of vulnerability and risk perceptions

Studies in local level governance and participation in managing climate induced disasters have steadily been gaining precedence globally and locally. **?** posits that in recent years, there has been a deliberate, though slow shift towards assessing and understanding the role of the local level managers, and communities on implications of global phenomena such as climate-change impacts and especially SLR, in relation to urban governance. **?** and **?** contend that the role and speed of urbanisation in most developing countries have put a special strain on the capacity of planners and municipalities to bridge the gap between climate-related impacts/vulnerabilities versus community preparedness for mitigation and adaptation.

Perceptions of risk play a significant role in how people engage with current events and future risks (**????**). Perception of risk and vulnerability to negative events

is different among individuals and various sectors of society, especially because the impacts of such events are not equally experienced/shared across urban areas, within communities, households or individuals.

? and ? argue that one's experience of a disaster influences the perception of future risk and thus influences immediate and long-term preparedness for responses. Engaging with community vulnerability perceptions of extreme climate events across different areas and communities would be key to effectiveness of any mitigation strategies. Equally, the complexities of building resilience to impacts of climate extremes in a developing country context are comparatively unexplored, especially where daily survival challenges constrain the capacity of individuals and municipalities to cope with extreme events. And yet it is within the individual and the local context that adaptation strategies/initiatives are most likely to be effective (?).

According to ? and ?, these complexities and challenges are articulated through the range of perceptions of risk within a society. As a result, understanding the complexity and challenges related to community vulnerability and perceptions thereof remains a necessary precursor, towards building useful structures and behaviours to reduce vulnerability and build resilience, adaptation as well as mitigation to such risks.

In order to enhance this experience, moderated perception-based knowledge constitutes a significant opportunity to build resilience through effective participation in assessment and appraisal processes for mitigation and adaptation. Perception based knowledge would facilitate the empowerment of communities through a reflective cognition of their experience and developing social networks towards building locally specific solutions to external shocks and risks.

Besides, community vulnerability, a lack of preparedness in the developing world has resulted in widespread and persistent climate-change impacts in urban coastal environments. Faced with this insight, climate adaptation governance needs to ensure a participatory risk analysis approach geared towards enhancing adaptation to the perceived risk and thus enhancing resilience to related impacts (?). Urban management should therefore be viewed as a unique opportunity to strengthen the ability to manage climate-related impacts through participatory approaches in all phases of the vulnerability assessment process including baseline mapping/assessment, response planning and mitigative action/implementation and recovery initiatives.

2.7.2 Participatory research in coastal climate change vulnerability analysis

The art of participatory research, planning and evaluation entail closely related practices. It mobilises the vital indigenous knowledge of a people living and connected to each other and their environment while also enhancing a collective understanding of a research objective thus enhancing ways of collectively acting towards a mutually positive outcome. It is a pragmatic engagement of mind with a world that invites us to reason carefully with rigour while caring for and empowering others.

The need for adaptation strategies beyond mitigation of climate change has received increasing attention since the climate change debate begun. The co-production of measures that could reduce the impact on the people (depending on a given climate-change threatened resource) is a classic way to help increase awareness and enhance local adaptation capacities (**?**). Most climate impact assessments have been criticised for the usual "top down" approach to mitigation in contrast to "bottom up" approach in assessments. The need for policy change and options have increasingly led to an involvement of the local stakeholders, in the analysis of the areas of risk or threats and the co-formulation of flexible policy options in response to immediate disaster risks facing a community.

Participatory action research, or participatory vulnerability assessment (also referred to as community risk assessments) seeks to be inclusive and through integrating communities to participate effectively in identifying the risks and in co-production of mitigative strategies (**??**). Participatory natural resource management and planning are explicitly captured (if not always prominent) in significant policy documents on climate change of most countries. Indeed, participation is enshrined in Article 6 of the 1992 United Nations Framework Convention on Climate Change, which calls for Parties to the Convention to promote and facilitate "meaningful public participation in addressing the effects of climate change and in developing adequate responses".

The method involves researchers working together with participants to examine an underlying risk or problem, in order to develop a mutually responsive solution. Participatory process is hailed as a method that transcends the conventional approach to academic production of knowledge in favour of a flexible and socially/collectively owned process. The process is thus viewed as representing a counter-hegemonic approach to knowledge production. This approach to research has systematically co-evolved with social and environmental studies.

During action research, investigators and participants agree on the issues at hand

through an initial/status quo awareness survey relating to the impacts of a climate-related issue such as impacts on agriculture. The objective of the participatory process is to allow both the researcher and the participants collaboratively reflect on the process in conjunction with anticipated outcomes. In its joint report of 2011, the International Institute for Sustainable Development reflects on the need to mainstream climate change adaptation processes to "ensure the effective participation" and empowerment of poor communities. Such participation would fast track adaptive adaptation decision making (**?**).

Alongside the calls for greater stakeholder involvement in environmental policy, others argue that participatory processes may at times be problematic **?**. **?** identify two important sets of issues, the type and level of participation, which thus cover the different modes of engagement as described in the typologies of local community involvement in a research process, and the extent to which they constitute active or meaningful participation. These two factors are critical in any form of participation and inclusion research processes and especially in climate change mitigation and adaptation action plans which are also commonly referred to as integrated coastal zone management plans.

The obvious practical and conceptual difficulties in achieving the desired broad-based public engagement include, the prioritisation of who participates (inclusion and the exclusion criteria) and on what basis they are to be involved. Both sets of issues are essential for meaningful participation and are intimately connected with interest based politics and social power relations. In such cases, **?** suggest that the level of involvement and pre-planned terms of reference are, critical towards ensuring that the participation of communities has both positive effects and remain manageable within the realms of research for both the researcher and the community concerned.

An understanding of perceptions of individuals and communities constitutes a key factor towards building effective mitigative and adaptive measures, towards enhanced resilience to related vulnerabilities (**?**). For the purpose of this study, perceptions are defined as the way in which individuals and communities understand inundation and its association with SLR, based on their knowledge and experiences of such events (**?**). **?** postulates that there are three broad categories of responses to risk and threats which are denial, apathy and transformation. Individual perception of risks and their related responses can similarly be categorised into similar categories (**?**, 333).

> *"People learn about uncertain events about hazards from personal experience than from being provided with a description of the possible outcomes and their likelihood".*

The term learning suggests that people's responses to risk are shaped by their individual as well as collective experiences, knowledge and perceptions of the potential risk. As a result such perceptions are not homogeneous across or within communities (**???**). For instance, a community that has recently been affected by a flood is, more likely to adopt preventative action against future flooding than a community that has never experienced a flood. As a result, anticipatory adaptation efforts at the local level, tend to be most effective when they are based on a community's perceptions and priorities, as community members can take ownership and responsibility for these actions.

Equally, planning for mitigative strategies to reduce future risk is unlikely if the immediate threat to survival is already high (**?**). Unless the urgency for addressing climate-related risks is seen as a priority within a community's day-to-day commitments, it is unlikely that early action will be taken to avert the risks. A key underlying assumption of this study is that as experience and awareness grow and change, climate change impact mitigation and management practices will evolve and also become more likely to be integrated into day to day functioning of multiple stakeholders and actors.

Communities and stakeholders within Mombasa and Lamu have continually been plagued by flooding that often washes out homes and infrastructure during the rainy seasons, and in high tides whose frequency has suddenly increased, causing increasing loss of properties and lives. By including a component of awareness and perception of SLR related risks into the process, the study enhanced the understanding of climate-related extreme events that may cause inundation and flooding within the neighbourhoods, and thus enhanced the prioritisation of the search for SLR related adaptation and mitigation strategies.

2.7.3 Participatory action planning (PAR)

In itself PAR is not a method but rather an overall research approach that includes, many different techniques/methods such as group dialogue discussions, interviews, diagramming, video, photography, art, surveys, mapping, the collection of environmental data, and computer analysis of the generated datasets. It is about jointly producing knowledge with affected stakeholders/communities in order to arrive at critical interpretations which are actionable, accessible and understandable to all those involved (**?**).
It seems that PAR evolved out of three streams of intellectual development and action:

- Social research methodology.

- Participation in decision making by low-ranking people in organisations and communities.
- Socio-technical systems thinking regarding organisational behaviour.

Participatory action research allows researchers to operate as full collaborators with members of communities and organization on the ground, in studying and transforming different concepts that are of interest to the communities and agencies concerned. It is a learning process approach that emphasizes co-learning, participation, and organizational transformation. PAR adopts a critical and different approach to traditional studies in the way it actively engages the chosen participants in the research process, from study design to dissemination. According to **?** PAR challenges a positivistic approach to science where the focus is on finding knowable truths, eliminating bias and subjectivity, quantifying constructs into measurable units, and prediction of future scenarios as well as control.

According to one PAR handbook, **?**, participation is the main and the central ingredient in PAR research approach. The label "participatory" in this context signal, collaborative processes aimed at finding answers with an enhanced opportunity for inclusiveness and enhanced agency to initiate and sustain the required action. The importance of insisting on participation is that all those participating in PAR projects are participants and not merely subjects or informants, who are invited and actively engage in the research which is motivated by the members and focused on meeting their specific needs of the research.

As diverse and challenging as participation may be, it constitutes the core ingredient of community engagement. It entails an active involvement of the local stakeholders in all aspects of a PAR project. However, in some cases the participation can be limited to specifically agreed upon stages based on general understanding and availability of the participating groups and the logistics of the process itself. To facilitate an interactive and productive PAR, the question of "who", "how", "when" and "why" they are participating constitutes important criteria that bring out the real understanding of underlying issues amongst researchers and participants (**?**).

Understanding the typologies and forms of participation is critical in exploring the positive and adverse relationship between participation, the current power and politics within the communities and the effect of the participatory process on external stakeholders. Meaning and effectiveness in participatory processes requires that the researcher is not the primary actor, but instead, the interested

parties and community participants, agree, shape and mould the research process to meet the desired collective ends.

The word action in PAR denotes that the study is supposed to encompass and generate activity and change. In essence, a study involving stakeholders needs to be action-and- transformation oriented. However, there are considerable differences in the emphasis given to "action" in the research including its orientation which in this case involved the active participation for research towards the co-production of the vulnerability atlas. Some researchers and scholars prefer the term participatory research over participatory action research because action research sometimes fails to be truly orientated towards social empowerment and community transformation and fails to meaningfully engage local participants in the process and direct experience of the investigation (**?**).

?, argues that it is the word "action" that needs replacing but that the process needs to be re-energized, as too much focus has been placed on research at the expense of the participatory action itself. Instead, they argue that PAR rejects the possibility of a neutral stance on research, and is more concerned with the subjectivity of participants as well as a commitment to research that has implications beyond publication in peer-review journals, and especially the acceptance and acknowledgement of the significant relationships between researchers and participants. PAR therefore challenges not only the status of investigators as experts but also raises questions about how knowledge is generated and disseminated among the parties involved.

The prevailing scholarship practice is that trained researchers should enter a field with their predefined sets of objectives and hypotheses (often provoked by findings from previous studies or the context). Within that approach the aim of a researcher is to collect the required data using objective methods and leave the field with minimal disruption and thus not include the subjects as co-researchers. This approach is strongly contested under/through a participatory approach where participants/subject (either as recipients of the results and/or ultimate actors on transforming their own lives) are included in such research endeavors. Instead of benefiting academics only, especially with climate and environmental change studies, PAR offers mutual learning opportunities for both the researcher and participants. Such inclusion allows for meaningful adaptation and mitigation strategies that are communal in nature.

It is through such interactions among participants and the researcher that knowledge is generated. The goal is not to undertake research for research sake, but rather research to focus on making an acceptable and practical difference to the transformational challenge facing participants. In essence, a participatory

process means that the field and actual research methods used can vary significantly across different PAR projects. In most planning studies, PAR researchers apply both qualitative and quantitative analysis techniques as demonstrated in this study.

? notes that there are some limitations posed by action research component. Firstly, PAR projects have a challenge of ongoing involvement of local area participants across the entire research cycle. For example, data analysis (as is in the case of this study) is often done by the researcher in isolation due to the time and availability constraints of the participants, as well as the trust in the researchers own skills, or recognition that the full participation in data analysis can create its vulnerability for a group or its members.

Secondly, research in academia is most often associated with the development and refinement of practice and theories. In PAR related projects, the research is not aimed at primarily on theoretical development per se and refers more to the method of exchange of information, collecting and presenting information to inform, empower and mobilise a group of actors for collaborative action. Whereas new theories may emerge from the participatory process and experience, the emphasis is on generating and advancing local knowledge that improves on a local socio-economic process. The study in Mombasa and Lamu incorporated data analysis procedures during the mini-charrette to improve participants' trust in the participation of the research component, thus allowing for co-generation of adaptive interventions which are closely aligned to current scientific analysis and understanding of climate-change induced SLR.

Finally, for some researchers or disciplines, PAR is disqualified as research at all, as it is viewed to be similar to a consultancy process or political activism in disguise thus using the term "research" to provide its proponents with respectable cover. Within this perspectives, PAR engenders a legitimacy and credibility that is intent on hiding the highly subjective nature of its initial design, data collection methods, and analysis techniques. The mini-charrette method was done based on good professional practice including the GIS-based data analysis techniques. Although GIS manipulation entails a highly technical process, the participatory process allowed this study to navigate through the often limiting levels of understanding among participants thus facilitating knowledge sharing on how the concept is applied in vulnerability assessment. The process also helped facilitate the objective of creating a discussion around SLR-induced flooding and navigate the available options which were also understandable to participants who varied in age among other social background considerations.

It is also often argued that the dissemination of findings from a PAR project is best

done through interactive websites, drama and community-based book productions and informal conversations in contrast to academic papers in peer-reviewed journals or conference presentations which are beyond normal access by participants in question or through formally taught courses. The mini-charrette in Mombasa and Lamu endeavored to make the participatory process meaningful and effective by including a component of an interactive blog. This blog is consistently updated as a means for sharing the scientific and underlying concepts of SLR globally and specifically focusing on Mombasa and Lamu. Through the blog many more Kenyans have been attracted to adding their voice to the issue of coastal tourism and climate change based on a live and open e-on-line platform. For the same objective, a manual and a vulnerability atlas (included in this study as an appendix) will be printed as a booklet to make the research process and findings more widely shared among stakeholders in Mombasa and Lamu.

2.7.4 Adaptation and mitigation strategies for SLR

As the consequences of climate change and especially SLR are starting to be felt in coastal regions globally, related adaptation and mitigation strategies are starting to emerge. According to IPCC, without proper and timely adjustment, the impact of accelerated SLR will be substantial, as it poses the risk of wiping out significant portions of coastal countries by 2100. Adaptation measures aim at reducing potential impacts on coastal systems by a factor of between 10-100, as it comes at a relatively lower cost compared to the damage avoided. Given the fact that adaptation depends on socio-economic contexts, the rank order of most vulnerable countries is different from the rank order of most exposed countries which have disproportionately high low-lying coastal zones.

Mitigation and adaptation can only reduce SLR impacts to a limited extent since the momentum of SLR is anticipated to accelerate by 2100. The need to stabilise carbon dioxide concentrations at 550 ppm and temperature increase to less than 2°C would reduce the impacts by 2100 by a margin of 10%. However, affordability constraints to the total cost of emissions reduction lowers the subsequently avoided impacts by up to 25% (within an average of 10%). The decrease is therefore mainly due to low availability of adaptation resources, especially in developing countries, and also due to the increased coastal systems sensitivity such as the threat to loss of wetlands as a result of certain adaptation strategies.

Given that implementers and net beneficiaries of adaptation/mitigation solutions are likely to be different, implementation should be targeted at local managers of resources, whereas mitigation solutions and policy approaches should be aimed at the national and international arena. Within urban contexts, areas for which

adaptation measures work well include housing, energy, transport, and infrastructure networks.

There is concern, however, that the overall costs of infrastructure protection will be beyond the financial means of many coastal cities of developing countries and especially those of Island nations. Vulnerability studies conducted for selected small islands suggest that the costs of coastal protection ("hard" options) would be a significant proportion of 'their respective GNP (**?**). In some island countries such as Malta and Cyprus, the cost of coastal protection is estimated to be in the range of US$550 million and US$190 million respectively.

This is the capital investment needed to provide adequate shore protection works against a 20-30 cm rise in relative sea level (**?**). Whereas estimated protection costs may not be excessive in the context of developed economies, they represent considerable financial challenges and resources which would be beyond the means of developing small island states. The vulnerability and the socio-economic implications of climate change for coastal cities and small island nations cannot, therefore, be overlooked or ignored as is happening in Kenya at the moment. Information required for the integrated vulnerability assessment is therefore critical towards initiating management, adaptation and mitigation strategies as well as required implementation plans.

2.7.5 Sea level rise and vulnerability assessment in Kenya

Climate-change related developments and adjustments in Kenya fall under the National Environmental Management Authority (NEMA). Policy on climate-change adaptation and management was developed in 2011 but has yet to be approved for implementation. In the absence of such policy it has proved difficult to plan any adaptation and mitigation measures with regards to critical impacts such as SLR. This has in turn constrained the necessary integrated approach as each line ministry (tasked with an environmental responsibility) executes its individual mandate in isolation thus leaving SLR planning unattended.

In the absence of the policy to manage climate-related impacts, there are ripple challenges in coastal planning, especially in relation to mitigation of risks. Moreover, arising from the new constitution that has paved way for devolution of governance to county governments, implementation of climate change mitigation and adaptation activities has been met with yet additional challenges. For example, the coast region, which used to be governed under the former Coast Province, is now governed under six counties which are Mombasa, Kilifi, Lamu, Tana River, Taita Taveta, and Kwale.

In the spirit of the county government strategy, every county must prepare its own five-year financial and development plan with input from local stakeholders. The county's plans must maintain linkage with the overall national development plans and Vision 2030 document in particular. Furthermore, coastal urban government plans are expected to keep a link with the local coastal zone management plans, which is under the ministry of environment and natural resources.

This devolution, which is still in its early stages, has only further complicated the well known competing interests among various sectors under line ministries. Such competition often leads to failure in urban and regional planning processes, as reported in the Mombasa District Development Plan (**?**). County governments are still grappling with this division of the planning role especially among the planning ministry versus the department of environment. In general, the institutional fragmentation in environmental planning processes in Kenya makes it difficult for the adoption of climate change mitigation strategies within local planning frameworks in pursuit of mitigation and adaptation goals (**?**).

Whereas the decentralizing of planning roles to county levels is an important step in the fast-tracking of county led initiatives, it also facilitates each county to prioritise its own unique challenges and allocate budgeting and human resources accordingly. Climate change impacts such as SLR are unique to specific geographic areas (as is the case for Mombasa and Lamu counties) and strategies that directly include the county governors in these areas may yield better and/or expedited planning outcomes.

In the past, vulnerability studies based on mathematical models for SLR have been extensively applied without actively involving communities under threat. The result has been an ineffective uptake/adoption of the findings by governments and communities. As observed earlier, existing studies on SLR for Mombasa applied different variables with different presentation methods in which spatial analysis for the larger Kenyan coast was not included (see for example **?**). Building on these studies, this study assesses the geographical areas under threat and compiled a vulnerability atlas that can be adapted for the study of coastal areas under similar SLR threats.

2.7.6 Mini charrette process in vulnerability assessment

? note that a charrette is a collaborative planning workshop aimed at addressing a given issue of interest and can take up to seven consecutive days to implement and much longer to plan and prepare for. A mini-charrette, on the other hand, uses the dynamic components of the main charrette to address similar issues but

within a shorter period as compared to the main charrette. The key advantage of a charrette is the fact that it can save time and money and allow for a more integrated understanding of the research issue (in this case, effects of escalating SLR). The process also enhances empowerment towards adaptation strategies especially when knowledge and awareness are systematically shared.
Charrettes are thus viewed to facilitate the following opportunities:

- Provide a forum for those who can participate in the research design decisions to meet and begin planning the project
- Encourage agreement about study or project goals
- Kick off the research or design process
- Save time and money by soliciting ideas, issues, and concerns for the research project design to help avoid later iterative study activities
- Promote enthusiasm for a research project and result in a new direction for the project outcome

?note that the possible structures of charrettes vary considerably depending on the design or study problem at hand and the individuals in the group. Charrettes often take place in multiple intense sessions in which the main group can be subdivided into sub-groups to deliberate on the issues in depth and present the outcome in plenary for input and further dialogue. This process is then repeated among the different subgroups to facilitate an integrated approach to the issues under consideration.

Charrettes provide an invaluable platform for stakeholder participation as well as facilitating quick generation of a study solutions while integrating the larger communities' aptitudes and interests especially within a diverse group of people. They are commonly used in many disciplines, including environment and land use planning or urban planning in general. In planning (whether about design or, as in this case, climate change vulnerability assessment), the charrette has become an important technique for consulting with multiple stakeholders over sessions ranging from one to five days or more.

The diverse range of interested parties drawn to a charrette (sometimes called an inquiry by design) includes local municipal officials, scientists, subject specialists, developers and residents. A successful charrette promotes understanding of the study problem while also facilitating the joint ownership of co-created solutions. Whereas charrettes tend to involve a small representative group, the participants need not to be viewed as representatives of all the residents nor claim a moral authority to represent all or some of the stakeholders.

Mini charrette process

For climate-change induced Mini charrette process SLR assessment largely involves the use of a workshop format plus interactive exercises over one to two days with a key facilitator and working towards the following key outcomes;

- Provide a forum for those who can participate in climate change and SLR effects to understand and make decisions to enhance responsiveness and action towards mitigation and adaptation efforts
- Encourage agreement about levels/status of the threats and the extent of SLR and climate change induced changes at the coast from where they eke a living
- Kick off the plans, adaptation and mitigation strategies for responsive action planning
- Save time and money by soliciting ideas, issues, and concerns of the communities living around coastal areas on the protection of their resources from climate-related changes especially SLR
- Promote enthusiasm for any suggested adaptation and mitigation strategies for the communities as well as addressing apathy to the participatory action processes

In most participatory processes participants' level of expertise on the matter needs to be well understood and responded to especially in relation to climate change awareness where most participants' are rarely experts in the scientific analysis of issues except under experience-based analysis (sometimes identified as the indigenous knowledge systems -IKS).

2.7.7 Summary

Many of the world's largest coastal cities are in low-lying areas that thrive in related socio-economic activities such as tourism and world trade logistics supported by harbors and related port infrastructure. **?** allude to the grim realities of low-elevation coastal zones globally which now face threats from effects of climate-change induced SLR. Although coastal towns have always been more vulnerable to disasters such as flooding, extreme heat events and salt water intrusion among others, the danger of increased cyclones and storms have already started complicating planning for these areas, thus escalating the need for adaptation and mitigative interventions. The potential impacts that coastal cities face due to extreme weather events in the 21^{st}century are increasingly severe.

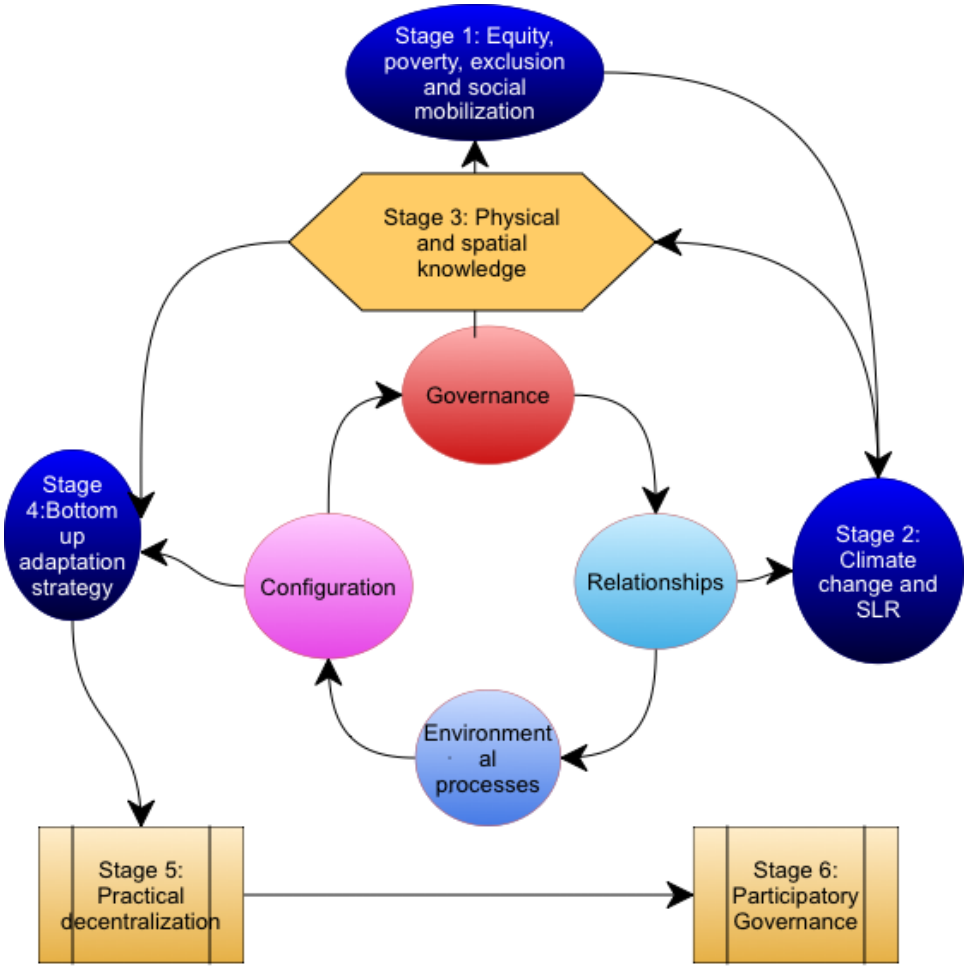


Figure 2.5: The relationship of coastal urban development and environmental sustainability.

Source:**?**

To ensure effective responses to climate-related risks, a good understanding of the risks to both physical and social environments are critical. The impacts of climate-change induced impacts span across physical infrastructure and social networks as well as political boundaries. In the case of SLR and related extreme events, data on the physical characteristics of these developments and their spatial distribution are vital to understanding the extent and intensity of inundation-prone areas. Similarly, understanding how communities engage with these events is necessary for identifying vulnerable communities and regions as well as assessing their awareness and readiness for mitigative or adaptive action. In this context the role of social inclusion or exclusion and levels of poverty have been highlighted as important parameters in disaster response (**?**).

Integrated vulnerability assessments could also serve as a way of co-development of adaptation and mitigation measures. Such measures are of particular importance for isolated communities with high dependence on exposed critical infrastructure and limited essential services. It is also imperative to acknowledge that human activities and communities co-exist interdependently with their respective environmental systems, and especially through livelihoods from coastal eco-systems. Assessing one loop of such a co-existing network in isolation (SLR in this case) overlooks the need for integrating the human systems and activities as well as factoring the significance of related response strategies.

This therefore calls for co-production process with the communities geared towards stimulating action based adaptation and mitigation responses to SLR, as reported in this study and the subsequent chapters of the theses. Whereas the spatial scientific methods of vulnerability assessment offer the basic knowledge for understanding the concept of impacts of climate-change induced SLR, an integrated approach offers a better option towards influencing perceptions and actions for resilience through responsive adaptation and mitigation measures. This is greatly facilitated when processes like the charette are included in the community workshops in order to expedite the understanding of the problem. This methodological approach as applied in this study (for the coast of Mombasa and Lamu) is a novel concept that allows for a dissemination of SLR impacts and co-production of knowledge with the stakeholders in order to improve planning as well as catalyse for mitigation and adaptation measures.

Chapter 3

Research design and method of study

3.1 Description of research method steps

The study applied a combined and integrated approach based on the following key steps:
STEP 1 (Chapter 1-Overview of Literature): The section introduced the concept of vulnerability assessments methods evolved over time, climate change and its related effects of SLR on low-lying islands and why such islands are vulnerable to the impacts of SLR. The chapter looks at the critical choice and decision-making features of vulnerability assessments and especially integrated assessments, the principles of community participation in vulnerability assessments and why/how spatial analysis of SLR could include a meaningful participatory process.

STEP 2 (Chapter 2- Literature-appraisal): The review considered studies on global SLR and how it has been reported. It also included the key areas of contradiction and weaknesses between the different vulnerability assessment methodologies. The contradictions and weaknesses of methods were appraised as well as how shortfalls in scientific analysis (as a standalone process) could be improved through a participatory process (especially through a mini-charrette). Additional issues appraised under this step include stakeholders perception of vulnerability due to SLR and how the assessment methods could respond to those contradictions and weaknesses. Finally appropriate human/behavioural responses from perception change and adaptation/mitigation efforts were appraised.

STEP 3 (Chapter 4- Analysis Atlas): This step uses a combination of GIS-based analysis based on Global Mapper and ARC GIS 10.2 software. The two software were used to develop the flood inundation scenarios in order to derive areas vulnerable to SLR effects along the coastline. The process included the analysis

of inundation zones, and identifying exposure indicators used in the extrapolations. The calculation of SLR impacts was based on a 1 in 100-year return cycle of inundation probability. The produced flood maps were overlayed with the area maps to identify critical infrastructure under threat. The derived Vulnerability Atlas would be essential in decision making and improving methodological process using the two GIS-based software.

STEP 4 (Chapter 5- Community engagement through a mini-charrette): This step entailed the implementation of mini-charrette and applying the subsequent results towards the analysis of perceptions and change of mindsets in support of participatory decision-making patterns. The chapter gives the narratives from the participatory process, and how the participants from these two areas transformed participants' perceptions on the consequences of SLR within their neighbourhoods.

STEP 5 (Chapter 6): This step concludes on the specific way in which the participatory process and the spatial analysis processes complement each other. The step discusses how scientific spatial stand alone analysis falls short of the goals of adaptive management and proposes the integrated approach which aligns better with the community and the need for prior information in decisions which affect them. A vulnerability manual is introduced as a way forward in integrated vulnerability assessments. The vulnerability manual merges the two processes in order to serve as a guide for subsequent studies in this field.

3.2 Study site description- Mombasa and Lamu

The research on vulnerability assessment considered Mombasa and Lamu islands as case study cities to illustrate the importance of co-production in SLR vulnerability assessments. A case study approach was prioritised for this study to allow for a detailed comparison of phenomena distributed along two different sites with different characteristics. The key focus of this research revolves around a social aspect within a primary scientific/environmental investigation. The quest was to explore how to challenge the status quo perceptions and how prevailing mindsets could be transformed can shape each other towards a more empowering understanding of SLR within the urban environments in which we live.

? argues that an understanding of the in-depth variables of multiple case studies can provide knowledge of the important aspects of a new research area. The richness and value of the information gathered during case study investigation is an intricate means of the learning process for beginners to experts. According to **?** and **?** social science has not succeeded in producing general,

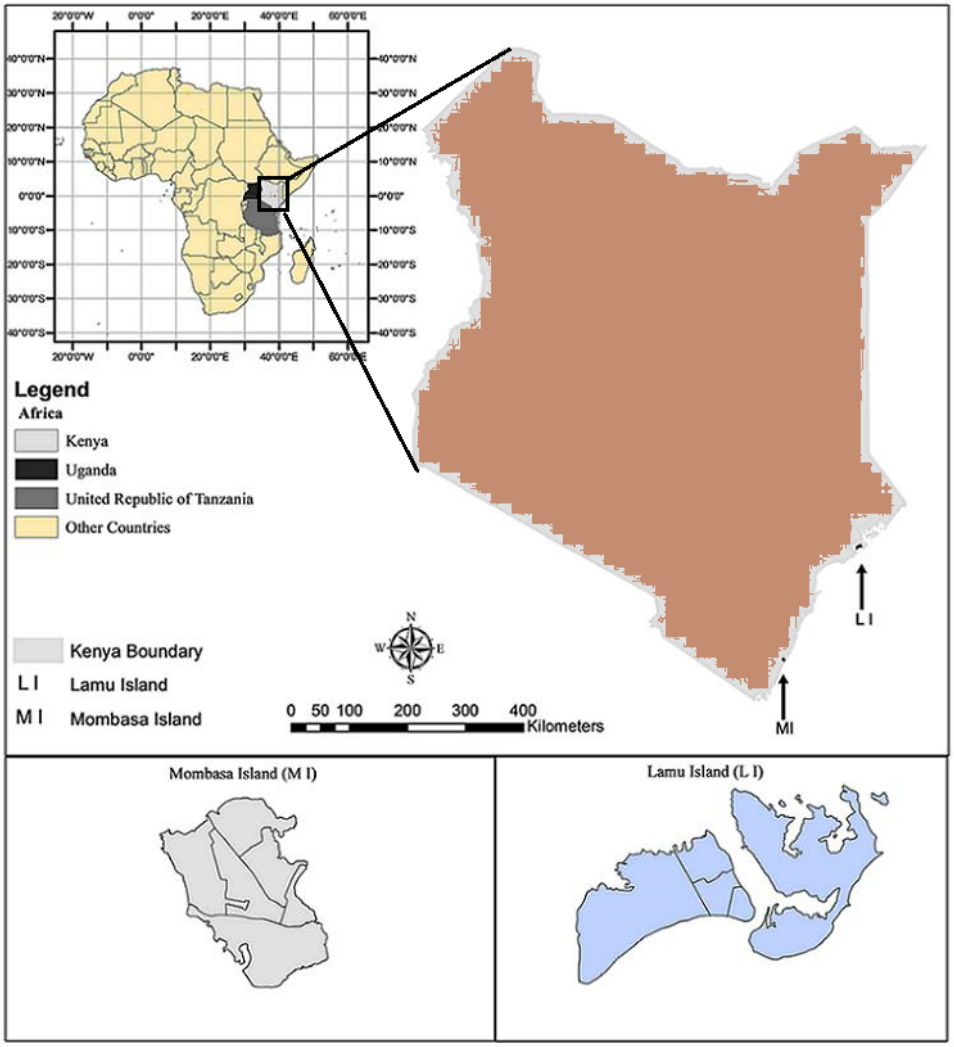


Figure 3.1: Study site of Mombasa and Lamu islands

context-independent theory and, thus, has in the final instance, nothing else to offer than concrete, context-dependent knowledge. The case study approach is therefore especially well suited to produce this type of knowledge.

A case study not only allows information to be gathered in various ways but also allows for a comparison and review of theories towards advancing new hypotheses or generating new concepts for an already understood idea. The procedure allows the researcher to understand and separate conflicts in research focus as well as refine a research process in the form of methodology as is envisaged in this study.

The research sites were also selected based on the national economic blueprint where Mombasa and Lamu islands are the tourism and technology development hubs of the region (Kenyas Vision 2030). The main infrastructure projects included in the vision 2030 blueprint include the transport corridor (LAPSSET) and the redevelopment of Mombasa Port. Equally the two cities currently represent areas that are important for both nature and cultural-heritage conservation and for the overall country's economy through the tourism industry and the fact that both cities may be already experiencing adverse impacts due to climate-change.

Sea surface temperatures are highest during the North-East Monsoon, averaging 28.4 °C with a maximum of 29 °C) and lowest during the South-East Monsoon, averaging 26 °C with a minimum of 24 °C. The coastal seasonal temperature variations decrease with increasing water depth (see Figure 3.3), with temperatures stabilizing at 6 °C to 7 °C at 1000m and 2.5 °C at 2000m depth (**?**).

Salinity variation along the East African coastline, range between 34.5 and 35.4 parts per thousand (ppt) which is assumed to be on the lower side (**?**) with the standard ocean salinity ranging between 34 and 36ppt. This variation is primarily due to rain between March and May and the associated terrestrial freshwater runoff, as well as freshwater input from rivers. There are on average two tidal cycles along the coast every 24 hours (known as the mixed semi-diurnal tides). The data and reference point for tidal observations in Kenya are located at the Kilindini port, where the maximum tidal range does not exceed 4.8m which is deemed to be high given that tidal ranges vary between 3.1m and 5.2m for most coasts.

3.2.1 Study area- Mombasa Island

The target area of this study is the Kenyan coast with a particular focus on the two island cities of Lamu and Mombasa, which were used as empirical case study areas in order to facilitate the co-creation approach envisaged as a core method of the study. Mombasa is the smallest county in Kenya and Mombasa city covers the

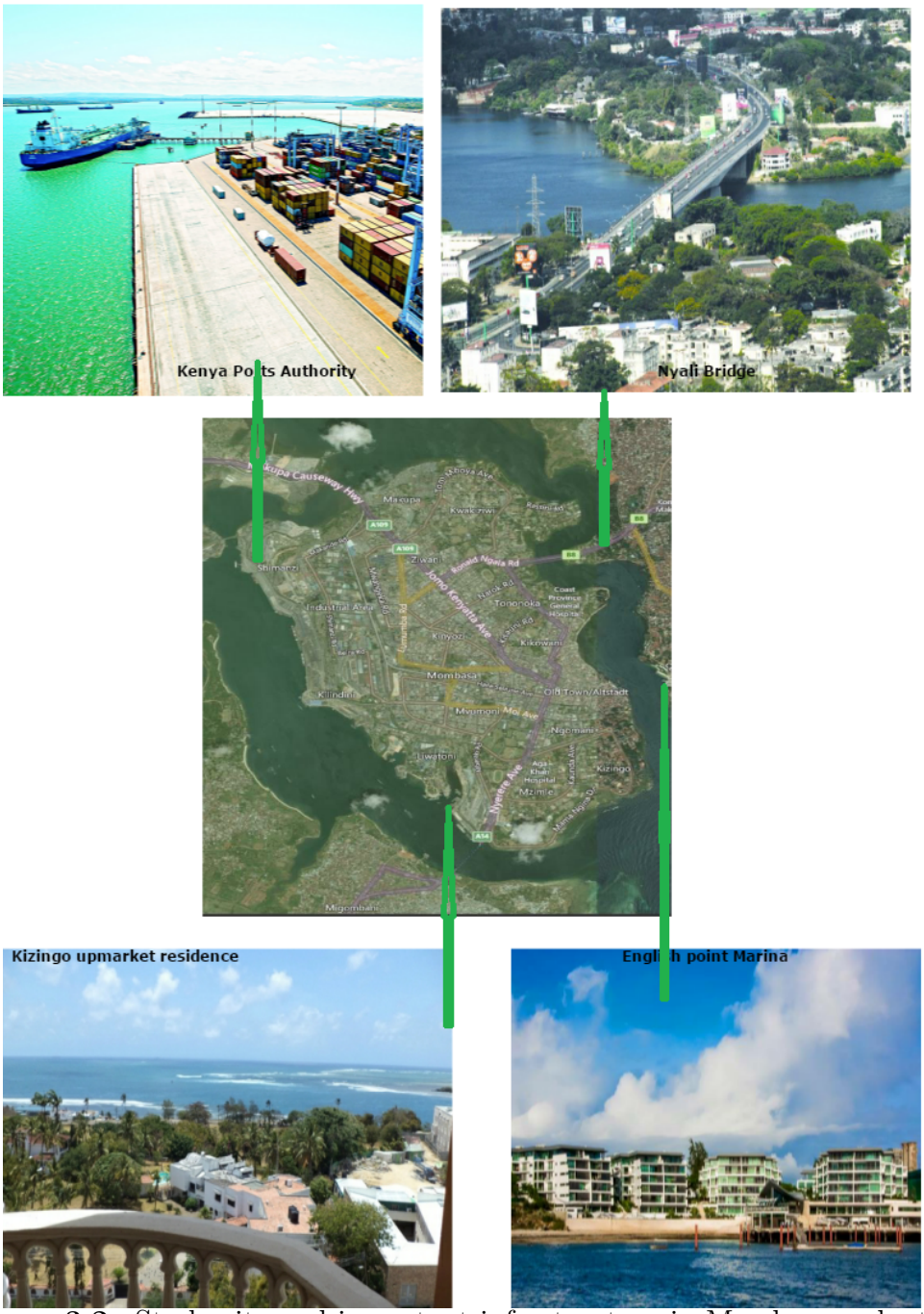


Figure 3.2: Study site and important infrastructure in Mombasa: adapted from ?

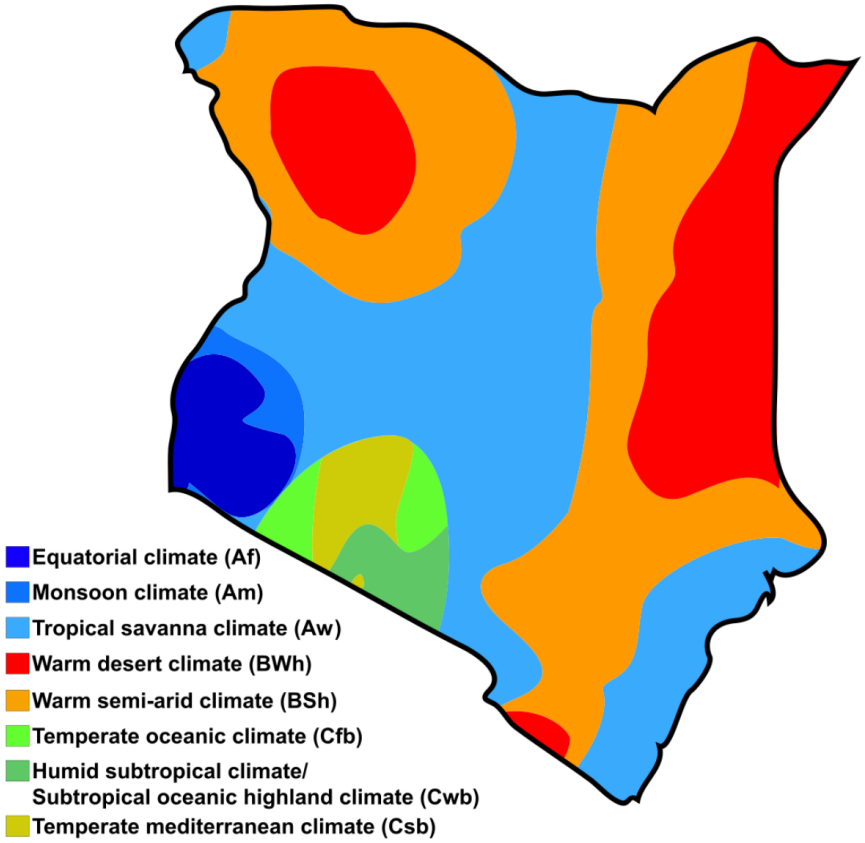


Figure 3.3: The Koppen climatic classification for Kenyan coast Source: Mombasa County April 2016.

key landmass of the county. Mombasa city is the second largest town in Kenya after Nairobi.

The city hosts several five-star and three-star hotels and also serves as an important city in tourism destination in Kenya. Some of the other critical infrastructure in the city apart from the hotels are the port facilities under the Kenya Ports Authority (KPA), the Kilindini Harbour, the Kizingo and Nyali upmarket residences. Others include the only main exit highway and bridge from the island to North Coast (Nyali Bridge) as well as the Kipevu Oil Refinery facilities located in the industrial area (see Figure 3.2).

3.2.2 Study area- Lamu Island

Lamu county is located on the north coast of Kenya and bordered by the Indian Ocean to the east. The county lies at $2^0 16'$ South and longitude $40^0 54'$ East. It has a land surface area of 6,273.1 km^2 which includes the mainland and over 65 islands which constitute the Lamu Archipelago. The coastline is 130km with a mass water

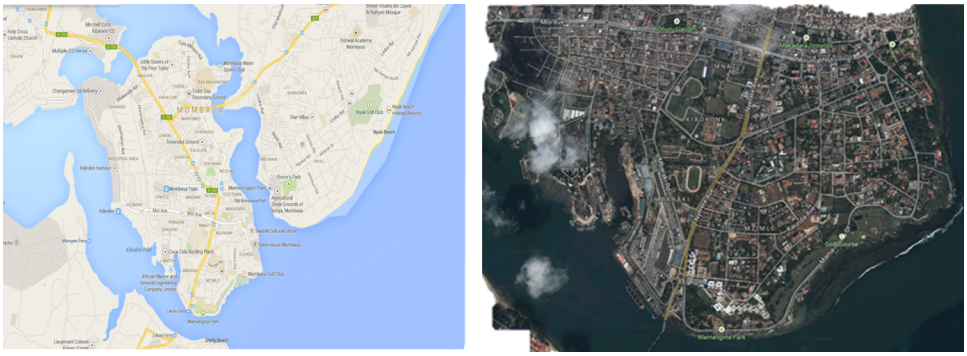


Figure 3.4: Land development within Mombasa Island
Source: **?**

area of 308km^2. The archipelago is supported by four major catchment areas which are the Dodori Coastal zone, Duldul Catchment, the Lamu Bay drainage and Tana River catchments.

Lamu County is mainly flat and lies between 0 to 50m above sea level (**?**). The mainland of Lamu along the Manda Bay is hosting the core infrastructure of the upcoming Lamu Port South Sudan Ethiopia Transport Corridor (LAPSSET). The island holds the oldest and best-preserved example of Swahili settlements in East Africa. Description of the economic growth and phases in the history of the region (alongside Mombasa and Zanzibar) finds its highest expression within Lamu Old Town for its architecture and town planning (**???**).

Lamu archipelago lies along the equatorial coastal climatic zone and is characterised by two monsoon winds (see Figure 3.3. The climate is warm with average precipitation of between 550 and 1100 mm per year. There are two rainy seasons along the archipelago with the extended rain period between March and May and the short rain period between mid-October to mid-December. Temperatures are usually high, ranging between 23°C and 33°C annually. The hottest months fall between December to April, and the cooler months fall between May to July.

Lamu and the island area around the Manda Bay are the sites of Kenya's second harbour project currently being constructed as part of the LAPPSET project. The port is expected to increase the demand for services including fresh water supply. The port has several infrastructural projects linked to it which include an upgraded railway line (from Lamu to Juba, the South Sudan capital through Addis Ababa in Ethiopia). A comprehensive road network, oil transport pipelines (Juba and Addis Ababa), an oil refinery at Bargoni and three airports within the extended hinterland that (includes Isiolo and Lokichogio). Additional projects linked to the harbour



Figure 3.5: Flooding in Lamu during high tide: Source: Lamu County April 2016.

development also include three resort cities along the Lamu-mainland, Isiolo, and Lake Turkana shores, are also envisioned under the programme. All these projects demonstrate how critical LAPSSET programme to Kenya's 2030 vision as well as the immediate and long-term development goals of her neighbours.

Lamu has maintained its social and cultural integrity and also retained its original building design and structure up to the present day. Unlike other related Swahili settlements along the East African coast, Lamu has been continuously inhabited for over 700 years. With the threat of sea level rise, this globally recognized cultural heritage is now vulnerable to destruction, especially due to SLR impacts of flooding and submergence.

Geography and oceanography

Geography

The coastline of Mombasa is unique for its psychographic features, such as coral reefs, creeks, tidal flats, mangrove forests, and lovely sand beaches which make

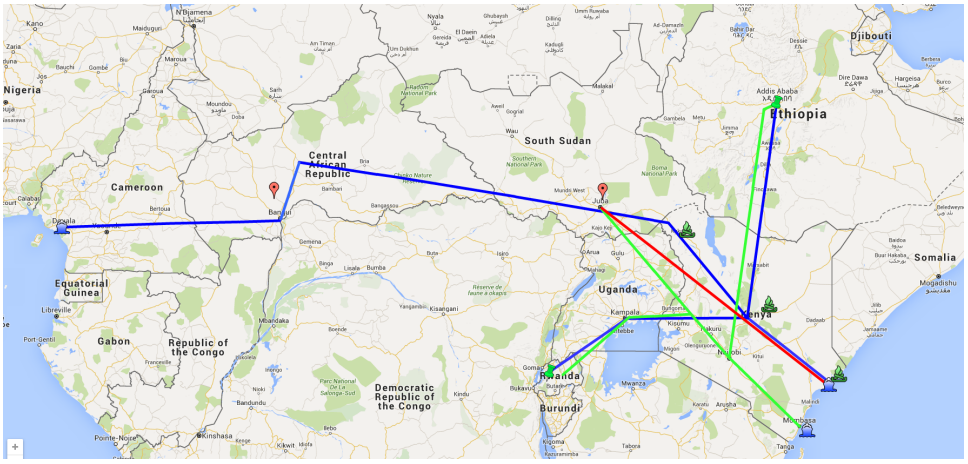


Figure 3.6: LAPSSET extent and neighboring countries.
Source: Adapted from **?**

the city an essential tourist destination (see for example **?**, **?**). Most households depend on these coastal resources for livelihoods through sector activities such as fishing, beach tourism, hotel industry as well as water sports.

Oceanography

Four ocean currents influence the Kenyan coastal region. The currents are the East African Coastal Current (EACC), the Somali Current (SC), the Southern Equatorial Current (SEC) and the Equatorial Counter Current (ECC). The Somali Current and Monsoon winds both influence the distance the EACC travels up the East African coast. During the South-East Monsoon, the EACC joins the Somali Current beyond Malindi and flows northwards to the Horn of Africa. However, during the Northeast Monsoon, the EACC reaches only as far north as Malindi or Lamu. The EACC then meets the opposing Somali Current, the only current off the coast of Kenya that seasonally reverses its flow. The meeting of the two currents causes upwelling, which is thought to account for the high productivity in fish production at the northern Kenyan coast (**?**).

3.2.3 Extreme events

AR5 report **?** conceptualises extreme events as changes in several extreme weather and climate events observed since the year 1950. Some of these changes have now been linked to human or anthropogenic influences, including but not limited to a decrease in cold temperature extremes especially in winter and an increase in warm temperature extremes in summer. Additional observations include the thermal expansion of oceans, leading to accelerated rise in sea levels and an increase in the number of abundant and or reduced precipitation events in some regions.

? note that significant coastal changes typically occur during extreme events.



Figure 3.7: Overview of Lamu Island with the narrow streets.

Processes such as barrier overwash and breaching (which can radically reshape a shore) mainly occur only during or after major storms. Such storms, also deliver the majority of the wave energy felt on a coast thus leading to long-term coastal changes, such as the SLR impacts discussed above, which in most cases are associated with punctuated but extreme catastrophic events.

Even where a coastline has not frequently experienced storms previously, rising sea-level will make all low-lying coastal islands and barriers more susceptible to storm damage and breaching during single extreme incidents. According to IPCC, climate change will affect coastal wave patterns and frequency and strength of high tides. These changes will disproportionately affect low-lying coastal areas that have no flood defence measures (which is the typical case for Mombasa and Lamu). Changes in coastal processes due to climate change could also change patterns of alongshore sediment transport and also reconfigure sandy coasts as well as exacerbating erosional patterns at some locations.

3.3 Research design

3.3.1 Data and equipment needs

The data collection method included primary data and secondary data which were then analysed for the production of the atlas based on a participatory process.

Primary data sources

Primary data were required for the analysis of the areas under threat in the two islands. The data included the initial spatial and land uses along the coastline that is within the LECZ mark. This area and point data for the assessment of infrastructure that are low lying were supplemented by data from the mini-charrette process, where community members identified areas of their interests and households. The aim of primary data collection was to gather both quantitative and qualitative information to be used in the vulnerability analysis. Data collected included point data collected using the Garmin (GPS) and land use data gathered from the ministry of lands and physical planning to identify the sites of significant infrastructure and areas of interest for the mapping of the area and threatened critical zones.

The second set of primary data was collected through the mini-charrette process, where community forums in the two islands were convened with assistance by the local community-based organization. In Mombasa Island, the Kisauni Environmental Programme community-based organization facilitated the call for

the meetings for the mini-charrette process. In the case of Lamu, the Save Lamu community-based program, as well as the Kenya Forest Service, was active in the advertisements and facilitating the community meetings with guidance from the researcher.

The raw secondary data from the USGS and STRM (in the form of the digital elevation model (DEM) for both islands) forms the primary basis of the analysis of inundation zones. As discussed in Section 3.4.3 and 3.4.4 (Chapter 3) the DEM characterization was used to describe the height levels through the contours. The analysis is based on the zero (m) elevation of the ocean, from which the characterised areas of inundation are then identified.

Secondary data sources

Secondary data collection was for the analysis of the quantitative data on the mapping and the positioning of Mombasa and Lamu island in relation to SLR. Data collected in this phase included a complete and detailed inventory of the critically exposed assets and resources (land, population and urban infrastructure) for qualitative analysis with the inundation zones, projected for a current 1-in-100-year storm surge. Spatially-disaggregated data sets were sourced from various public sources such as the National Aeronautics and Space Administration (NASA), the US Geological Survey (USGS), Dynamic Interactive Vulnerability Assessment (DIVA), the World Wildlife Fund (WWF) and Centre for International Earth Science Information Network (CIESIN) among others.

The NASA source was necessary for the provision of the DEM for Lamu Island as it was clearer (less cloud interference and therefore, needed fewer modifications) while and USGS data included the DEM for Mombasa Island. The land uses and subdivision data were supplemented with data from Kenya Regional Centre for Mapping of Resources for Development (RCMRD) which is based in Nairobi. The data were required for a comparison of the global DEM versus the local DEM. The importance of comparison of remotely sensed data was to allow for the best fit data with better resolution for the purpose of analysis. The comparison was therefore, necessary in order to reduce the magnitude of errors that can result from widely disaggregated data.

The Kenya Meteorological Department(KMD) data were used to assess the temperature and rainfall pattern for the two counties. The data were coupled with the SLR recording stations managed by the Kenya Marine and Fisheries Institute (KMFRI). The data were then used to guide on the low and high tide ranges in the two counties as a key factor when assessing the impact of a storm surge in the coastal zones. Other secondary data (including the Physical Planning

Act, the county planning and development documents important in the analysis of the desired area and infrastructure) were collected from the Ministry of Devolution and Planning, and the Ministry of Land Housing and Urban Development as well as their county equivalent within the respective governments.

Table 3.1: Summary of overall approach/strategy of study.

Research question	**Data needed and source**	**Data type**	**Data collection tools and process**	**Data findings and analysis**	**Where consolidated and analysed**
1. Nature and extent of infrastructure vulnerability to SLR in Mombasa and Lamu	• Physical and online assessment of infrastructure and areas along the coastline close to the ocean	• Primary and secondary data	• Use of GPS to create points of interest and literature review	• Create a composite atlas showing areas of vulnerability	• Chapter 2, 4 and 5 for the maps.
2. Extent of inundation risk for Kenya's coast based on scaled-down regional models	• Generate a DEM from available sources and use of GIS techniques to map out spatial extent	• Primary and secondary data	• ArcGis spatial extent analyst tool, as well as Global mapper.	• Analysis of flood risk/inundation areas and future sea level effects	• Chapter 4 cross referenced in chapter 5 and 6
3. Analyse the level of awareness/preparedness of stakeholders to threat of sea level rise	• One on one meeting with the community members.	• Primary data	• Mini-Charrette participatory process, photos, videos and audio	• Description of the process and the collected information	• Chapter 1 and 2 in literature review and chapter 5 in analysis of findings
4. Develop a "how to" vulnerability evaluation and mitigation adaptation Atlas adapted for such assessment	• From the field work and the Mini-Charrette process	• Primary data	• Field work coalescing of both the GIS and mini charette process	• Discussion based on fundamental principles and linking findings to research question	• Chapter 3 and attached as an appendix to the document

Climatic patterns

The climate and weather patterns of Kenya's coastline are dominated by extensive pressure systems of the western Indian Ocean (El Nino, Indian Ocean Dipole, and the Madden-Julian Oscillation). Two different monsoon winds also characterised the pressure systems, themselves partly related to the existence of the ocean currents (**?**).

The monsoon systems lead to bimodal rain distribution throughout the year with annual averages of 500-900mm on the north coast (**?**). From November to early December, the predominantly dry wind (termed as -the north-east monsoon and locally known as the Kaskazi) is prevalent in the coastal weather. During the March and April transition period, the wind blows in an east-to-southerly direction with strong incursions of maritime air from the Indian Ocean which brings torrential rains (the long rains) from mid-April to the end of June.

In the months of May to August, the south-easterly monsoon (locally known as the *Kusi*) influence sets in and the weather becomes stable with cooler temperatures. Between September and December, the north-east monsoon dominates again, bringing short rains from November to December. Temperatures are strongly related to rainfall patterns. The range of temperature falls between 23 °C to 32 °C throughout the coastal zone. The highest temperatures are in spring since rains tend to cause a temperature increase due to increased cloud cover and the latent heat of evaporation from moist surfaces. The mean temperature is 27.9 °C. The relative humidity of the region is around 69% with a wind speed of between 6mph and 9mph. The coldest months are May to July while the hottest months are December to April.

3.3.2 Spatial vulnerability analysis

Analysis of current scenarios used

This study concentrated on the two extreme RCP scenarios (RCP2.6 and RCP8.5), as appraised in Table 2.1. The prioritised scenarios were then analysed under the different periods to 2030, 2060 and 2090. The process was aimed at establishing the various SLR effects on the high tide on the coastline or especially during a storm surge. The analysis gives an indication of the extent of flooding due to escalating SLR under the different scenarios and years. This enabled an assessment of spatial extent of land and settlement areas threatened under the different global and local climate forcing, thus facilitating an understanding of how to prioritise mitigation and adaptation measures for both islands.

The projected seasonal temperature and precipitation changes for the SRES scenarios were customised/adapted from global averages to local level estimates. However, given that the RCPs are yet to be downscaled to the local level regional-scale climate information from IPCC (**?**) was used as the secondary data for this purpose. Projected changes in average monthly temperature, precipitation and sea surface temperatures up to 2100 were derived as secondary data from IPCC.

Analysis of inundation/flood risk areas

The maps used in the analysis were secured and collected from the USGS, NASA LD, and AAP depository, with the landsart images as well as the digital elevation models (DEM) for both the Mombasa and Lamu islands being prioritised for initial analysis. Secondary data on land-use were collected from the Regional Center for Mapping of Resources for Development (RCMRD) in Nairobi Kenya. The analysis of the areas under threat of inundation due to escalation in SLR based on the 1 in 100 years repeat cycle scenarios were done using the Global Mapper software. The GIS software had the capacity to handle large rasta files as compared to ArcGis and was best suited for the initial flood risk analysis. Image analysis for different flood zone areas were projected and the results identified and discussed towards the key findings.

Delineated inundation zones were subsequently overlaid with indicators for land area, population, as well as urban infrastructure/assets in order to facilitate the modelling of the effects of SLR under different scenarios and the available topographic maps. The derived scenarios are based on the prioritised IPCC SLR scenarios. Finally the surface indicator maps (LECZ and population density maps) were overlaid with the inundation zone layer in order to determine the spatial exposure of each of the two indicators.

Calculating population at risk

Two geographic data sets were required for this assessment. The first set delineates the extent of the LECZ itself. The study adopted the definition of LECZ as land area contiguous with the coastline up to a 10-metres elevation, based on the measure from the Shuttle Radar Topography Mission (SRTM) elevation data set that were localized for Mombasa and Lamu island. The second data set required for this analysis is a population grid for each of the islands and associated with each grid cell and land area. Estimates for the population was collected and analysed from the 2009 census data sets, which were allocated to urban extents or surrounding rural areas.

For the assessment of exposed assets, the exposed population was translated to the amount of capital per inhabitant. This capital per inhabitant is computed from the GDP per capita in each county and an estimate of the ratio of "produced capital" to GDP. The ratio of produced capital to GDP is calculated using the World Bank dataset published with the "Changing Wealth of the Nations" report. The resulting ratio was an average of 2.8 and was applied to both counties.

The analysis was based on the 30-year periods (2030,2060, and 2090) based on and described under the pessimistic scenario (RCP 8.5) and the optimistic scenario (RCP 2.6). Being at the equator, Mombasa and Lamu Islands are not expected to experience critical escalation in tropical storms. Scenario 1 (RCP 8,5) is based on current linear SLR. Scenario 2 (RCP 2.6) is based on a global reduction in population as well as an adaptive society. The analysis helped in determining the spatial exposure of each city-Island under each of the two scenarios.

Vulnerability to future SLR analysis

For the co-production of the map using the STRM database, the LECZ maps for the island were produced (see Figure C.4 for Mombasa island and Figure C.6 for Lamu Island). These maps were then subjected to inundation and alternative storm-surge (wave height) scenarios analysis based on application of the equation by Nicholls under the RCP2.6 and RCP8.5 for the periods to 2030, 2060 and 2090 as recorded by IPCC. Secondly, the county surface maps for each exposure indicator were constructed to determine exposed population and urban extent.

These surface indicator maps were then overlaid with the inundation zone layer. The overlaying of the maps helped in deriving the spatial exposure of each of the two indicators (population and urban extent) under inundation threat for the two counties. More detailed descriptions of these steps are as follows.
The calculation of storm surges (extreme sea levels) followed the method outlined by **?** and also applied in several global studies such as **??** where storm surges are

calculated as follows:

$$\text{FSS} = \text{S100} + \text{SLR} + \left(\frac{\text{UPLIFT} * 100\text{yrs}}{1000}\right) + \text{SUB} + (S100 * x), \tag{3.3.1}$$

Where

- FSS= Future sea storm
- $S100$=1-in-100 years surge height(m),
- SLR=sea-level rise (based on the IPCC prediction),
- UPLIFT=continental uplift/subsidence in $mm/year$,
- SUB=$0.5mm$ (applies to deltas only),
- x=0.1, or increase of 10% applied only in coastal areas currently prone to tsunamis and tropical cyclones.

Calculating assets exposed to SLR effects

For the analysis of exposed assets, values for 2015 National per capita GDP and the Purchasing Power Parity (PPP) were obtained from the International Monetary Fund database. PPP values are recognized and used as a reliable standardised value indicator for economic comparison across economies/countries. Normally, GDP is assumed to be equal throughout the country thus urban GDP per capita equals rural GDP per capita in a given year. For analysis of future cities, the relationship is also assumed to hold. The assets exposed and at risk are calculated as shown in Equation (3.3.2 below. The national per capita GDP is preferred to the local per capita which would be translated regarding the coastal contribution to the national GDP (see for example **??**). In estimating the losses, a method suggested by Nicholls and adopted by **?** and **?** was used and is described as follows

$$E_a = Ep * GDP_{percapitaPPP} * 2.8. \tag{3.3.2}$$

Where, *Ea*= Exposed assets, *Ep*= Exposed populations, and *GDPpercapitappp*= the country's per capita Gross Domestic Product(GDP) purchasing power parity (ppp)

According to **?** the factor of 2.8 translates to per capita GDP, i.e. the annual production of the economy divided by population, to the per capita value of assets. In earlier studies this factor was set at 5 but was later revised downwards to the factor of 2.8 based on current GDP values. In their argument, annual investments usually represent, on average, about 25 percent of GDP. Since economic resources in cities include buildings, transport infrastructures, utility

infrastructures, and other long-lived assets, assuming a lifetime of 40 years for these investments was deemed to be acceptable. Assuming also that per capita asset value in the city is growing by 3 percent a year, a rapid calculation suggests that the value of these assets is between 4 and five times per capita GDP. Consistent with this calculation, previous experience from studies of historical losses from flooding events have been undertaken, shows that losses accrued from flood events are within five times greater than the GDP of the affected areas.

This factor of 2.8, however, is likely to underestimate the property at risk particularly for developing regions, where there is a greater inequality between cities/towns and rural areas. That being the case, the calculation of the exposed assets in this study gives an initial estimate of the value of the infrastructure and losses that may result due to climate-related SLR impacts. The urban GDP per capita is assumed to grow at the same rate as national (or regional) GDP throughout the period to 2090. Equally, urban GDP is assumed to be equivalent to rural GDP per capita throughout the study periods.

Total GDP for each city is therefore, the product of projected urban population and per capita GDP in 2090 for the two counties. The analysis for the future projections is based on the population projections until 2100 as well as the poverty index derived from the GDP of Mombasa County as well as Lamu County. These projections are also in tandem with the individual county population projections.

The population of the two islands and the countries Gross Domestic Product (GDP) is used in the analysis of the number and extent of exposed infrastructure, people and associated economic assets. The population density maps were overlayed on the digital elevation model after the development of the analyzed elevation contours to ascertain population living in the LECZ and within the susceptible areas.

The population of each sub-county within the island county was then estimated. The analysis of the exposure is based on the 1 to 100-year return episode of extreme water events and in the absence of sea defense mechanisms along the coastline. The scenario modeling process developed by Nicholls is summarized in Figure 3.8.

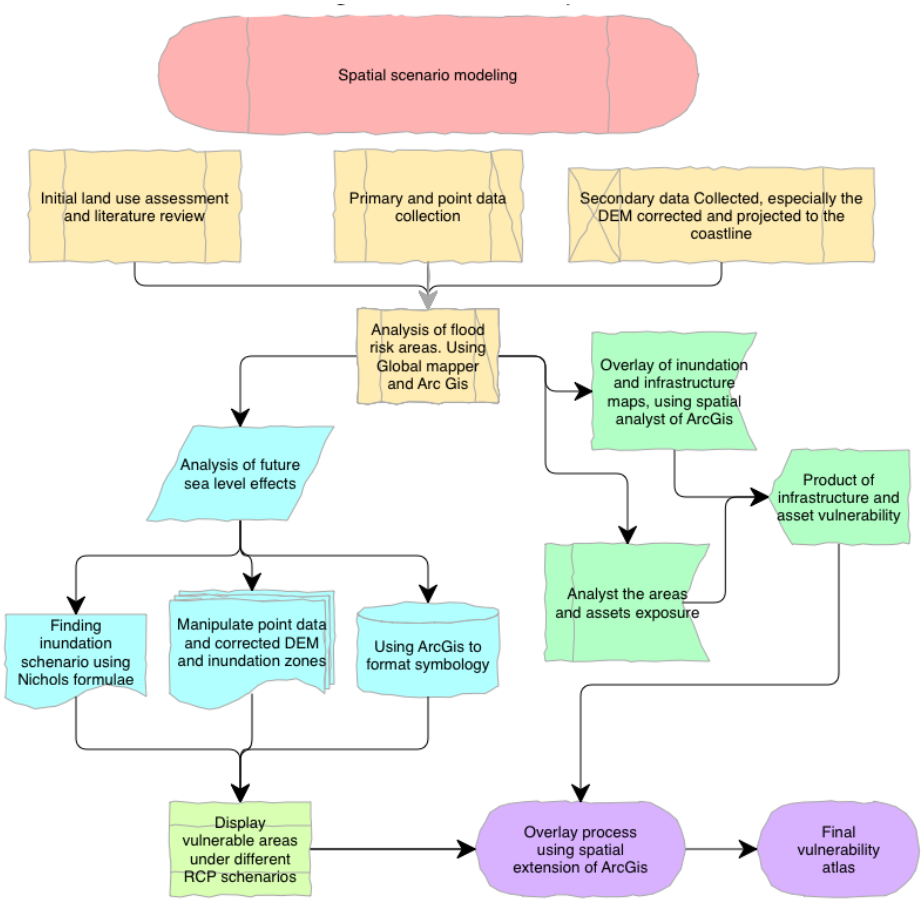


Figure 3.8: Conceptual framework for spatial inundation scenario modelling. (based on Equation 3.3.2 **?**)

3.3.3 Participatory research design

The PAR process was meant to address two research sub questions as follows:

- What is the level of awareness of the people living in these areas to the threat of SLR?
- Could participatory approaches in vulnerability assessments serve as an effective mechanism for enhancing stakeholder preparedness and empowerment to act in adaptation and mitigation of the identified vulnerabilities?

Awareness levels and PAR

The participatory process with focus groups from communities living in Mombasa and Lamu island was applied as the primary approach to the assessment of the current status of awareness on climate-related changes and especially on SLR. A set of questions generated during the mini-charrette process were used as a guide to provoke discussions on levels of awareness of SLR and related impacts (see the appendix D for further details).

The questions were used during the participatory meeting to help ascertain the level of understanding on the concept of SLR. The participants were then subdivided into smaller groups of six to eight participants each in order to discuss the questions in detail and provide a consolidated response to the best way to answer the specific issues. The issues were meant to gauge the awareness of the members on the knowledge and level of understanding of climate-change impacts and especially SLR.

Stakeholder preparedness for adaptation and mitigation

The initial results collected from each group on the awareness levels were then presented to the joint panel in the afternoon session and the roll over session for the case of Lamu Island where participants discussed each group's responses after which the facilitator introduced participants to the issue of adaptation and mitigation possibilities. The essence of the discussions was to ascertain if and how the community-based process can fit into the county's and the government's general adaptation and mitigation initiatives to climate change and SLR in particular. Responses from these sessions were written down and video recorded for further analysis. Lamu Island participation experienced a lower turnout to the meetings due to the fear of congregating several individuals in a room as a result of the prevailing security scare at the island in the period of the fieldwork for the study.

The identified inundation zones and flood-prone zones for the periods to 2030, 2060 and 2090 were included in the mini-charrette process (participatory process) to enhance the discussions of SLR based on a better understanding of the vulnerable areas and infrastructure/assets and people under threat. The final vulnerability atlas prepared including participants' perspectives on adaptation and mitigation were presented to the participants and methods of management were conceptualised.

Location of mini-charrette process

The mini-charrette workshop for Mombasa was held in April 2015 followed by the Lamu workshop on June 2015. Mombasa Island meeting took place at the premises of the Mombasa Youth Polytechnic and was facilitated by the Kisauni Environmental Programme assistance to the researcher. The Conservation Office and the Save Lamu offices in Lamu Island offered the venue for the Lamu workshop as it was central and familiar to residents and also mitigated the risk of gathering in one place.

The sites selected were both safe and convenient for the local participants to access and participate. However, with numerous civic events planned and at a busy time of the year, it was hard to find the ideal time for the mini-charrette process. A Saturday was chosen for both sites, and the researcher provided refreshments (tea and snacks) for the participants. The workshop was advertised a month in advance using posters in public locations, and community newsletters for the case of Mombasa Island as well as by word of mouth during the community committee meetings which raised awareness for the meetings.

Participation and participatory process used in the case studies.

In addition to deriving the infrastructure and socio-economic impacts of SLR a deliberate effort was made to involve the local communities in the two island counties towards co-creating the vulnerability atlas collaboratively. The research process was openly advertised to allow a self-selecting team that would participate effectively in the deliberations. The open call was therefore intended to reduce bias and selectivity in the participation. It was also important and thus encouraged that members of the public from different areas of both counties and age groups do participate in the mini-charrette. Participant consent was solicited for both groups as guided by the research ethics requirements, and they agreed to participate freely in the focus group discussions. The initial discussions were mainly on the challenges perceived in relation to coastal environments and their daily activities; This was then narrowed down to appraising SLR awareness to

help understand status quo awareness and perceptions of climate change and especially SLR around participats' communities. See appendix D for structure and core themes of the mini-charrettes.

Mini-charrette format and structure.

This study focused on identifying multiple participant community characteristics and perceptions on climate change and especially SLR and how changed perceptions could contribute towards building adaptive capacity and, thus mitigating vulnerability to a broad set of climate change impacts. For the Island of Mombasa, the workshop consisted of a common introductory session, three facilitated group sessions, and a fourth full group idea-sharing session. In order to facilitate a wider ideas sharing as well as making connections with individuals over a common workspace, working groups were restricted to no more than seven people and a facilitator. The researcher, two facilitators from a local community-based organization, and a research assistant (who was helping in the video recording) were from the research team while the other facilitator was a resident of the area and a coordinator of Kisauni environmental programme, who was also experienced in community workshops.

Although there were no official 'notetakers', facilitators recorded observations and two local students were invited to participate and make notes of the proceedings. Upon arrival, participants registered and were provided with background information on the study and workshop. Participants were encouraged to voluntarily create their groups in order to minimize discomfort and to feel at ease, despite the potential bias or influence this may have on panel discussions. Each group-table was equipped with a large poster paper roll, markers, a largely simplified version of a locally analysed vulnerability map for one scenario, and two small street maps (for members to pin their areas of interest) for Mombasa and Lamu Islands produced through the spatial mapping and modeling processes. This process facilitated the collection of primary data on community perceptions during the subgroup presentation and question time as well as during the opening and conclusion of the meetings.

Before the start of each session, exercises were introduced, and it was explained that each session provided a foundation for the next session. To support this, the work that each group produced was presented by each cluster member after posting it on the mini-charrette venue hall for others to read as well as for reference and reflection and discussion at the end of each session. In the case of Lamu Island, the prevailing insecurity constrained participants' attendance for the meetings. Two groups of six participants each were involved in the study with two facilitators and a local community representative helping with the participation process.

Mombasa participants created their groups equipped with the vulnerability map as well as the local map. The predetermined question guides were given to the groups after the general introduction and each group was guided on deliberating on the issues using sheets and marker pens. The first day involved the discussion of general SLR and the awareness levels for the participants living on the island. As earlier mentioned the Lamu meeting was followed through to a the second day for the participants to appraise methods of adaptation and mitigation strategies that can be employed in response to the impacts discussed the previous day.

Co-production and integrated vulnerability processes

The co-production process that merged the GIS and the mini charette processes is described in Figure 3.9. The process enhanced the double loop learning approach of adaptive responses to the identified SLR impacts. The processes were implemented as follows:

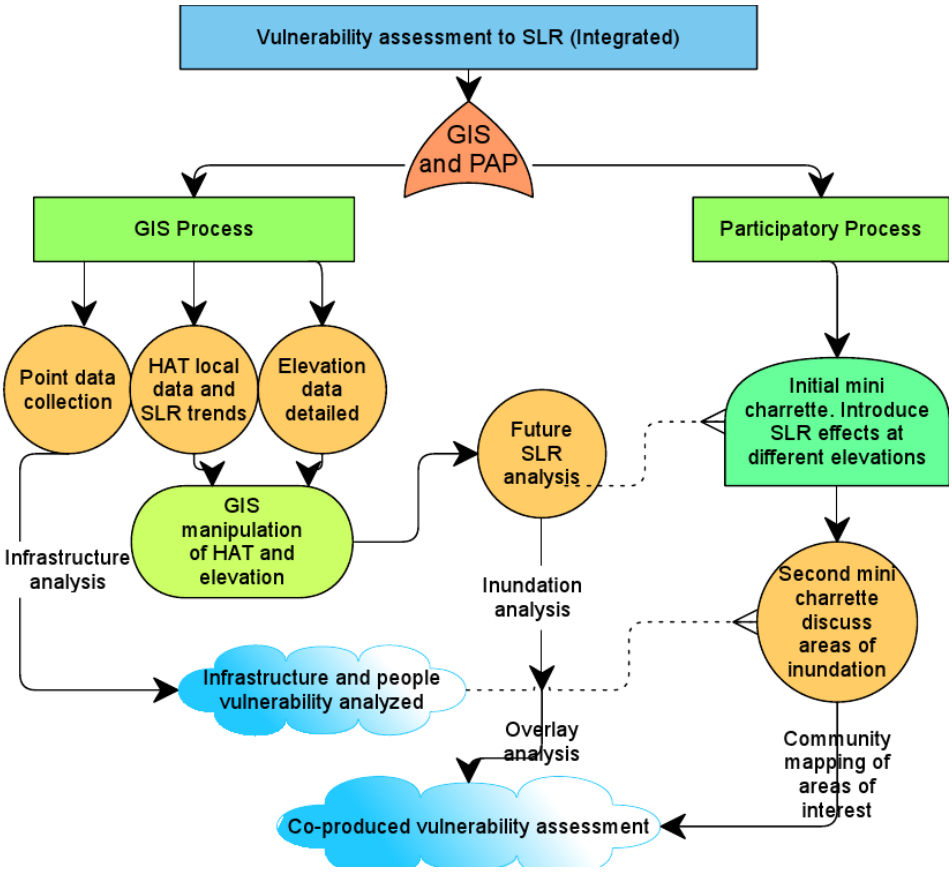


Figure 3.9: Integrated SLR assessment process.

In opening the mini-charrette sessions, an introductory video in global coastlines was presented to provoke discussions on coastal systems and their relationship to changes such as SLR. A participatory approach was employed after an introduction

to the simple processes of hazard mapping for the identification of vulnerable areas using the available local topographic maps and problem trees.

A problem-solving perspective on sustainability was the main focus where adaptive planning was encouraged (**?**). The problem trees helped in the initial analysis of the problems or advantages felt with regards to SLR. The identified problems were then paired together with the supposed improved wealth, either from the increased presence of seafood or its reduced availability.

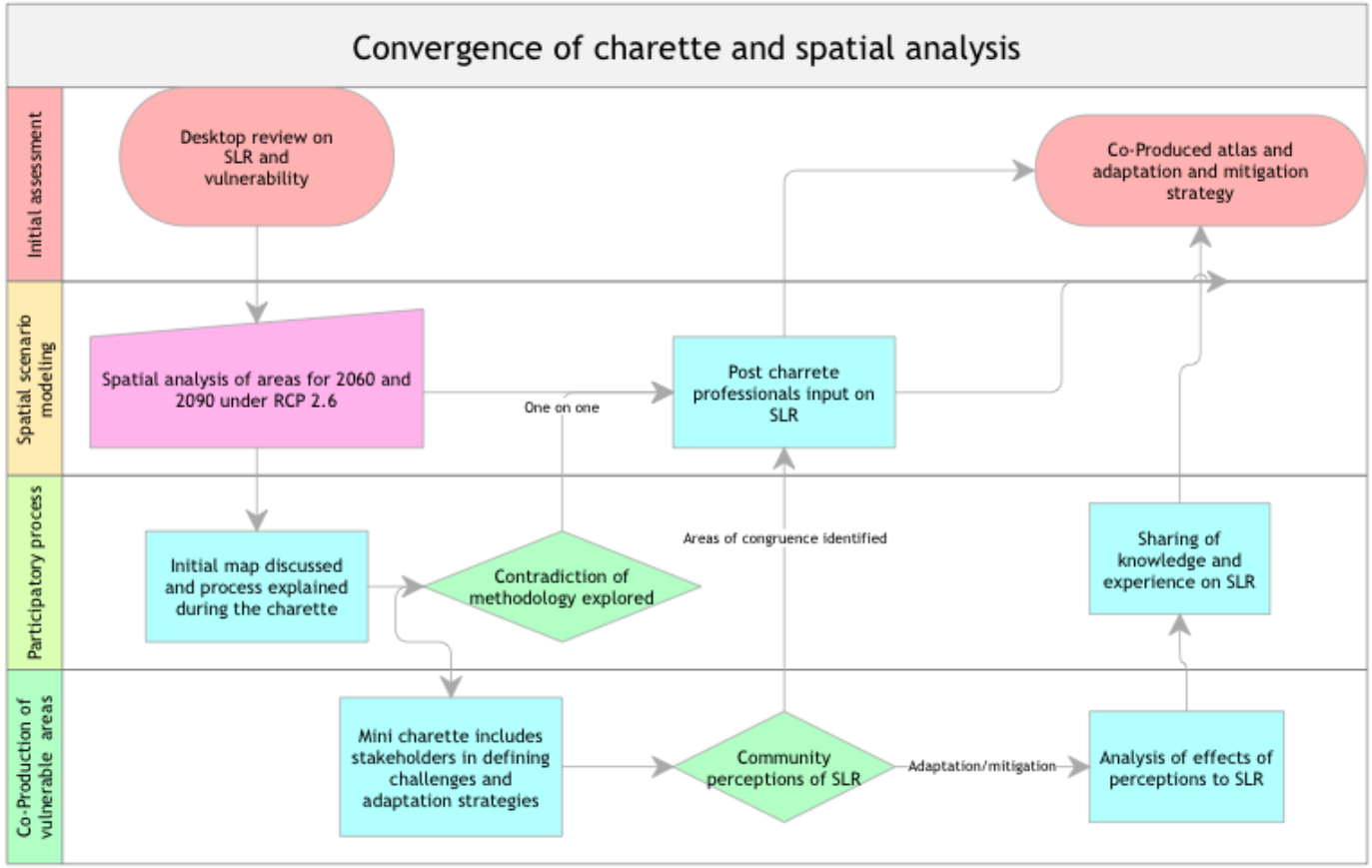


Figure 3.10: Convergence of spatial analysis and PAR process of vulnerability analysis

3.4 Data analysis techniques and presentation

Point data collected for infrastructure identification served as input into GIS in order to facilitate the analysis of infrastructure and service areas in Mombasa and Lamu. The product of this analysis was the infrastructure and asset maps produced from GIS. The DEM data collected from USGS and STRM served as input into the Global Mapper (GIS software) to facilitate the localization of the DEM for Mombasa and Lamu. This was then overlaid with the counties' division map to produce surface population maps as well as the LECZ classification maps for both cities. The DEM elevation model was also used in the GIS system to generate the inundation maps for the two islands under RCP 2.6 and RCP 8.5 for the periods to 2030, 2060 and 2090. The results and findings were shown in maps as presented in Chapter 4, Section 2 and 3.

The primary data from the mini-charrette was analysed using content analysis where the verbal and recorded data was categorized based on the awareness levels prior and after the co-production process. The characterisation of the verbal data was applied towards classification, summarization and tabulation. Content analysis in this study was done at both the basic level/manifest level, where a descriptive account of the data i.e. this is what was said or was presented, but with no comments or theories as to why or how. The second level of content analysis was the potential level of analysis which is also the interpretive analysis that was concerned with the response as well as what may have been inferred or implied.

Secondary data on land use, population and GDP were incorporated into a GIS system to analyse the populations at risk from the impacts of accelerated SLR. These maps were overlaid on the inundation maps of the islands over the various periods (2030,2060, and 2090) in order to derive the populations under threat. The maps were then integrated with the qualitative data of the mini-charrette process in order to derive the action-based model to be developed and the compilation of the comprehensive SLR atlas for the Kenyan coast.

The surface maps including population and urban extent were analysed using the "Spatial Analyst" extension of the ArcGIS 10.2 TM software of the ArcGIS tool which allowed for the integration of several aspects towards the derivation of the most vulnerable portions. Using (**?**) method of flood simulation sea areas susceptible to inundation and increased flooding were derived through an overlaying process towards the two indicators (population and spatial/urban extent). The synthesized data were applied as input into the GIS system for the final production of the maps. The co-production based processes included the mini-charette process as described narratively in this chapter and cross-referenced in Chapter 5.

3.4.1 Ethical considerations

Ethics consideration for the study were addressed through multiple strategies guided by the non-medical ethics criteria of the University of the Witwatersrand. Kenya's specific ethics considerations were also factored through the research process based on human subjects guidelines from the National Council of Science Technology and innovation at The National Research Council of Kenya.

The implications meant that consent for meetings to be recorded was solicited, and mini charette participants consented to participate freely in the research process with a clear understanding of how the research findings were to be reported. The group discussions and results have been presented with no mention of individual names. Consent was also sought to use photographs and video recordings for data collection and especially for the mini-charrette process. The data were also consented for sharing with the community through the online blog (http://valentineenvironment.com/), which was meant to facilitate to ongoing discussions on coastal protection and SLR amongst participants and the community in general.

Chapter 4

Extent of inundation and SLR vulnerability for Mombasa and Lamu islands

4.1 Data overview and presentation

Data presentation and analyses are structured as follows:

- Data overview
- Population spread and density
- Derivation and presentation of elevation areas as the basis of flood and inundation risk zones
- IPCC AR5 temperature and rainfall pattern prediction
- Analysis of inundation zones and future vulnerability based on the RCP scenarios
- Extent of inundation risk by SLR based on the IPCC SLR assessment
- The impact of SLR on infrastructure and services within the inundation zones

4.1.1 Data overview

Local land use and planning data sources included the Kenya Regional Centre for Mapping of Resources for Development (RCMRD) based in Nairobi, Kenya Marine and Fisheries Research Institute (KEMFRI) located in Mombasa, under the Department of Physical Planning under the Ministry of Lands and physical planning. The following data and maps were collected for analysis on each island as described in Section 3.4.2 in Chapter 3.

Population and economic data analysed for the production of the population density maps and the elevation classification data were collected from the Kenya

National Bureau of Statistics(KNBS). Metadata for each of the maps is listed as part of the appendices. Primary data collected from the mini-charrette process is described in detail in Chapter five. The other primary data regarding point data to identify areas of interest in Mombasa and Lamu Island is incorporated with the population data projected to 2016 and used in the analysis of the inundation levels and the production of the maps.

4.1.2 Population structure and density of study location

The study focus was mainly on the Kenyan coast from where the two case study island cities of Mombasa and Lamu were prioritised as illustrated in Figure 3.1. The individual island characteristics are reviewed in detail in the subsequent sections of this chapter.

4.1.3 Population distribution for Mombasa

Mombasa island falls within Mombasa County which is situated in the south-eastern part of the former Coast Province. Mombasa County mainly entails the city of Mombasa and it is the smallest of the county regions and towns within the former seven districts of Coast Province. The county covers an area of 294.7 Km^2. The county is bordered by Kilifi to the north, Kwale to the south and west and the Indian Ocean to the east. The county lies on latitudes $4^0 2' 12'$ South and longitudes $39^0 0' 10'$ East with most of the city lying at 5m or less above sea level. Table 4.1 shows the administrative units and municipal electoral Wards by Division within the County.

Table 4.1: Population distribution (2009) for Mombasa county and its six subcounties.

Division	Population	% Population	Area(Km^2.)
Changamwe	147,613	15.7	16
Jomvu	102,566	10.9	29
Kisauni	194,065	20.7	88.7
Nyali	185,990	19.8	22.88
Likoni	166,008	17.7	41.10
Mvita	143,128	15.2	14.80
Mombasa county	939,370	100	222.8

4.1.4 Population density and projections

Population distribution and settlement pattern in the county is influenced by infrastructure networks and especially the main roads. Other factors that have

affected distribution include the availability of clean water services (salt water intrusion is a problem in the county), access to electricity, availability and accessibility to gainful employment activities especially along the beaches, availability of suitable housing, security and land tenure systems.

High population densities and high quality infrastructure are found in the Island Division and along the major highways such as Mombasa Lunga-Lunga roads in Likoni Division, Mombasa-Nairobi road in Changamwe Division and Mombasa-Malindi road in Kisauni Division. The sparsely populated areas are found on the outskirts of the county which are also closely associated with the least developed infrastructures. These areas include Mwakirunge which serves as the location of the main city dumpsite, the areas around Maunguja, Mkupe Jetty and Mwangala. The population density pattern for the various areas around the island and the administrative units are illustrated in Table 4.1 and Figure 4.1. The population is set to increase to about 1.3 million by 2017 based on the county projections (see Table 4.2).

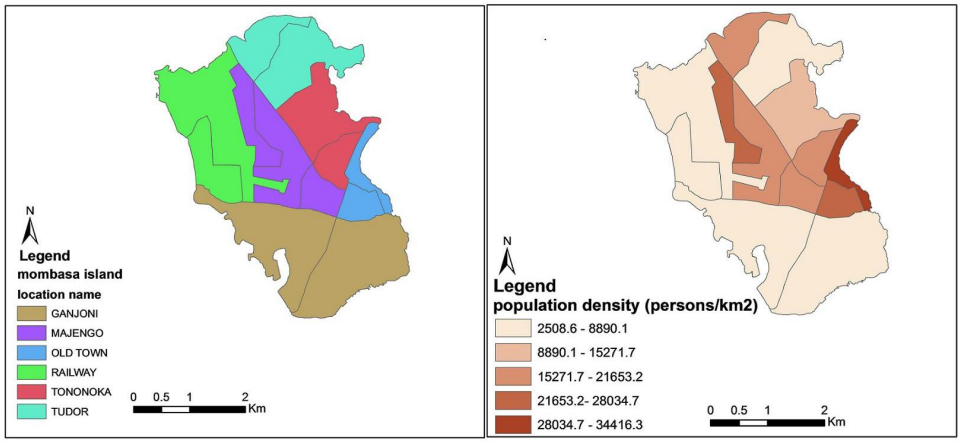


Figure 4.1: Population density for Mombasa County.

Table 4.2: Population projection for Mombasa County: Source KNBS:(2015)

Division	**2009 census**		**2012 projections**		**2015 projections**		**2017 projections**	
	Population	Density (People/Km^2.)	Population	Density (People/Km^2.)	Population	Density (People/Km^2.)	Population	Density (People/Km^2.)
Changamwe	147,613	9,226	165,438	5,705	185,415	6,394	200,005	6,898
Jomvu	102,566	3,537	114,951	7,184	128,832	8,052	139,005	8,688
Kisauni	194,065	2,188	217,499	2,246	2143,762,	2,293	263,762	2,474
Nyali	185,990	8,129	208,832	9,103	233,619	10,202	252,066	11,007
Likoni	166,008	4,040	186,054	4,527	208,520	5,073	224,986	5,474
Mvita	143,128	9,671	160,411	11,078	179,781	12,416	193,977	13,396
County	939,370	36,791	1,053,185	39,843	1,179,929	44,430	1,269,801	47,937

4.1.5 Elevation and LECZ characterisation

Mombasa Island is classified as a low-lying ecological area with 21.9% of the area falling in the range of 0 to 5m above sea level. The infrastructure/assets mainly within this zone include the railways and parts of the Nyali Bridge (the only main road exit from Mombasa Island to the mainland North of the coast).

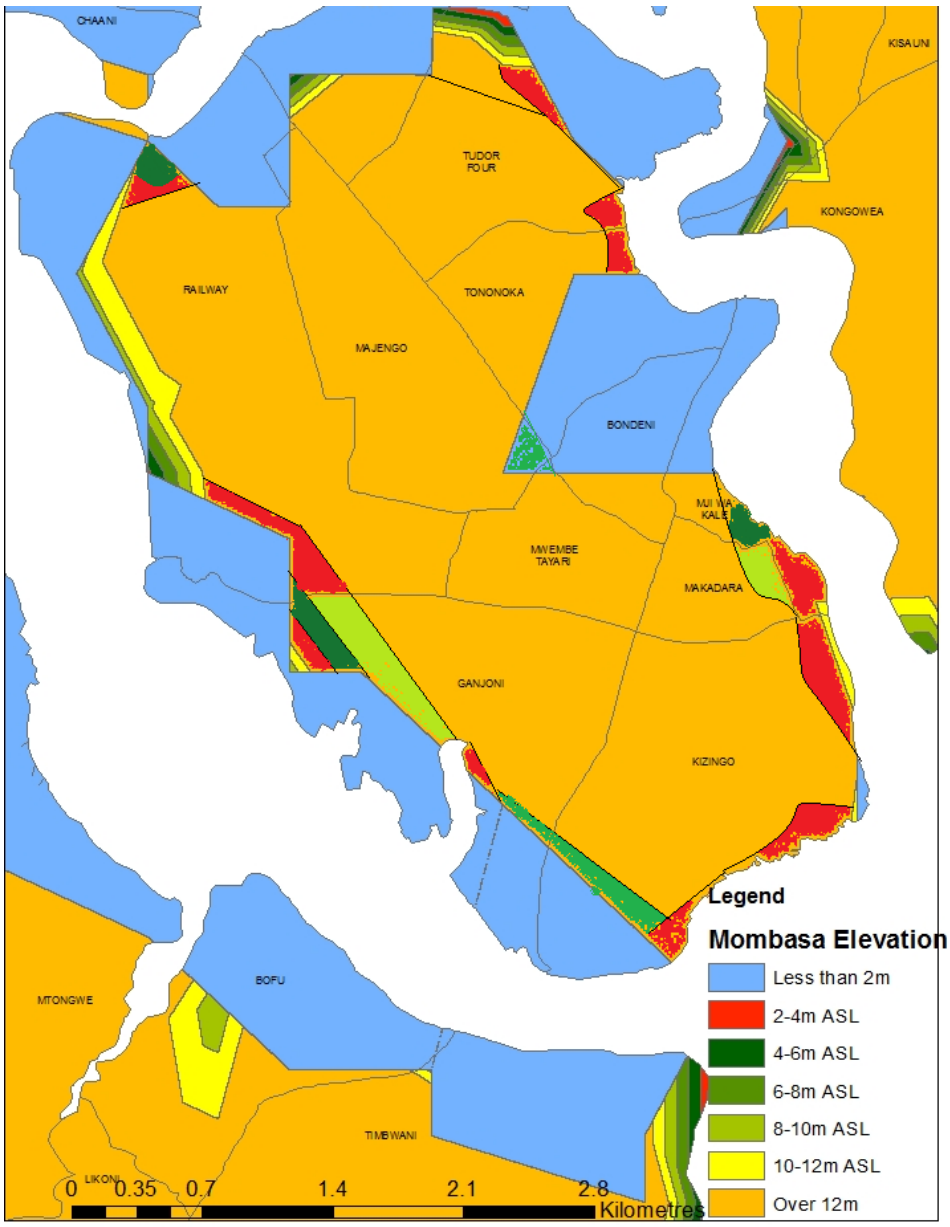


Figure 4.2: Elevation of Mombasa County based on LECZ definition.

4.1.6 Population of Lamu

Lamu County constitutes of the Lamu archipelago (with several islands which include Pate, Manda and Manda Toto)and a mainland comprising of small towns such as Mokowe, Hindi, Mpeketoni and Witu among others as described in Table 4.3.

Table 4.3: Population distribution (2009) for Lamu county and its seven divisions.

Constituency	Division	Population	% Population	Area (Km^2)
Lamu WEST	Amu	22,366	22	99.7
	Hindi	10,700	10	1150.8
	Mpeketoni	13,105	36	1727.7
	Witu	13,105	12.9	975.4
Lamu EAST	Kizingitini	8,346	8.2	79.2
	Faza	6,577	6.5	17.7
	Kiunga	3,918	3.9	2222.6
	Total	101,539	100	6,273.1

4.1.7 Population density for Lamu

Lamu Island (see Table 4.3 and Figure 4.3) is located along $2^0 16'$ South and longitude $40^0 54'$ East. The island has a total land area of about 50 Km^2. About 19 Km^2 of the island is covered by a double row of sand dunes located along the entire length of the coastline and especially from Shella covering the southern coastline. The primary source of water for the whole island is the Shella aquifer, whose unconfined section lies underneath these sand dunes.

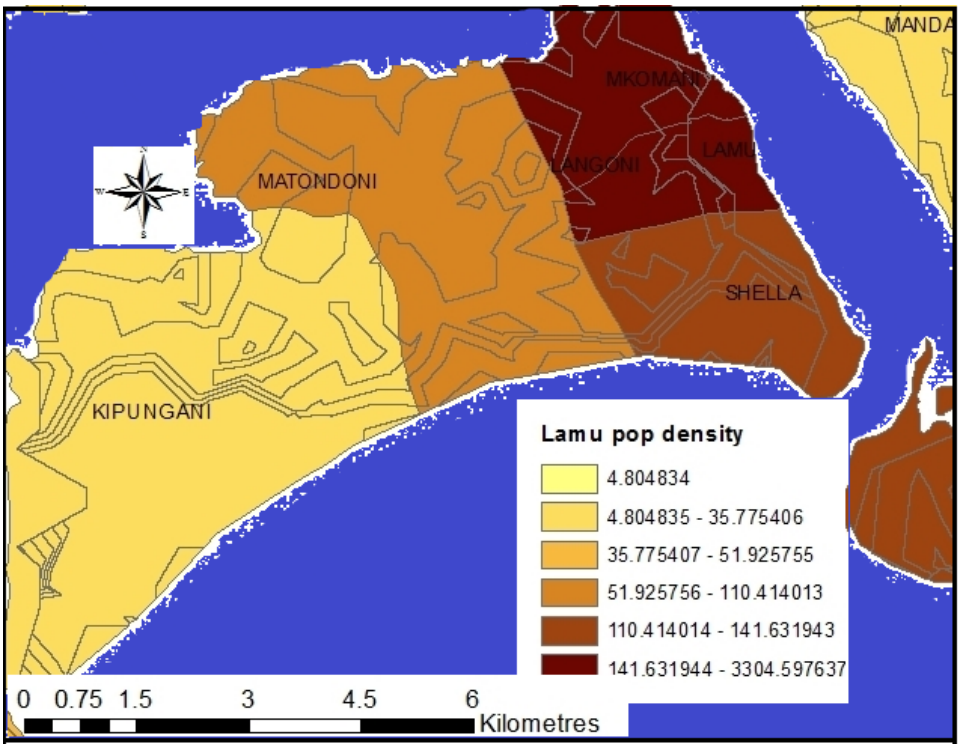


Figure 4.3: Population density for Lamu County.

4.1.8 Elevation and LECZ classification for Lamu

Lamu island is primarily classified as an LECZ zone as shown in Figure 4.4. The island is thus vulnerable to effects related to climate change and especially SLR. The vulnerability includes exposure to the impacts of temperature/tide variations and the probability of more severe coastal storm surges as an impact of global climate change. The increase in the impacts of elevated high tides is already being experienced (see Figure 3.5). The ocean wave along the island created a flood on the main road and the jetty used as a key transport infrastructure. Most households and businesses were flooded for the better part of the day.

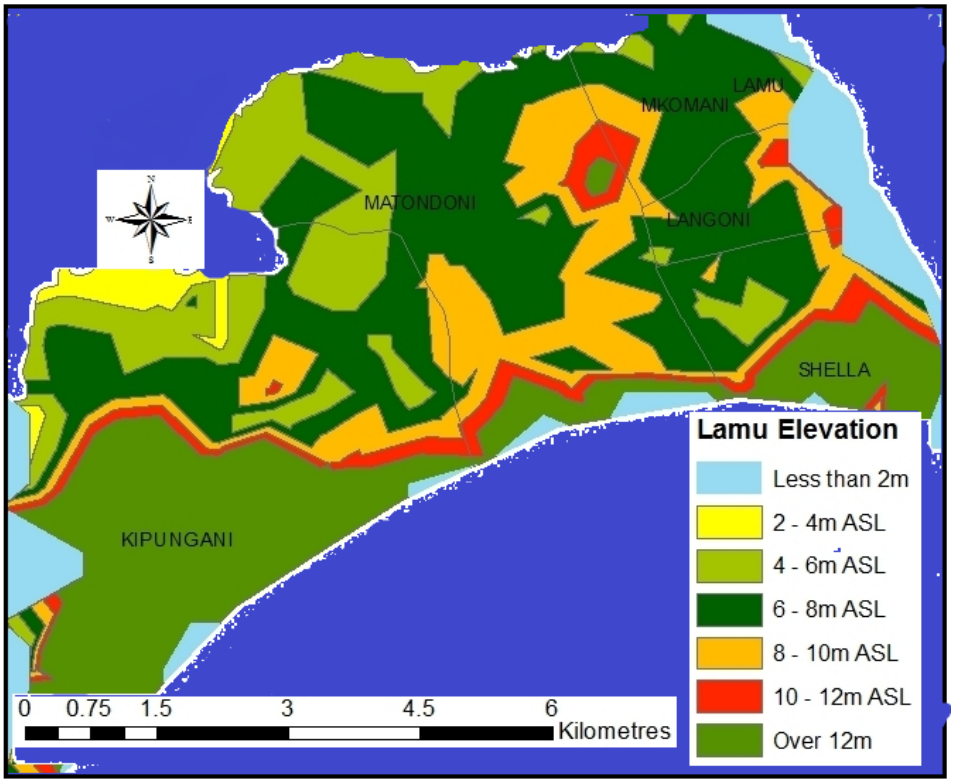


Figure 4.4: Elevation and LECZ classification for Lamu Island.

4.2 Future vulnerability outlook

This section provides an analysis of future vulnerability of the two islands with the base year of 2007. However, the analysis builds on a 30-year interval to the 22nd century. The period to 2030, 2060 and 2090 were therefore chosen as the anchor years for the scenarios analysed.

4.2.1 Derivation of inundation levels

After investigating critical infrastructure in both islands, their vulnerability to SLR was assessed based on the IPCC scenarios. Two different inundation scenarios were considered. These were originally mapped as part of the Mombasa and Lamu Vulnerability Assessment and are described here below:

1. Highest Astronomical Tide (HAT): HAT elevation as reported at the Mombasa, and Lamu tide gauge stations whose data is available on the PSMSL. The elevation was determined as 4.236 m, and this scenario is used to identify areas already vulnerable to frequent flooding in the short term. This is displayed in light blue on the LECZ maps (Figures C.4 and C.6.

2. HAT plus IPCC sea level rise based on each scenario added to simulate HAT with the addition of relative sea level rise per year plus envisaged escalation in storm

surge. The IPCC SLR scenarios were used as a base assumption as it represents a median value for global SLR projections. The elevation of 4.236m is secured from the DIVA database as an indication of a high tide facilitated the event and is used to identify areas vulnerable to flooding in the optimistic and pessimistic scenarios. This is displayed in light blue on the vulnerability maps (Figure 4.8 to Figure 4.15 for Mombasa and Figures 4.17 to Figure 4.24 for Lamu Island.

The areas prone to inundation were derived based on data from IPCC as earlier mentioned. When calculating exposure indicators for the delineated inundation zones, land area, and population size were the main issues of interest. Scenario composed of the RCP 8.5 (equivalent to the AIFI SRES scenario) and the RCP 2.6 (equivalent to the B1 scenario) provided for an appropriate comparison and were therefore selected for the spatial appraisal of the areas under threat within the two islands.

Based on the current high and low water tides, the IPCC SLR scenarios are adjusted to the current sea level scenario using Equation 3.3.1 (by Nicholls as described in Section 2.4.4). The surface indicator maps were overlaid with the inundation zone layer to determine the spatial exposure of each of the two exposure indicators namely land area and population.

The inundation areas were derived based on the two global scenarios of RCP2.6 and RCP8.5 under a range of different time periods to track SLR escalation and implications. Table 4.4 shows the global sea level scenarios under which the Mombasa and Lamu analysis are based.

Table 4.4: Accelerating global SLR estimates applied in the study based on the AR5 IPCC report.

Year	A1B Mid range(m)	RCP 2.6(m)	RCP 4.5(m)	RCP 6.0	RCP 8.5
2007	0.03	0.03	0.03	0.03	0.03
2010	0.04	0.04	0.04	0.04	0.04
2020	0.08	0.08	0.08	0.08	0.08
2030	0.12	0.13	0.13	0.13	0.13
2040	0.17	0.16	0.17	0.17	0.19
2050	0.23	0.23	0.23	0.23	0.25
2060	0.30	0.28	0.29	0.29	0.33
2070	0.37	0.31	0.35	0.33	0.42
2080	0.44	0.35	0.41	0.40	0.51
2090	0.52	0.40	0.47	0.47	0.62
2100	1.09	0.61	0.71	0.79	0.98

The Table 4.4 and Figure 4.5 illustrates the analysis from different climatic forcing and how the varying RCPs contribute to variations in sea level changes. Given

that the current RCPs and the related sea level changes have not been downscaled to regional or local scenarios, the SRES (BI mid range) has been added instead for comparison purposes.

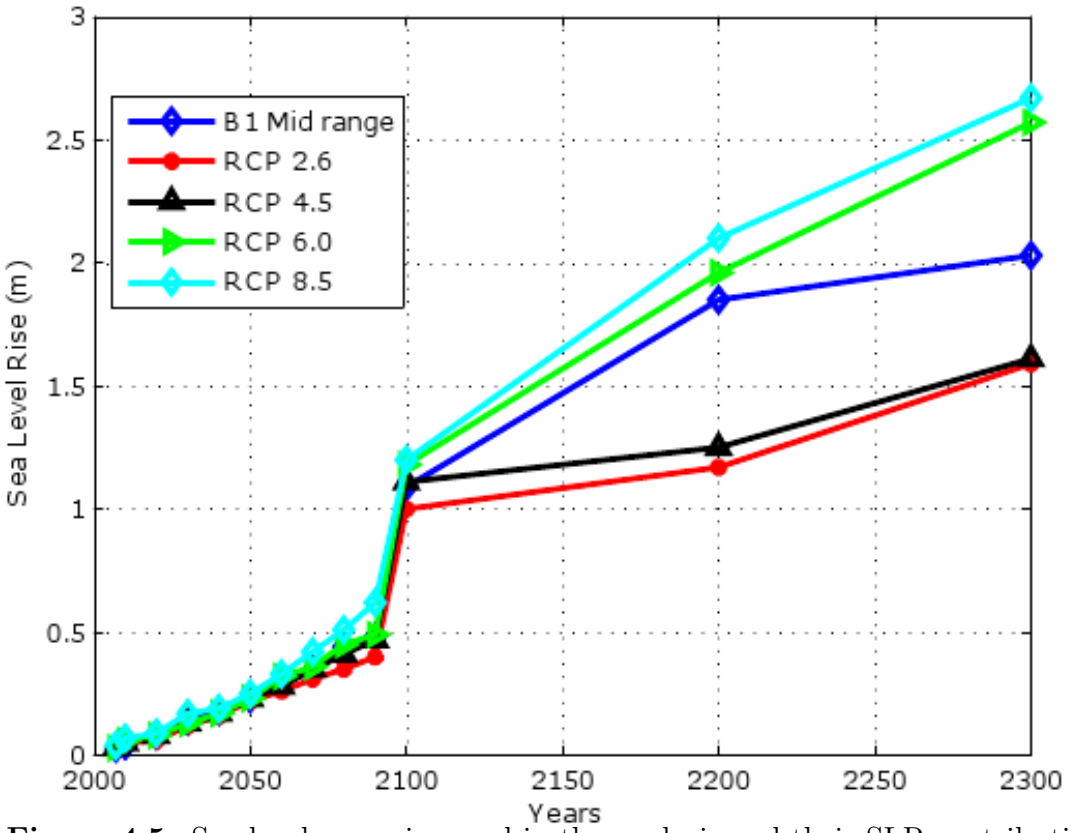


Figure 4.5: Sea level scenarios used in the analysis and their SLR contributions. (B1 equivalent to RCP 4.5 medium low, A1F1 equivalent to RCP 8.5 high and A1B equivalent to RCP 6.0 medium high.)

Based on several models, the IPCC was able to deduce the extent of annual sea level changes around the world. Whereas the changes are initially based on global models as shown in Figure 4.5, these changes are based on global models. In essence, sea level changes are, to some degree, also influenced by the specific regional characteristics such as uplift and subsidence, astronomical high tides of regions as well as GIA in specific areas. This global trend is therefore corrected based on the local climatic conditions and other local factors to analyse the effect of SLR within the selected regions effectively.

The combined analysis includes the 1 in the 100-year cycle of an extreme event leading to inundation, including the effect of increased coastal storminess due to climate change guided by low and high tides experienced at the coastline. The corrected sea level and inundation impacts are therefore a product of global climate

change and the HAT of the region. Table 4.6 shows the adjusted values based on the equation developed by Nicholls (see Equation (3.3.1)) and discussed in detail in section 2.4.4

Based on the prioritised scenarios and inundation levels selected, Table 4.6 presents the selected RCP 8.5 and RCP 2.6 values that were used as input into the Global Mapper to assess the localised future inundation scenarios under the different reference years of 2007, 2030, 2060 and 2090. This facilitated the production of the initial vulnerability maps as indicated under the inundation zones in the subsequent sections.

Table 4.5 is the adjusted SLR scenarios based on the 1 in a 100-year cycle of increased storminess and the probability of a high tide creating a flooding event in the region due to SLR. The adjustments made were based on the method on projecting future storm surge as presented in Section 3.4.1. These are the values subsequently used in the spatial analysis of the extent of inundation and the socio-economic calculation for the population and assets under threat from SLR impacts.

Table 4.5: SLR values for the study based on Nicholls formula and the AR5 IPCC report.

Year	A1B Mid range(m)	RCP 8.5 (m)	RCP 2.6 (m)
2007	4.277	4.317	4.267
2030	4.371	4.447	4.337
2060	4.552	4.668	4.489
2090	4.771	5.231	4.651

Table 4.6: Calculated extreme decadal SLR based on HAT and Nicholls equation

Year	A1B Mid-Range(m)	A1B+HAT (m)	RCP 2.6 (m)	RCP 2.6+HAT(m)	RCP 8.5(m)	RCP 8.5+HAT(m)
2007	0.03	4.277	0.03	4.267	0.03	4.317
2010	0.04	4.291	0.04	4.291	0.04	4.291
2020	0.08	4.331	0.08	4.331	0.08	4.331
2030	0.12	4.371	0.13	4.381	0.16	4.447
2040	0.17	4.421	0.17	4.421	0.19	4.449
2050	0.23	4.481	0.23	4.451	0.25	4.501
2060	0.30	4.552	0.25	4.489	0.33	4.668
2070	0.37	4.621	0.35	4.561	0.42	4.671
2080	0.44	4.691	0.41	4.601	0.51	4.761
2090	0.52	4.771	0.47	4.651	0.62	4.871
2100	1.09	5.341	0.61	4.841	0.98	5.231

4.2.2 Extent of inundation risk due to SLR

This section presents the results of the spatial analysis of accelerating SLR change for the two islands. The high and low coastal tide data collected in Mombasa station through the Permanent Service for Mean Sea Level site (PSMSL) facilitated the simulation of the inundation scenarios. The description of this data is presented in Section 3.2.1. The graphs on the high water tides and sea level are described below.

4.2.3 Tide gauge stations Lamu and Mombasa

Time series records from tide gauges of sea level heights are crucial because they provide vital information on the highly variable nature of the boundary between land and sea. The study and analysis of long time series of data now available from several stations have revealed a worrying trend of a continued rise in mean sea level. In Kenya, the first gauge was installed in 1933 in Kilindini Harbour, Mombasa by the former East Africa Railways and Harbors Corporation and remained in operation until 1956. Another gauge (Munro gauge), which is current and can deliver sea level changes and stormy changes in real time, was installed in the 1960's at the Kipevu pilot jetty at the present KPA Headquarters and operated intermittently up to 1976 when the tide gauges were reinstalled and managed by the KMFRI.

The collected data from the tide gauges in Kenya are presented in Figure 4.6 for the monthly mean readings and Figure 4.7 for the annual sea level mean readings. The data highlights the fluctuations of sea level during the high and low tides in Mombasa and Lamu Islands.

Mean sea level readings

Data on sea level monitoring is reported by two data sets which are the tide gauge data and still water level data. The Mombasa station has been offering tide gauge data to ascertain sea level status since 1956. Surprisingly this data has never been analysed to evaluate vulnerability to extreme events in the two islands. Figure 4.6 gives a description of the data collected from the Mombasa Liwatoni Jetty tide gauge and gives a summary of the relative sea level signal averaged between 1986 to 2008.

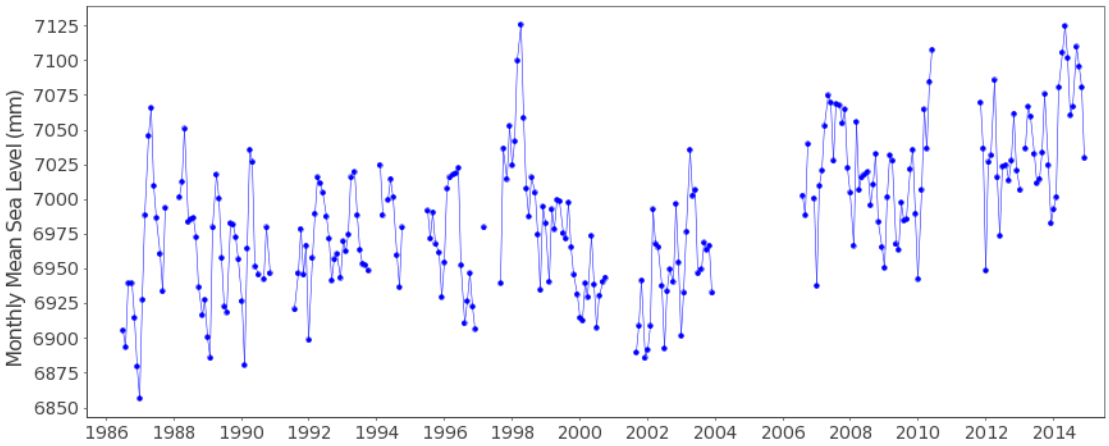


Figure 4.6: Monthly mean sea level for Mombasa from PMSL data sets.

The annual sea level rise figures for Mombasa Island are identified and extracted from the monthly readings. The readings can give an indication of the changes in ocean volume and pressures as well as adjustments in the water levels. Mombasa average annual mean sea level changes averaged at 4.94m slightly different from the data collected from the DIVA database that gave an average of 4.23m.

According to PMSL the Mean Sea Level (MSL) means the 'still water level', which is the level of the calm ocean without waves or tides. MSL is averaged over some period, such as a month or a year. The annual and monthly MSL is measured at fixed marks on the land/jetty which are also known as 'benchmarks'. Since MSL data are recorded in relationship to the land, they can change either due to a change in the volume of the water (as one of the factors in SLR and climate change) or due to uplift or subsidence of the land. For this reason, measurements from a tide gauge are sometimes referred to as 'relative sea level'.

As seen in Figure 4.7 the average mean HAT from the tide gauges for the city of Mombasa averaged at 4.94m above sea level. The HAT of the area is a critical component in assessing the effects of extreme events that can pair up with a storm of the stated coastline to cause negative impacts, especially when combined with a phenomenon like the accelerated SLR or a storm surge. The data is collected from PMSL measuring stations for Mombasa and Lamu islands.

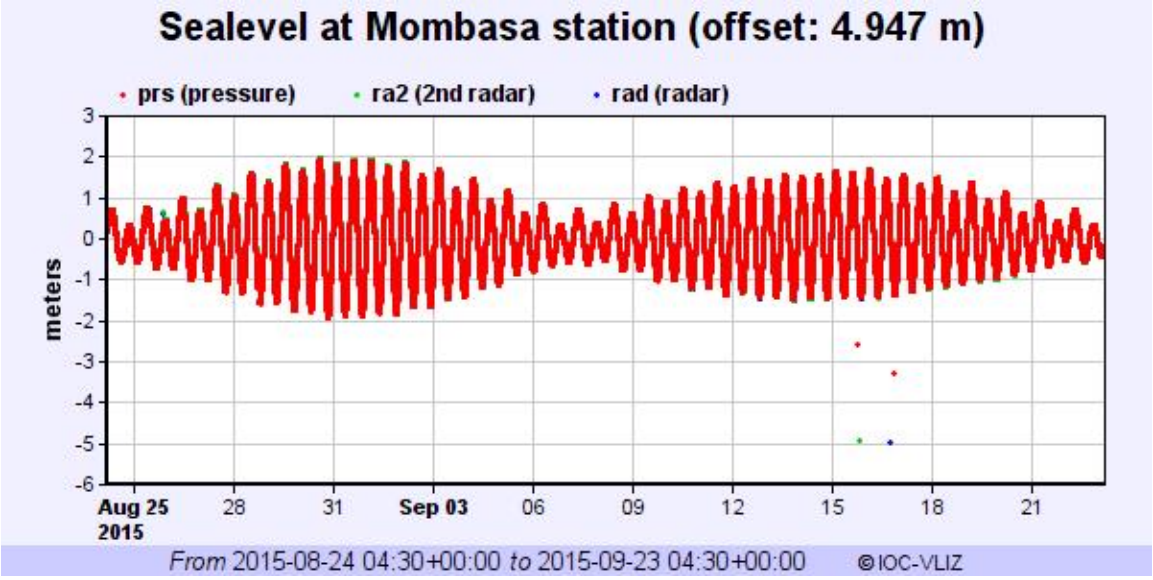


Figure 4.7: Daily MSL for Mombasa (For August 24th to September 2015) PMSL data set.

4.3 Projected impacts of SLR for Mombasa island

4.3.1 Inundation zones under threat from SLR

Based on the inundation scenarios the spatial GIS analysis for Mombasa Island by 2030, 2060 and 2090, are appraised as follows.

Scenario 1: Under the RCP 2.6 by 2030

As discussed earlier, this is the most optimistic scenario where the world is seen to have successfully curbed emissions and thus mitigated global warming such that the associated sea level changes can be presumed to be lower than under the other three IPCC scenarios. Under this scenario, Mombasa Island and its infrastructure, especially the five and three star rated hotels, along with its critical port city facilities (servicing eight countries for central and eastern Africa) would fall under threat from inundation as a result of accelerated SLR.

Areas around the Changamwe Oil Refineries, Kilindini and the Likoni areas (especially around Mama Ngina Drive) would be under threat from effects of accelerated SLR. Overall exposed area under threat from inundation is 0.5 Km^2.

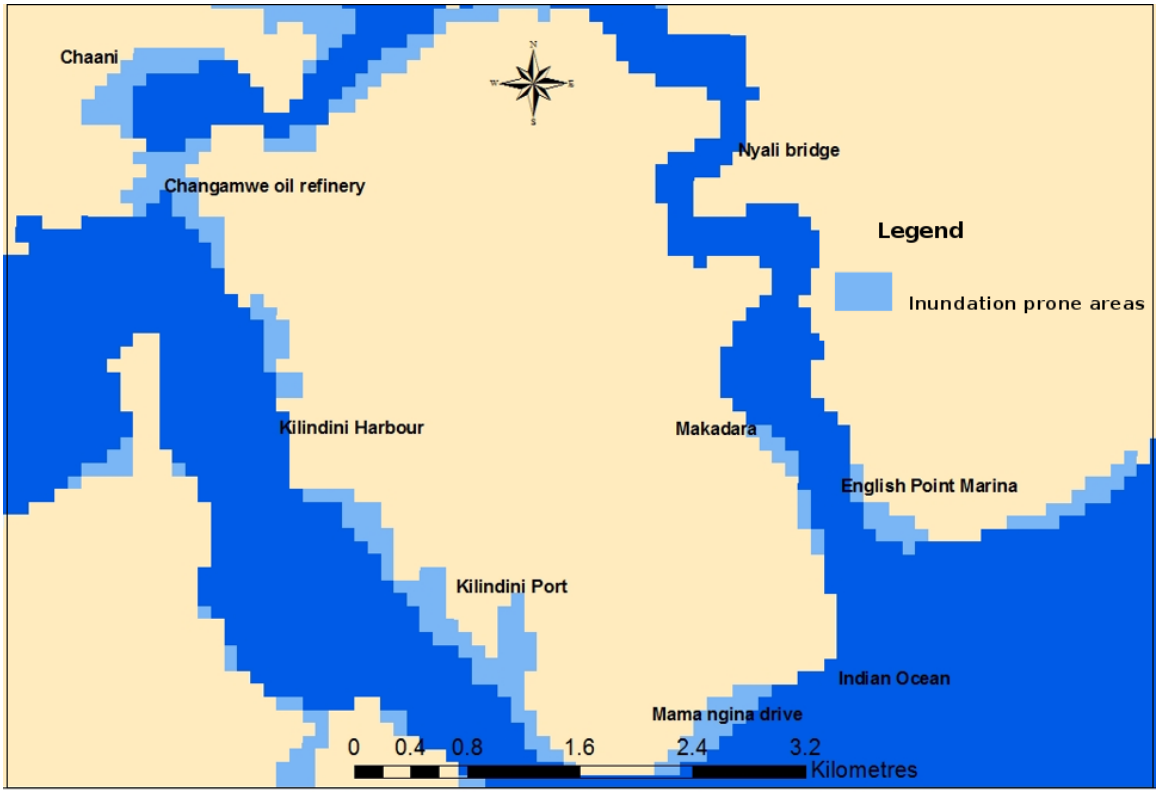


Figure 4.8: Inundation areas for Mombasa by 2030 under the optimistic RCP 2.6 scenario.

Scenario 1: Under the RCP 2.6 by 2060

The inundation-prone areas under the optimistic scenario of RCP 2.6 by the year 2060 are shown in Figure 4.9. By this time, island area of up to 1.4 Km^2 is low lying and susceptible to ocean disturbances in the event of a severe coastal storm event, clarified at a 1 in 100 years (1-100) year return cycle of an extreme event. The areas under threat translates to 10% of the land mass. The new areas include the areas around Makadara, the Chaani residential area on the north western side of the island, portion of Old Town and the Fort Jesus tourism attraction centre which is managed by the National Museums of Kenya.

Additional areas classified as low lying (and thus threatened by the effects of extreme events) include the railway division of the coast of Kenya, which hosts part of the Kenya Ports Authority offices and bays. Under the year 2060, the areas prone to inundation increase substantially including the areas along Mama Ngina Drive where the current State House in Mombasa is situated and sections of Kizingo as well as the Mtongwe channel which serve as the only connection between the Island and the south coast.

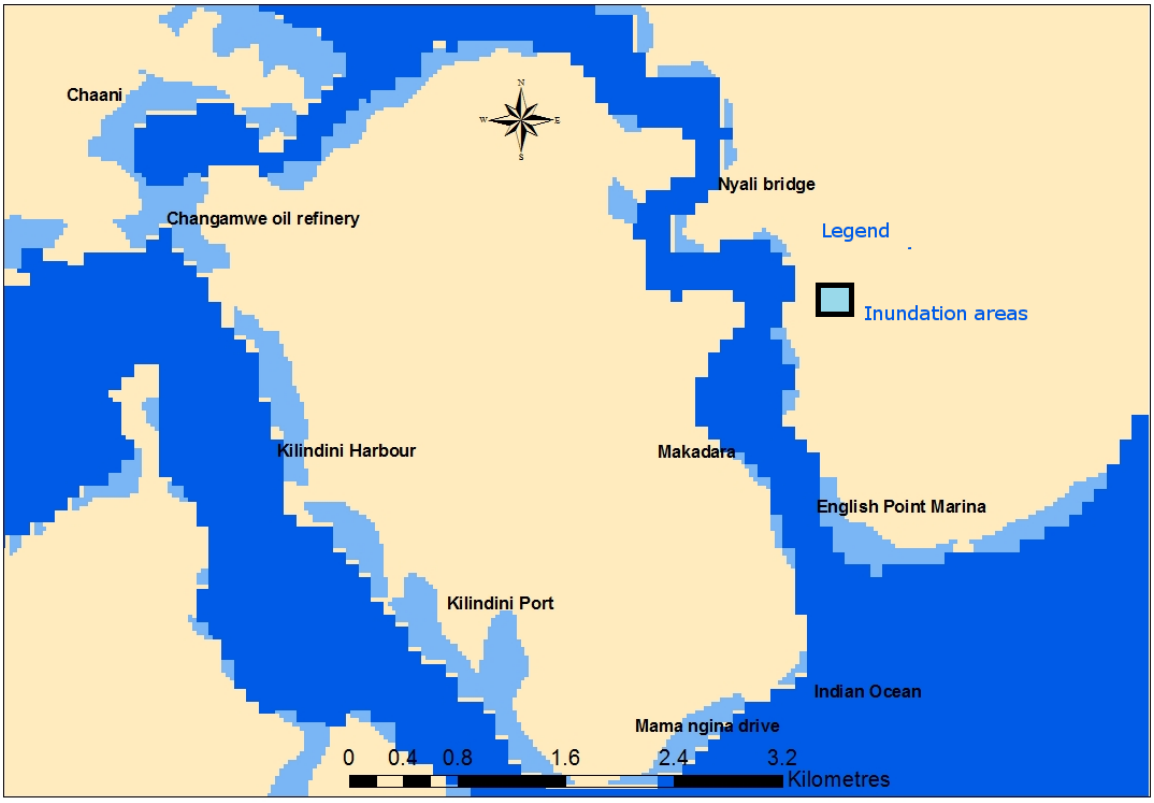


Figure 4.9: Inundation areas for Mombasa by 2060 under RCP 2.6 scenario.

Scenario 1: Under the RCP 2.6 by 2090

As indicated in Figure 4.10, under the optimistic scenario of RCP 2.6 by the year 2090, island area of up to 2.3 Km^2 is low lying and is susceptible to ocean disturbances in the event of a severe coastal storm event clarified at 1-100 year return cycle. The vulnerable area is in addition to the 12.1% affected under the 2030 and 2060 scenarios. The cumulative vulnerable area across the full period under this scenario would therefore be around 23%. This translates to a quarter of the island area becoming vulnerable within the next 100 years even under the most optimistic scenario.

An important area that is fully under inundation in this scenario is the Kilindini Harbour, Kilindini Port and areas around the Changamwe Oil Refinery. This important area has been ideal for harbour infrastructure given its unique depth, the Port Authority has recently invested over US$ 50 million in new cargo handling equipment.

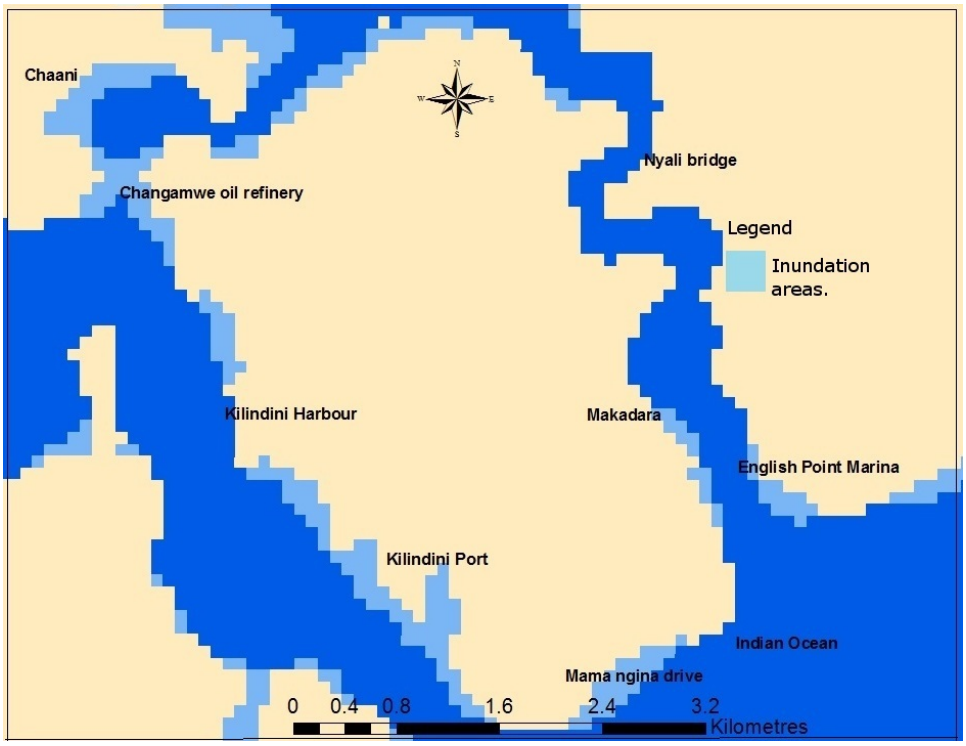


Figure 4.10: Inundation areas for Mombasa by 2090 under RCP 2.6 scenario.

The new Berth 19 project includes an additional 15-acre staking yard that adds an extra handling capacity of 200,000 TEUs per annum. Under the optimistic RCP 2.6 scenario, the port of Mombasa and the new Berth 19 would be under threat from inundation in the event of a coastal storm, as illustrated in Figure 4.10 under conditions of accelerating SLR.

Scenario 2: Under the RCP 8.5 by 2030

IPCC (**?**) deemed the RCP 8.5 scenario to be the most pessimistic scenario, where the world population is increasing and no significant effort is made to mitigate the prevailing trends greenhouse gas emissions and the related increase in atmospheric temperatures (global warming). In essence, under this scenario, the use of fossil fuels continues unabated through the next 100 years. Figure 4.11 illustrates the inundation-prone areas for Mombasa Island by 2030.



Figure 4.11: Inundation areas for Mombasa by 2030 under RCP 8.5 scenario.

The areas under threat of inundation under this scenario include the Nyali Bridge (which is the only exit to the main highway from the island) and the multi-billion new hotel enterprise known as the English Point Marina. Under this scenario, the Changamwe Oil Refinery and its facilities are under severe threat from inundation. The area of the island under threat translates to 2.3 Km^2 which is equivalent to 8.2% of the island area.

The extent of infrastructure loss under this scenario would therefore be more severe compared to the optimistic scenario RCP 2.6. The areas affected include

the Changamwe area which carries the main Mombasa-Nairobi highway and the Nyali Bridge as earlier stated, which is the main Mombasa-Malindi highway from the island to the north coast. Should these two road networks be destroyed or submerged as a result of an extreme coastal event, the two hinterlands would intermittently loose their existing connection to the island.

Scenario 2: Under the RCP 8.5 by 2060

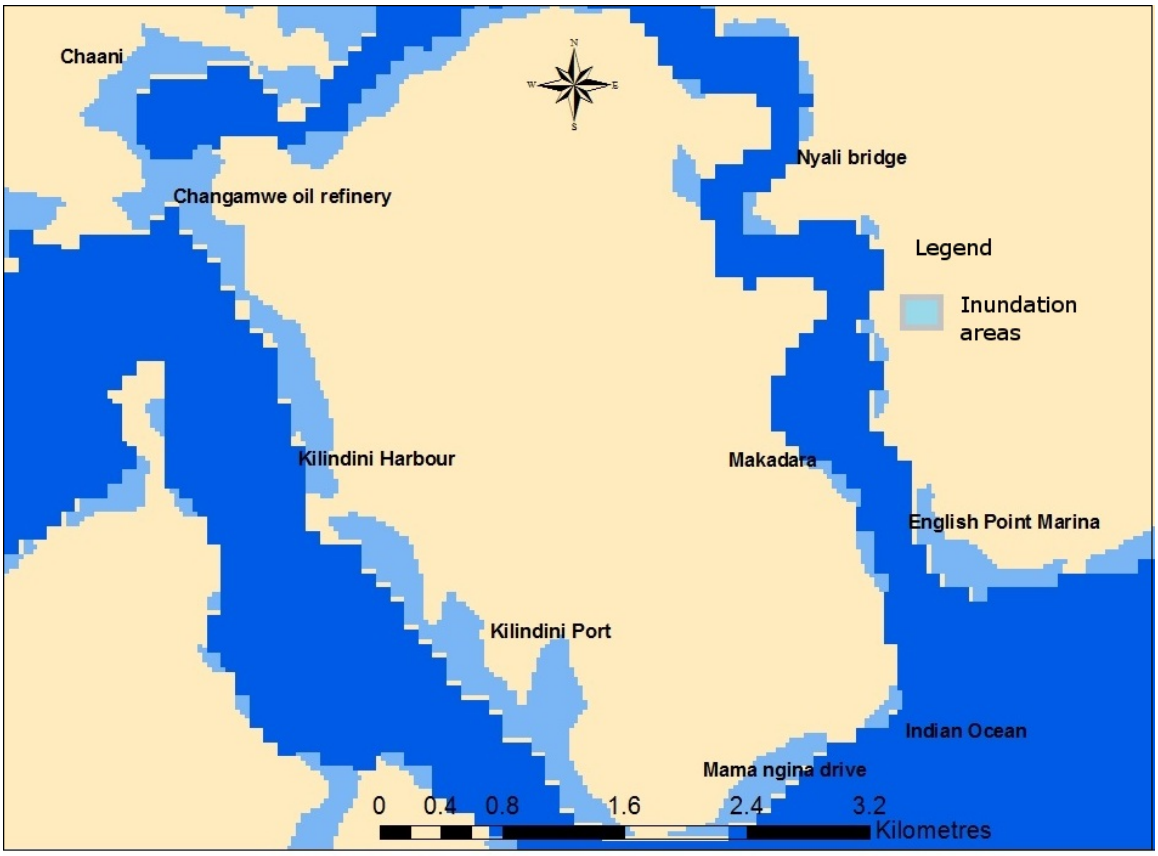


Figure 4.12: Inundation areas for Mombasa by 2060 under RCP 8.5 scenario.

The severity of inundation impacts under this scenario escalates drastically by 2060. The two main highways connecting to the mainland as well as the oil refinery and the port facilities (part of the backbone of Mombasa and Kenya's economy at large) would be prone to inundation. The area under threat would be approximately 2.9 Km^2, which translates to 20.5% thus leading to a total of 28.7% (including the inundation area of 8.2% by 2030).

Scenario 2: Under the RCP 8.5 by 2090

This scenario produces the most severe vulnerability results as the essential infrastructure (such as important main roads, the KPA areas which are important to the Kenyan economy, as well as the three and five-star hotels and residences along the coastal regions) are now prone to inundation. The island area of up to 3.1 Km^2 is low lying and is susceptible to ocean disturbances in the event of a severe coastal storm event, clarified at 1-100 year return cycle. The land mass under threat translates to 21.9% excluding the previous areas affected. This leads to a cumulative area of almost 50% of the land mass under threat from accelerated SLR. The significance of this result is that within 100 years close to 50% of Mombasa Island would be vulnerable to inundation and yet in contrast, hardly any specific SLR awareness or mitigation/adaptation strategies are being pursued either at local or national levels.

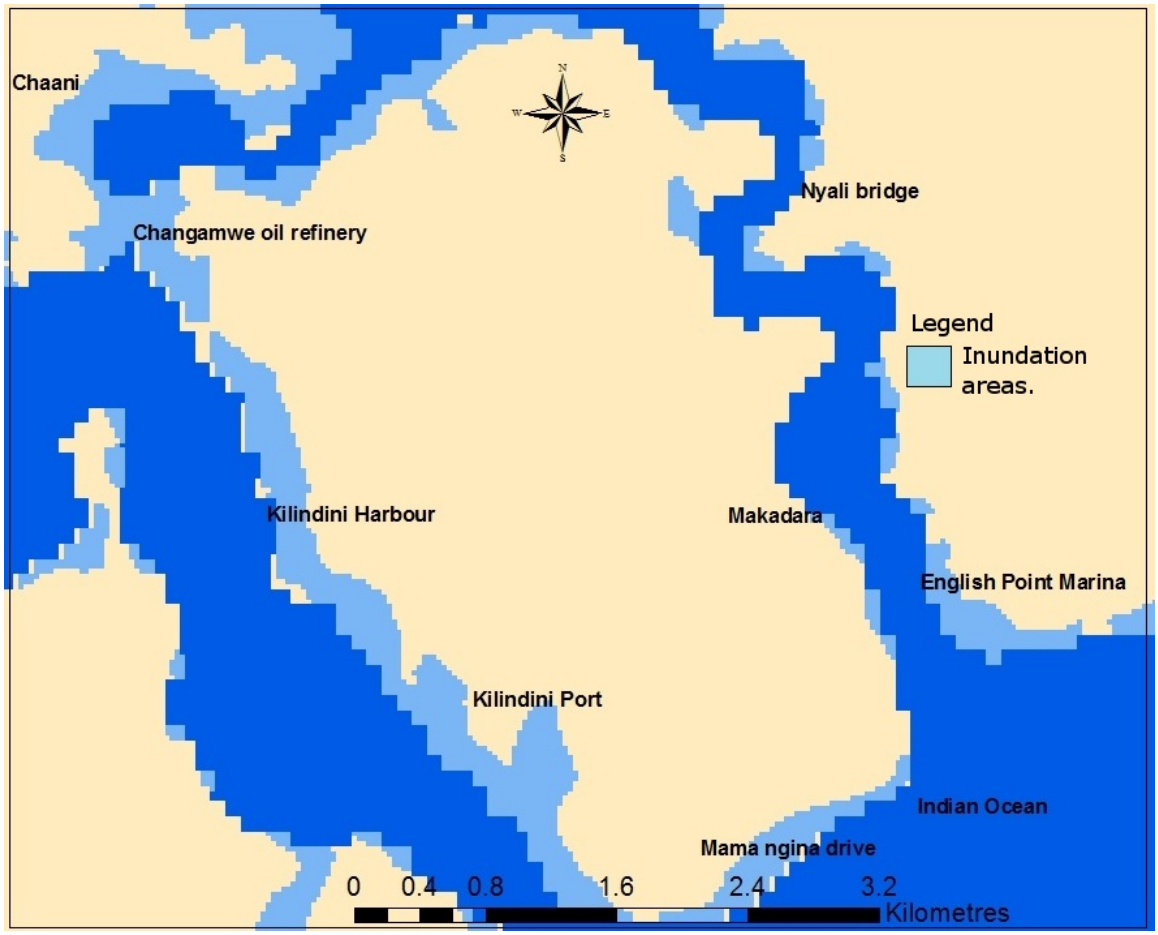


Figure 4.13: Inundation areas for Mombasa by 2090 under RCP 8.5 scenario.

4.3.2 Overview on the main infrastructure and assets under threat from SLR

The asset exposure was done based on Equation 3.3.2 as described in Section 2.4.4 (property exposed and its effect on the counties and country's GDP). The vulnerable areas and infrastructure for Mombasa Island under the RCP 2.6 effects include parts of Kilindini Port and Railways where the current Mombasa Port offices are situated around the Nyali Bridge. The precariously low-lying areas include the area around the Bondeni Estates, Tudor Creek (next to the Technical University of Mombasa) and Chaani informal settlement. Detailed analysis and presentation of the results are discussed in subsequent sections.

Mombasa and Kilindini Port

The port of Mombasa (located at latitude $4^0 04'$ South and longitude $39^0 41'$ East) is currently the only Kenyan international seaport and comprises of Kilindini Harbour and Port Reitz on the east of Mombasa Island as well as the Old and Tudor Port situated north of Mombasa. Kilindini Harbour is naturally deep and well sheltered and is the main entry harbour where most of the shipping activities take place. It has 19 deep water Berths including the new Berth 19, (developed recently at a cost of US$ 66.7 million), two oil terminals and safe anchorages and mooring buoys for sea-going ships.

Mombasa Port not only serves Kenya but is also the main gateway and entry to the eastern African hinterland which includes the landlocked countries of Uganda, Rwanda, Burundi, DRC and Southern Sudan. The port is currently managed and operated by the Kenya Ports Authority (KPA) which is a semi-autonomous parastatal. KPA also manages other small local trade sea ports such as Kiunga, Lamu, Malindi, Kilifi, Mtwapa, Funzi, Shimoni, and Vanga.

KPA also recently invested over US$ 50 Million on the upgrade of the port of Mombasa where the investment targeted new cargo handling equipment and US$ 56 Million Berth 19 project which includes an additional 15-acre staking yard adding a further capacity of 200,000 TEUs per annum. The port is a multi-purpose port with a capacity to handle all types of vessels including container carriers, cruise/passenger liners general cargo carriers, liquid and dry cargo carriers.

The important port facilities include the Kipevu Oil Terminal (situated on the mainland Port Reitz area) which has capacity to handle crude oil tanker, new



Figure 4.14: The new extended Berth 19 of the Mombasa Port: Source KPA 2016.

bulk grain handling facilities, bulk handling and bagged cement, fluorspar, coal, molasses as well as bulk petroleum and vegetable oil. Several private companies including Bamburi Portland, Kenya Fluorspar, East African Storage and Tecaflex have storage facilities around the port and would be severely disrupted by coastal storm surges as a result of climate-change induced SLR.

Changamwe Oil Refinery

Whereas the refinery was initially only storing crude oil, this has recently changed since 2016 when it started refining oil drilled from north eastern Kenya. The site falls within the area under threat from sea level changes and inundation. The refinery facility earns a monthly average of US$ 99 thousands for handling LPG, petrol, diesel, dual purpose kerosene and fuel oil. Due to the delays in the building of the oil pipeline, Tullow Oil (which is drilling Kenya's crude oil in north eastern Kenya), is currently using the facility for refining and distributing refined petroleum products.

Fort Jesus- National Museums of Kenya

The Portuguese built Fort Jesus in 1593, on the southern edge of Mombasa, over a sharp piece of coral rock that is resistant to sea corrosion, and kept it under their control for more than a century. It was built to secure the safety of Portugal's assets/operations on the island as well as the East African coast portion of the sea route to India and the far east. The fort has experienced a long history of hostilities

among diverse contesting parties and business people living in Mombasa and its hinterlands. Probably, no other fort in Africa has experienced such turbulence as Fort Jesus.

The fort bears witness (in its structure and subsequent transformations), to the trade and change of cultural values between and among peoples of African, Arab, Turkish, Persian and European origin as they contested to gain and maintain control over this strategic port. The fort is currently a tourist attraction along the coastline though it lies precariously within the low-elevation coastal zone.

On the 24th October 1962, after completion of renovations to transform it into a museum, the fort became a part of the National Museum under the custody of the National Museums of Kenya. It has therefore been enhanced into an important heritage and tourist landmark along the East African coastal region.

4.3.3 People and activities under threat in Mombasa

Chaani residential area

The Chaani residential area is an informal high-density residential area around the Kilindini Harbour. It is one of the low-income residential areas under threat from the accelerated SLR. As an unplanned settlement with no formal infrastructure, it escalates the vulnerability of the residents as it will become uninhabitable in the event of increased frequency and severity of storms or floods due to SLR. The lack of planning in such informal settlements manifests in a variety of shortfalls/backlogs such as limited road network and inadequate storm water drainage systems which thus undermine community resilience to climate-change-related impacts.

Tourism

Mombasa County hosts internationally recognised five, four and three-star hotels that have enhanced the niche of this city as an international and local tourist destination. Travel and tourism contributed US$ 2.5 billion to the Kenyan economy in 2015, and the tourist hotels in Mombasa are at the centre of the travel and tourism industry in the county. Climate-change induced SLR impacts would severely disrupt this important sector of the economy which is second only to agriculture in terms of contribution to Kenya's GDP.

4.3.4 Summary

Mombasa Island and its port infrastructure, as well as its five and three star rated hotels are vital for the overall economies of eastern and central Africa. The port serves eight countries and has a capacity that places it as the regional leader in coastal infrastructure and tourism for East Africa, coming second only to the Port of Durban in South Africa. In the absence of immediate mitigation and adaptation interventions, this important port will be under threat of increased SLR. Nationally and regionally, the port is crucial in the development and realization of Kenya's vision 2030 as well as the development of the neighbouring countries. More effort has to be made by the county and the national governments towards protecting these critical resources from the effects of the advancing oceans and especially escalating impacts of SLR.

4.4 Projected impacts of SLR for Lamu island

4.4.1 Lamu Island zones under SLR threat

Lamu Island is relatively far more low-lying compared to Mombasa Island such that even the most optimistic scenario shows dire impacts for the island. There was, therefore, no need to run the pessimistic scenario as the optimistic scenario already indicates catastrophic consequences across the 100 year period. The planners and developers of the Lamu Port development project and the related infrastructure thus need to integrate adaptation measures into this major and long-term infrastructure investment program for the city.

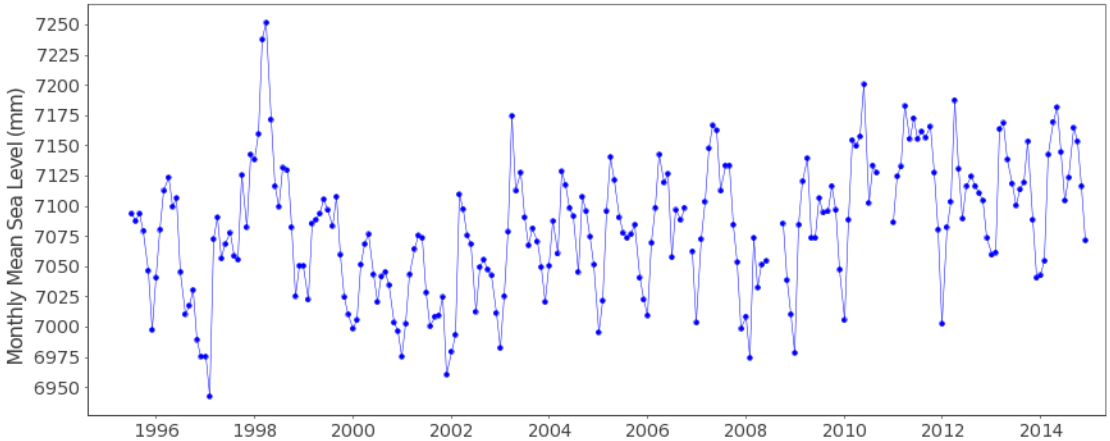


Figure 4.15: Monthly MSL for Lamu: Source PSMSL datasets (2016).

The MSL presented in Figure 4.15 (averaged over the years at the coast of Kenya)

ranges between 6935mm and 7125mm. The overall average HAT for the region is averaged at 4.29m (as extracted from the DIVA website that gives details on the HAT tide that can affect a region at a given time). As earlier explained, the HAT is the maximum tide reading which was corrected with the SLR to develop the inundation maps defined below. As seen in figure 4.16 the MSL ranges between -1 and 4.9m.

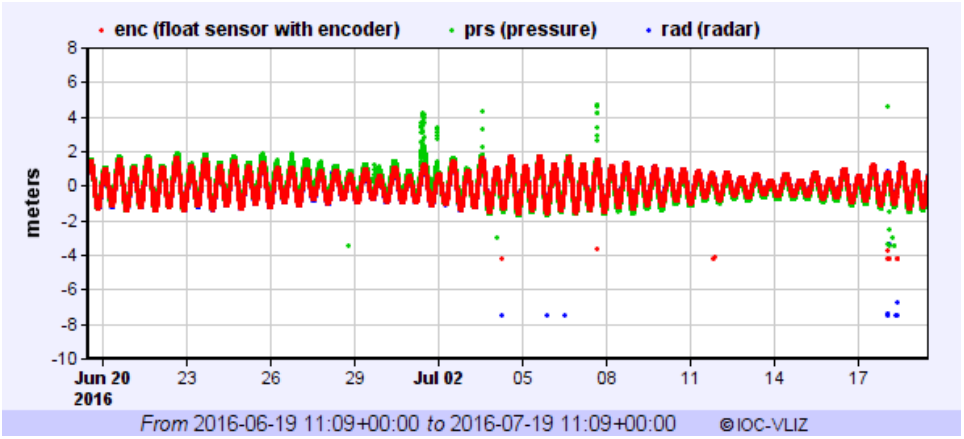


Figure 4.16: Daily MSL Rise for Lamu (For June 19th to July 19th 2016: Source PMSL data sets.

Scenario 1: Under the RCP 2.6 by 2030



Figure 4.17: Inundation areas for Lamu by 2030 under RCP 2.6 scenario.

Lamu Island is precariously low-lying compared to Mombasa Island, with almost 36% of the island being at risk of inundation during an extreme event. Figure 4.17 illustrates the zones and areas under threat by 2030 from increased SLR effects. The scenario indicates the corrected SLR based on the equation developed by Nichols and the IPCC SLR predictions and provides an assessment of the dire impacts even under the most optimistic scenario. The main island within Lamu Archipelago is seemingly getting disintegrated even with a slight increase in sea level.

Scenario 1: Under the RCP 2.6 by 2060

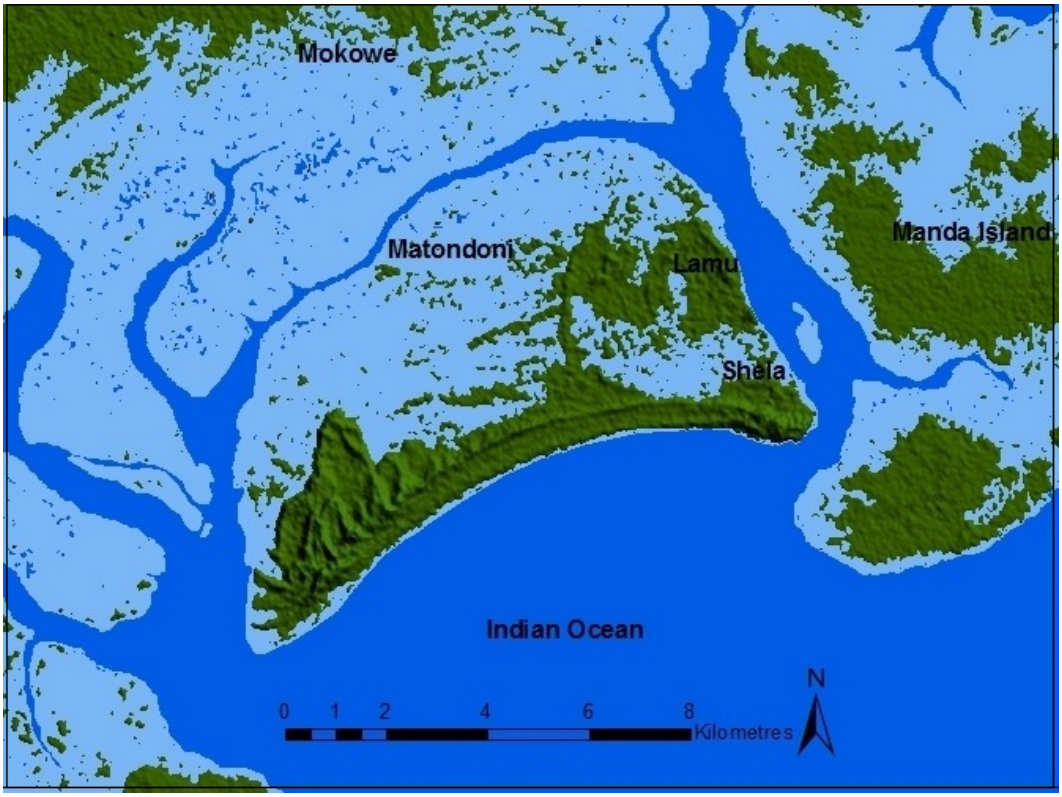


Figure 4.18: Inundation areas for Lamu by 2060 under RCP 2.6 scenario.

As a world heritage site, efforts need to be put in place for the protection of the island from effects of accelerating SLR. Under this scenario and by 2060 sections of Manda Island that hosts the Lamu Airport would be under threat. The mini Manda Toto, currently covered with mangroves, will be completely submerged by 2060. The island area of up to 28.3 Km^2 is low lying and is susceptible to ocean disturbances in the event of a severe coastal storm. The inundation translates to 48.6% of the land mass being under threat from accelerated SLR.

Scenario 1: Impacts under the RCP 2.6 by 2090

Under this scenario the island area of up to 35 Km^2 is low lying and is susceptible to ocean disturbances in the event of a severe coastal storm event, classified at 1-100 year return cycle. The inundation estimates translates to 52.6% of the land mass being under threat from accelerated SLR.

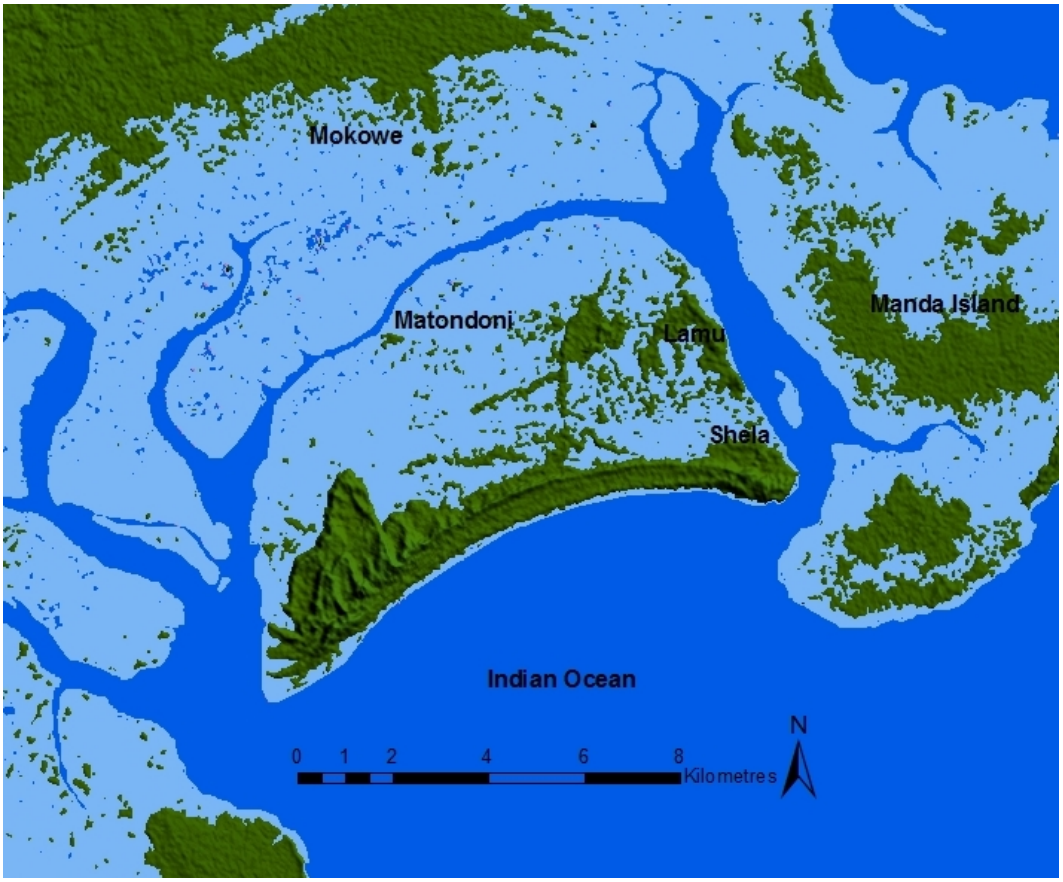


Figure 4.19: Inundation areas for Lamu by 2090 under RCP 2.6 scenario.

Scenario 2: Impacts under the RCP 8.5 for year 2030

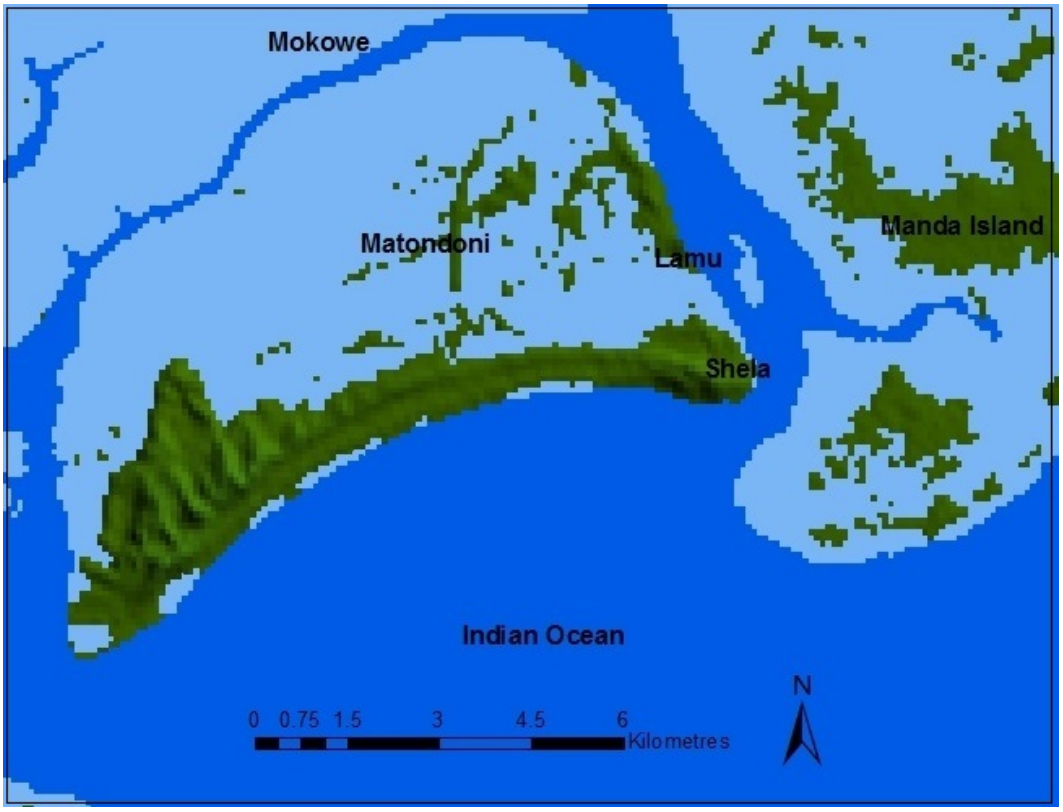


Figure 4.20: Inundation areas for Lamu by 2030 under RCP 8.5 scenario.

Under this scenario, Lamu Island completely disintegrates with the business district facing a serious threat. All the areas within the island, with exception of the Shella sand-dunes will be frequently inundated if climate change adaptation and mitigation interventions are not factored into its planning and development. The key areas under threat include the Amu division itself, areas around Matondoni, Manda and Mokowe.

Scenario 2: Impacts under the RCP 8.5 by 2060

Under this scenario, only a small mound of soil remains around Shella, as the Manda Island and Mokowe become completely under threat. Manda Island, the site for the LAPPSET project, disintegrates into separate mini islands. The airport on the island (the only one servicing tourists to the island) will intermittently be under water. Manda Toto, the small island that is currently full of mangrove forests, will be totally under water as shown in Figure 4.22.

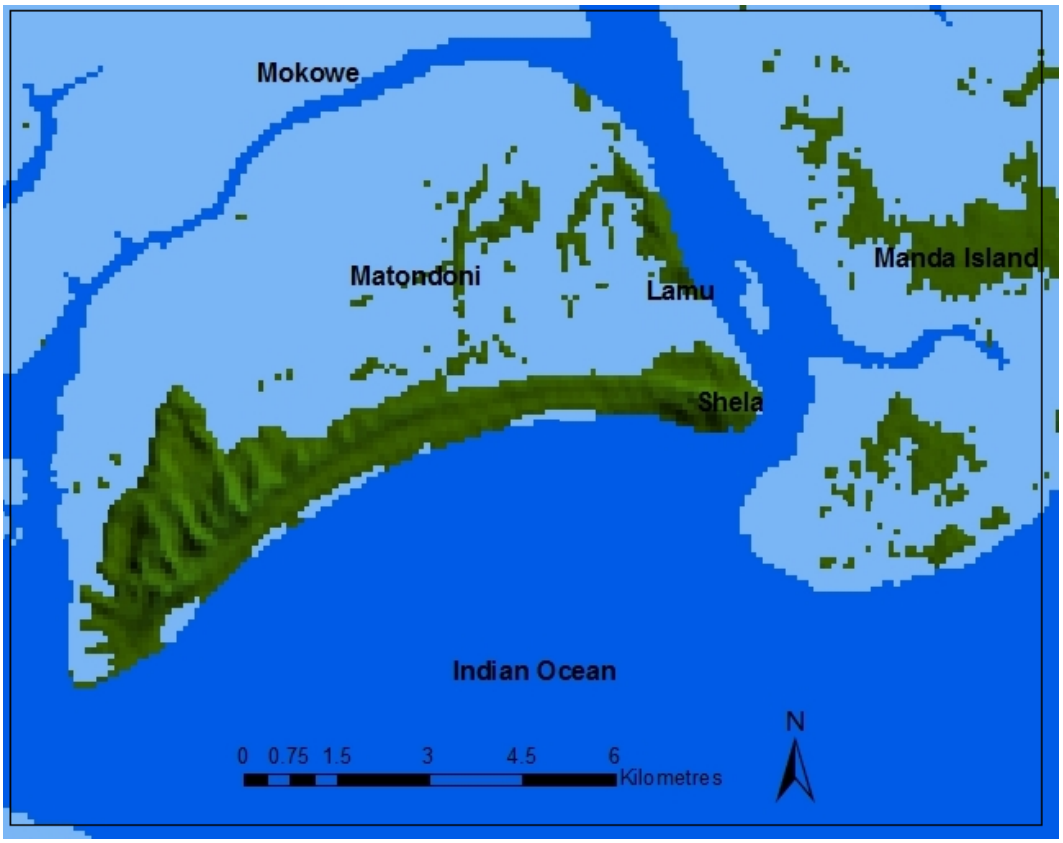


Figure 4.21: Inundation areas for Lamu by 2060 under RCP 8.5 scenario.

Scenario 2: Impacts under the RCP 8.5 by 2090

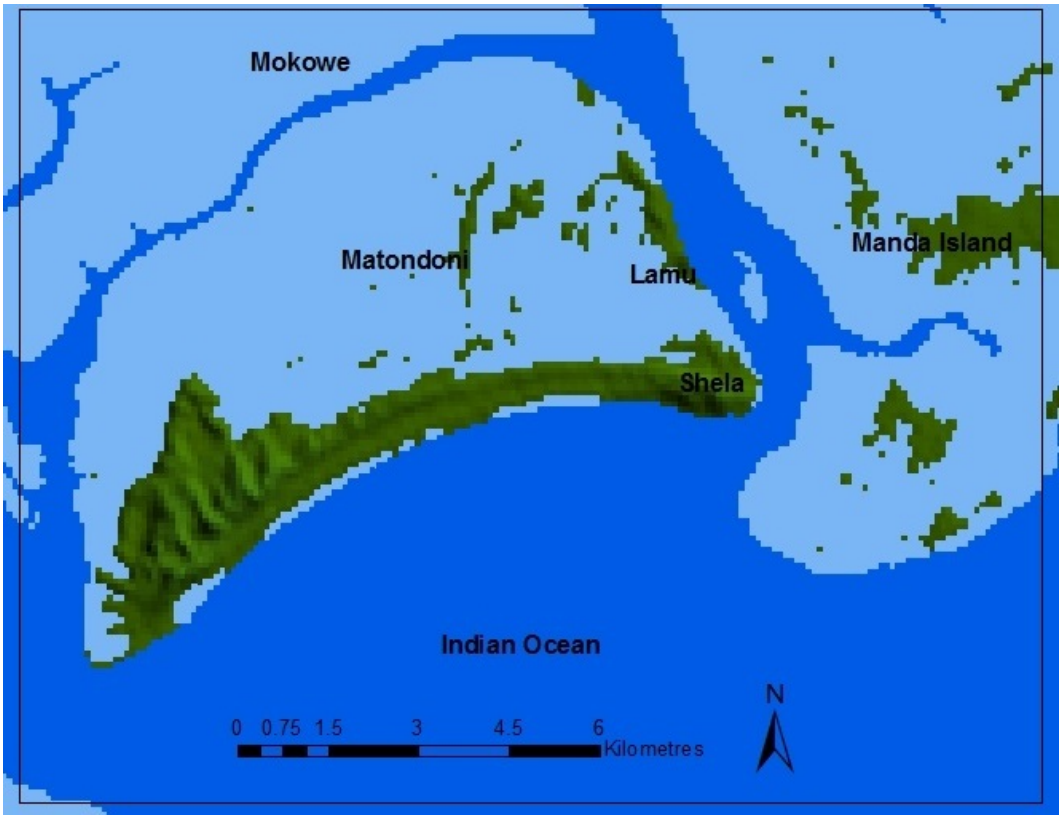


Figure 4.22: Inundation areas for Lamu by 2090 under RCP 8.5 scenario.

By the end of the century Lamu island would have disintegrated into several mini islands with the currently habitable areas becoming uninhabitable. Under this scenario Manda Toto completely disintegrates from the influence of SLR. New islands will be created and added to the archipelago as Manda island separates into two distinct mini islands. The current business district of Lamu will be under severe inundation as well as the new township created out of the ocean dredging. Overall cumulative land area vulnerable to SLR will be 80.1Km^2, translating to 79% of land area under threat.

4.4.2 Infrastructure and assets under threat in Lamu

LAPPSET project

This project (involving eight African countries and budgeted at US$25 billion) would severely be disrupted by the impacts of SLR if adaptation and mitigation measures are ignored. As earlier stated, port infrastructure in Lamu is part of the LAPSSET programme which has several other multiple infrastructure projects linked to it. These include, a railway line from Lamu to Juba (the South Sudan capital) and through to Addis Ababa in Ethiopia, as well as a comprehensive road network and oil pipeline system. Such critical public sector infrastructure projects should be assessed for their resilience in the face of the changing climate and related to SLR. In response, appropriate location or mitigation/adaptation interventions should be incorporated for the protection/resilience of such infrastructure investments.

Lamu hotels and residences

The Lamu archipelago and especially the Lamu Island, hosts some internationally renowned hotels tucked in the beautiful island. These include the Majilis, Kizingo, Kijani and the Peponi hotels among others. The hotels are consistently fully booked during the Lamu Maulidi festivals (Lamu cultural festivals) as they enjoy full view of the ocean. Lamu Island generates a significant portion of revenues from tourist related activities which are now under threat of SLR and thus threatening the economy of this small island county.

Individuals (nationals and foreigners) as well as public and private sector entities/businesses have properties on the island, including private residences meant for the British monarchy. Besides the business premises, the island also hosts communities who inhabit the island with livelihoods based on fishing, boat making, and repairs as well as serving as beach assistants. Such livelihoods are likely to be severely disrupted by the effects of SLR.

4.4.3 Exposed populations and infrastructure

Mombasa Island

The population living within the low-elevation coastal zone of Mombasa Island is expected to increase as shown in the population projections in Table **??**. The growing population means that almost 434,000 individuals will be living within

the zero to 4m elevation areas/zones by 2030. The population currently under threat stands at 219,000 people. When those living within the 6m elevation are included, a population of up to 453,000 become exposed to extreme storm events. The population exposure at the 10 m elevation stands at 954,000 by 2030 which then increases to 9.1 million by 2090. The population exposed is defined in Figure 4.23.

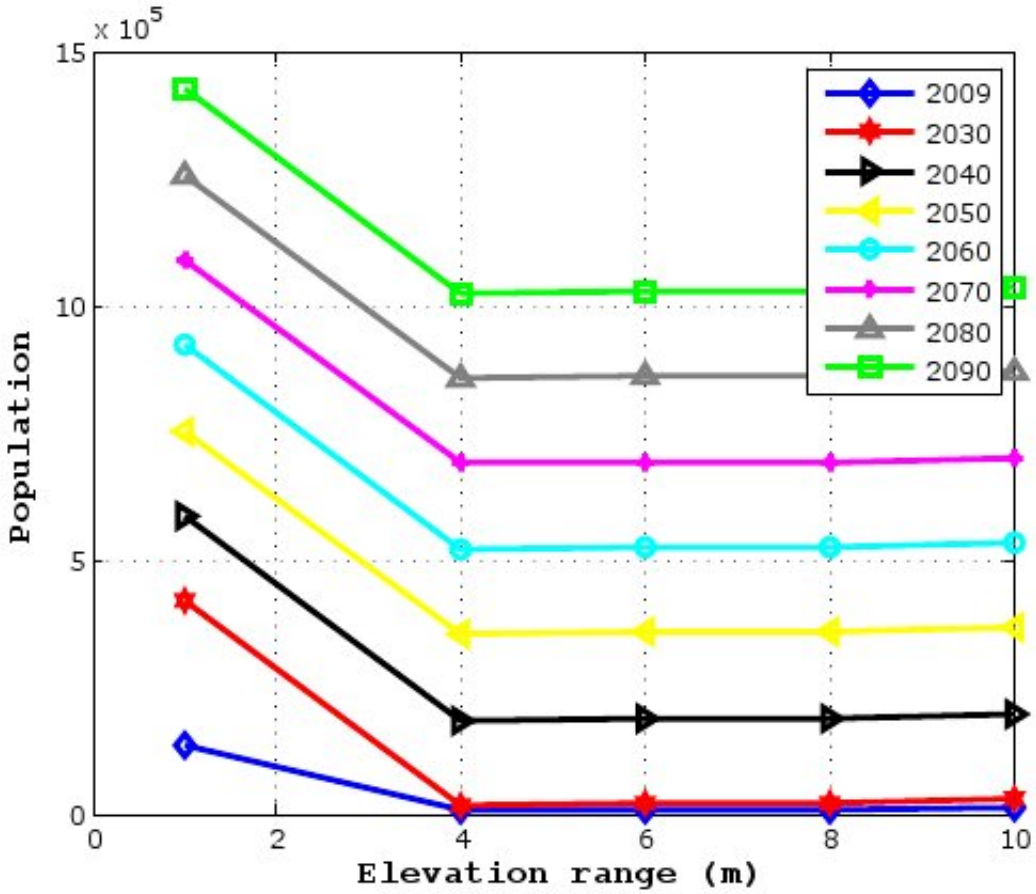


Figure 4.23: Population living within the low elevation coastal zone in Mombasa

Figure 4.23 for Mombasa Island gives an indication of the current and the projected population that will be living within the current elevation levels without the influence of accelerated SLR. The y-axis gives the number of individuals that are expected to be living within the elevation ranges. Generally, the area that will constantly be populated is under an elevation of 4m above sea level. This is typically in tandem with the global figures where most business and residential areas are built in favour of proximity to the coastline, thus increasing the vulnerability of the urban dwellers within this zone.

Lamu Island

Lamu island population living in Amu (the island) are fewer in number and therefore the population threatened is lower compared to that of Mombasa Island. Of the total population of 34,000 living on the island 21,400 people live between zero and 8m above sea level and thus classified as LECZ. The exposed population translates to 63% of the total population. The comparison is defined in Figure 4.24.

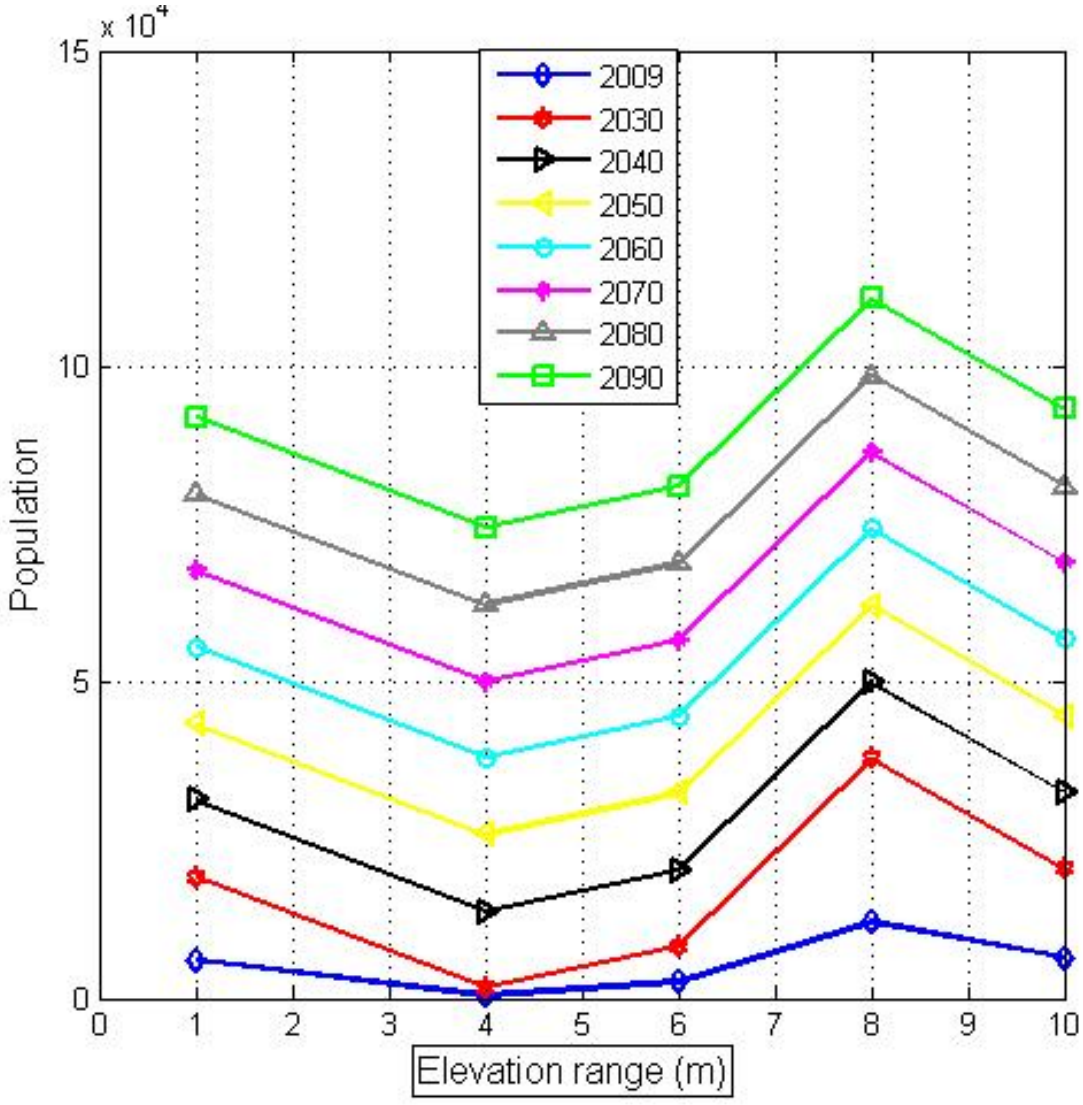


Figure 4.24: Population living within the low elevation coastal zone in Lamu

Figure 4.24 for Lamu island gives an indication of the current and the projected population that will be living within the current elevation levels without the influence of accelerated SLR. The y-axis gives the number of individuals that are expected to be living within the elevation ranges as shown in the x-axis.

Generally, the area that will constantly be populated is under an elevation of 8m above sea level. This is typically in tandem with the global figures where most business and residential areas are built in favour of proximity to the coastline, thus increasing the vulnerability of the urban dwellers within this zone.

Travel

The Lamu community depends on ocean channels for almost all their transport services. This includes the movement of food, fuel for the generators that supply electricity to the whole island as well as commuting from the Island to the mainland. Disturbances to Lamu's coastal waters will leave this community completely stranded unless systematic adaptation measures are integrated into their medium and long-term urban plans. Mini charrette participants from this island identified transportation challenge since they depend entirely on the water channels thus making them overly vulnerable to the effects of climate change and SLR. In this case, both adaptation and mitigation efforts (which do not currently exist) must be planned and implemented to protect this island (which is also a UNESCO world heritage site) including the communities and their assets as well as their infrastructure.

4.4.4 Socio economic analysis

The exposure of critical infrastructure as well as general resources, are the measure of the population and the assets that would be affected by a flood in the absence of protection from floods or SLR inundation. The exposure to coastal flooding in Mombasa was calculated with an intention of illustrating the area of land that would be affected by advancing ocean and thus becoming inundated. This data is analysed in detail in Section 4.5 for both Mombasa and Lamu.

Exposed assets

The exposed population is translated into the exposed assets using the formulae developed by **?**. The equation is applied for the population living within the low elevation coastal zone including the SLR within the elevation areas as well as an analysis of the effect on the country's per capita GDP.

For the analysis of the built environment as part of assets exposure, assets are subdivided into four large groups as identified in Table 4.7 **?**. The asset type were selected based on assets found at the coastline of Mombasa as a factor of net assets that may be lost. The fixed assets is the amount of property, plant and equipment reported on the balance sheet after deducting the depreciation.

Table 4.7: Asset categories used in Mombasa and Lamu.

Asset Type	% **Total value of net fixed asset**
Non domestic building and structures	42
Residential Buildings	36
Equipment and facilities	14
Domestic durables	9

According to **?** the damage that can be caused to each asset is defined based on the elevation and in our case, on the projected sea level scenarios by the year 2030, 2060 and 2090. Table 4.8 gives a summary of the scale of the damage as assessed for Mombasa and Lamu.

Table 4.8: Proportion of damage by asset categories in Mombasa and Lamu.

(Source: Based on guidance in **?**.)

Depth	**2030**	**2060**	**2090**
Non domestic buildings and structures	61	63	69
Residential Buildings	36	38	38
Equipment and facilities	7	13	15
Domestic structures	50	64	68

Mombasa island exposure

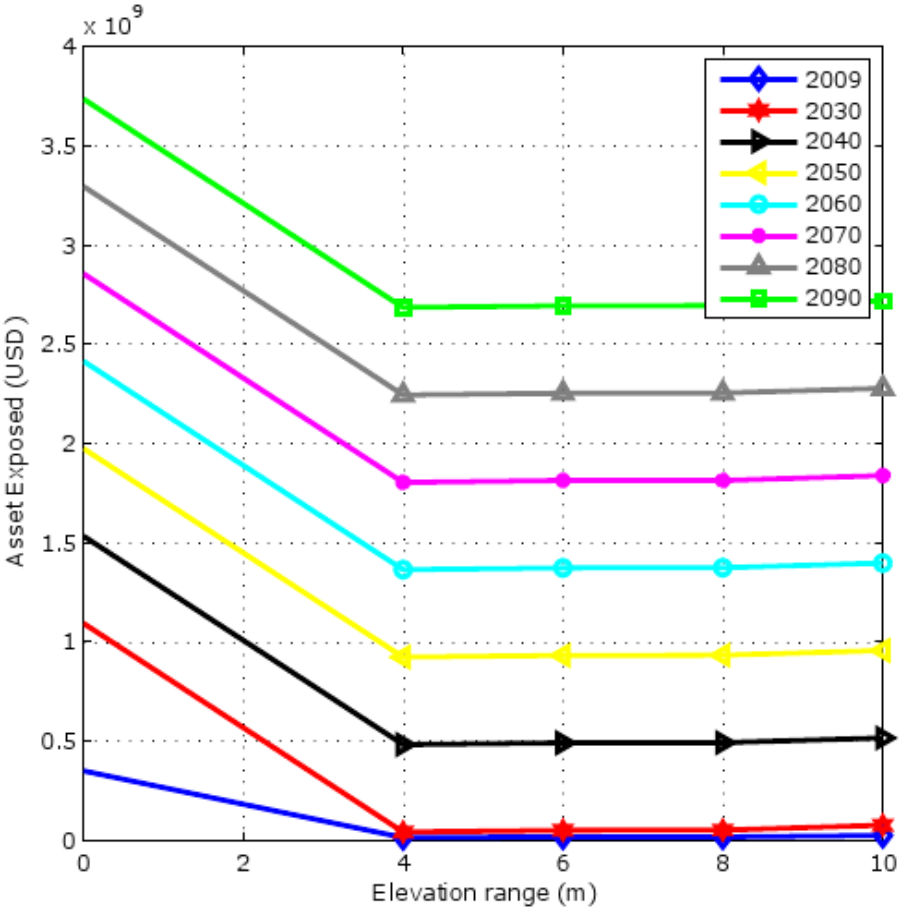


Figure 4.25: Asset exposure for Mombasa island based on an optimistic population growth up to 2090.

Due to the land tenure system on the coast (which is mixed including government owned land and privately owned land portions), the assumption is that few residential homes, personal property, and businesses are insured specifically for SLR impacts. The assumption is that the insured industrial, residential, commercial and industrial exposure is equal to the total exposure to these sectors as illustrated in Table 4.8.

Mombasa's current exposure population ranges from 433,300 in 2030 for the population living within the 4m elevation zone to 1.4 million by the year 2060 and up to 2.5 million by the year 2090. At the 6m elevation level in the exposed population rises to 453,000 by the year 2030, 2 million by the year 2060 and over 3.5 million by the year 2090.

The total exposed population at the 10m elevation levels ranges from 953,600 for the year 2030 and up to a total of 9.1 million individuals by the end of the century.

The exposed/vulnerable population for Mombasa is high and measures to mitigate SLR impacts are critical for the protection of lives, infrastructure as well as assets resources and enterprises.

Lamu Island

The exposed assets for Lamu island at the elevation of up to 6m above sea level puts the county losses to between US$ 5.12 million and an exposed population of 29,000 people by the year 2030. The asset exposure at the island stands at US$ 17.96 million by the year 2090.

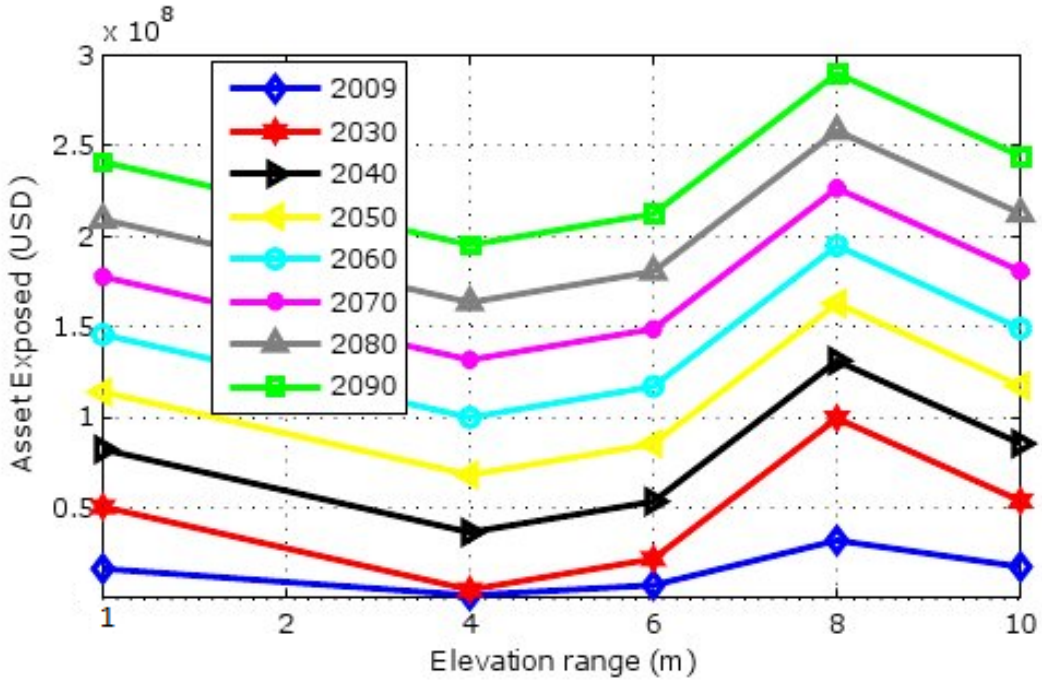


Figure 4.26: Asset exposure for Lamu island based on an optimistic population growth up to 2090.

By the same year a population of 101,900 will be vulnerable and property and infrastructure to the value of the US$ 25 million under the LAPSSET project will also be exposed. The total asset exposure is in the range of US$ 5.12. billion at the 10m LECZ. The asset and population exposure increases drastically when the 8m to 10m elevation ranges are included.

4.4.5 Summary

The key findings from this section have been summarised in Chapter 6 (see Section 6.1) towards the derivation of consolidated findings and conclusions while the key highlights are summarised in the table below

Table 4.9: Summary of spatial extent and SLR impacts on infrastructure, assets and people under RCP 2.6

Scenario	2030	2060	2090
RCP 2.6 Mombasa Island	• The most optimistic scenario and 0.5Km^2 under threat • Areas affected include Changamwe refineries, Kilindini and Mama Ngina • Population of 433,300 is exposed and threatened by inundation • The assets exposed in an extreme event under this scenario is US$ 1.1 billion	• Areas threatened include Makadara, Chaani residential, Old Town and Fort Jesus • Others include KPA offices and bays, Kizingo residence and Mtongwe channel • Island area of up to 1.4 Km^2 is low lying translating to 10% of the land mass falling within inundation zone • Population of 1.43 million is exposed and asset exposure sums up to almost US$ 3.8 billion	• Areas affected include railway's, State house premises on Mama ngina drive, the Kizingo residence, The Nyali bridge, Tudor creek and Mtongwe channel • Island area of up to 2.3 Km^2 (12.1%) is low lying • Population of 2.6 million people are threatened • Asset exposure is US$ 6.4 billion
RCP 2.6 Lamu Island	• Area of 36% of the island is at risk of inundation • Threatened areas include the Amu division Manda Island and Matondoni • Populations under threat is up to 21,000 persons • Assets under threat add up to US$ 54.5 million.	• Increased threats to Manda Island, Lamu Airport and Manda Toto • Area of up to 28.3 Km^2 is low lying and 52.6% of the land mass is under threat from accelerated SLR • People living within this zone are up to 93,700 • The asset exposure adds to almost US$ 251.2 million	• Lamu Airport and Manda toto will be completely be submerged • Island area of 35 Km^2 is low lying and translates to 60.4% of the land under threat • Others include the site for the LAPSSET project offices and bays, Lamu hotels and Amu town • Projected population of 167,000 will be living within the danger zone and exposed assets are towards US$ 435.8 million

Table 4.10: Summary of spatial extent and SLR impacts on infrastructure, assets and people under RCP 8.5

Scenario	2030	2060	2090
RCP 8.5 Mombasa Island	• Areas threatened include Changamwe refineries, Kilindini Nyali Bridge English Point Marina, and Mombasa State House • 2.3 Km^2 equivalent to the 8.2% of land area threatened • Population of 453,000 is exposed • The asset exposed adds to US$ 1.2 billion	• The areas around Makadara, Nyali Bridge, Chaani and Kizingo residence in changamwe, English Point Marina, Old Town and Fort Jesus are vulnerable • Island area of 20.5% equivalent to 2.9Km^2 is under threat • Population of 1.97 million people will be living within the inundation range • The asset exposure is estimated at US$ 5.2 billion	• All the critical infrastructure on the Island is under threat • New areas threatened include the Bondeni estates, Tudor Creek, KPA, Mtongwe in Likoni and area of 3.1 Km^2 is low lying translating to almost 21.9% • Population living within this area is about 3.5 million people • The asset exposure is estimated at US$ 9.1 billion
RCP 8.5 Lamu Island	• The scenario disintegrates most areas in Lamu island • Key threatened areas include Amu, Matondoni and Mokowe • Other areas affected include the Manda Island • Populations under threat equivalent to 29 000 persons and assets under threat add up to US$ 76.1 million	• Manda Island, Lamu Airport and Manda toto increasingly threatened • Area of up to 28.3 Km^2 is low lying • Area threatened translates to 52.6% of the land mass and population of up to 138,300 threatened. • The asset exposure adds to almost US$ 362 million	• Manda Toto completely disintegrates and separates into different Islands • Other areas under threat include the Amu division • Populations under threat add up to 247,500 persons • Assets under threat sums up to US$ 648 million

Chapter 5

SLR risks and community perceptions towards co-production of mitigation and adaptation strategies

"Is it true that modernization the sum of technology development, improved infrastructure, and transport systems, financial and information efficiencies, and globalisation increases the vulnerability of cultural systems?". **?**, .6

5.1 Introduction, chapter structure and data overview

5.1.1 Introduction

The analysis and presentation in this section differs slightly from the previous scientific analysis method as most of the data presented are mainly qualitative data based on the comparative results and narratives from the mini-charrettes of the two islands, as well as the appraisal of the discussions which were video, recorded during both mini-charrettes processes.

As earlier stated in Section 3.1.2, the data were collected through a mini-charrette process where themes were identified for the participatory process in each island and constituted the focus of the discussion with regards to climate change. The second forum then provided supplementary data which included the comments from the general public on the on-line blog and the media coverage of the initial stages of the research. These observations are also included as part of the community perceptions and responses to the risks associated with coastal planning and accelerated SLR.

5.1.2 Chapter structure

Chapter four was dedicated to inundation extent due to SLR and the projected areas/assets at risk. This chapter is devoted to data collected from the mini-charrette process and the analysis of the community participation including their perceptions of climate change and especially SLR and their transformed readiness to act due to enhanced awareness created from the process. The chapter addresses the third and fourth research questions on the role of participation in scientific-based studies and the significance of participatory methods in influencing perceptions and empowering the concerned stakeholders/communities to act towards adaptation and mitigation interventions (strategies and their implementation).

The chapter also describes the areas, populations and activities that are important to the coastal community members who are at risk from accelerated SLR, the changes they are currently experiencing concerning climate change, the responses as well as ideas for improvement, communication, and knowledge sharing. The chapter also appraises the communities' perceived steps towards adaptation as well as mitigation. A collective summary of the results is then provided followed by related sub-findings and conclusions in response to the third research question on status quo vulnerability and awareness and objective three on perceptions before and after enhancement of awareness.

5.1.3 Data overview and presentation

Mombasa and Lamu community participants in the mini-charrette were from two distinct communities. Lamu participants were primarily residents of Swahili settlements while most of Mombasa participants were a mixture of both local and international residents participating in business activities at the Kenyan coast. The participants' communities fall under their respective counties and governed by a senator, governor and a county government. Further background details on these communities are provided in Table 4.2, Table 4.1 and Table 4.3.

The initial discussions took a general format of climate change impacts especially those unique to SLR and related awareness. Participants for the mini-charrette process were identified and selected as discussed in Section 3.4. After the general group discussions in the mini-charrette, a one-on-one video chat with team leaders on the subject of SLR was done and the proceedings were incorporated into the debates. An interview with the county planners for both the county of Mombasa and Lamu was done to ascertain their level of awareness and inclusion

of communities in climate change-related adaptation strategies and especially SLR. The oral discussions are reported in the chapter 5 and 6.

The sequence of data collected and the presentation/analysis done was in the following format;

- Climate change and SLR status quo awareness for Mombasa and Lamu island
- Improved responses and adaptation to climate changes after mini-charrette
- Post mini-charrette steps towards mitigation and co-produced adaptation policies
- Conclusions

Community members who participated in both mini-charrettes had a good understanding of climate change. What the discussion identified was that the general atmospheric change aspects were part of life and to an extent, participants have been engaged in some forms of adaptations already such as the use of short season seeds to preserve agricultural productivity.

The data and description of variables

Instead of singly generating data content from the breakaway groups, data was initially made from the joint panel discussion (see appendix D) where the main question was the status of climate and its effects on the relationship with the participants. The solicited views from the general debate groups on the general effects of climate change at the coastal city was then divided into themes and classified under the most abundant item of the process as seen in Table 5.1. The classification of the topics was based on the link to the environmental resource (in this case the ocean) and how they related to it. These themes included the status quo on climate and tourism, fishing as a joint income earner for them, environmental challenges related to coastal environments as well as the social aspects that define their relationship with the ocean for their daily lives

The second phase was data extraction from both the breakaway groups and the general assembly. Data collected from the breakaway groups which included the assembly then discussed video recording and group work at the end of the day. The data analysis was also themed under specific climate-related themes which included the effects of SLR felt, the role of county governance (see for example Table 5.2 and Figure 5.1) and SLR related interventions. Besides the common effect of SLR, the

principal theme included their opinion on their relationship with how to improve adaptation and mitigation measures within their respective communities. This extraction of the data then facilitated the discussion on both the verbal and implied relationship between SLR, sea perturbations and community response mechanisms.

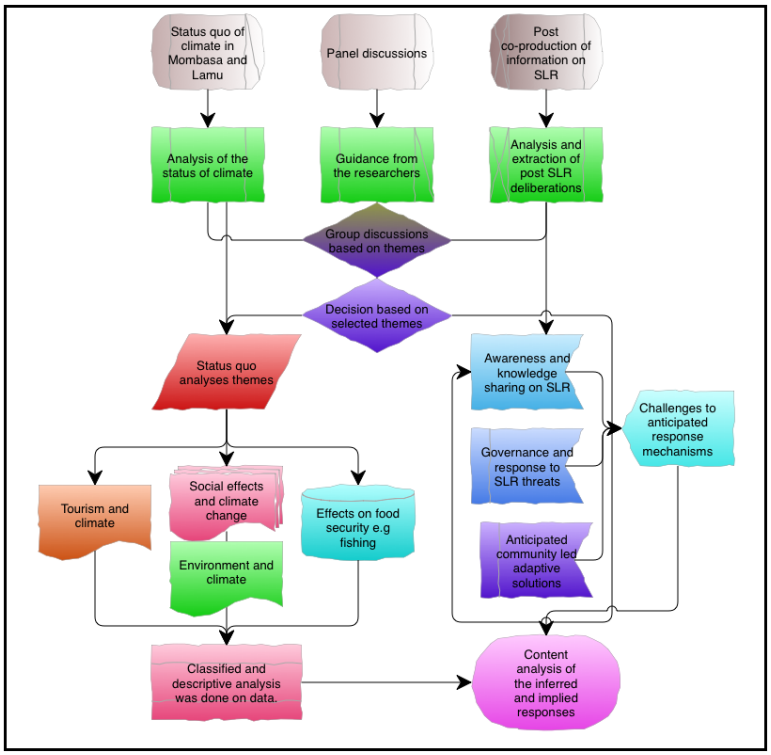


Figure 5.1: Data extraction and analysis based on thematic classification

5.1.4 General introduction to climate change and SLR

During the introductory meeting in Mombasa and Lamu, participants had initial discussions under guidance from the facilitator on the general issues affecting coastal communities that could be related to climate change (see appendix D page). The participants gave their views as summarised in Table 5.1. The general insight was that climate change is already affecting their normal lives. This could be related to the dwindling fish options as some species which were previously abundant have now become hardly available as well as the increased heat and tidal waves. The awareness of increased coastal disturbances was attributed to the frequent warnings from the meteorological department against going to the beaches because of stronger tides. The discussion initially explored the general climate change perceptions as identified during the early hours of the charrette, and then narrowed down to SLR and its possible impacts.

Most of the problems generated in the initial part of the discussion traversed

across all the aspects of SLR, especially the encroachment of coastal waters into neighbourhoods with tourist hotels in Lamu Island and Archipelago in general being one consistent example. Other factors that came up that are related to SLR included the disturbances caused by robust and high tides. During such seasons most activities at the beaches and coastline are halted. This includes transport and especially fishing activities which are mostly disrupted. The example in Lamu is presented in Figure 3.5 where the high tide flooded the single and main highway used for transportation activities. As identified by participants from this island, this trend is increasing especially during the April-May long rain season as well as September and October short rain season.

5.2 Status quo SLR and climate change awareness and perceptions.

During the mini-charrette, the study sought to identify the initial level of awareness of the participants with regards to climate change at the coast, especially SLR. The participants from the two communities were able to discuss their awareness of SLR. Understanding perceptions held by individuals and different communities is significant and vital to the process of building effective mitigative structures and behaviors to reduce vulnerability while also building resilience to identified risks (**?**). **?** and **?** posits that there are three broad categories of responses to risk which are denial, apathy, and transformation. Specific perceptions of risks and the resulting responses can be categorised into similar categories.

According to **?**, .333, the key responses regarding awareness and perceptions to SLR can be categorised as follows:

- The perceptions and community understanding of their vulnerability and what role they can play to reduce such vulnerability affects their perceptions and response action
- The normalcy bias and denial are aspects that greatly affects perceptions of risk, effectively resulting in a lack of efficient planning and preparedness as well as emergency evacuation methods
- Apathy and lack of involvement from the community members themselves with regards to a community threat greatly hampers adaptation techniques as they would prefer to leave the status quo as is

- The feeling of safety and the advantages that come along with staying at low-lying elevations especially in coastal areas provides a false sense of security, reducing the need for climate change-related adaptation and awareness initiatives

These factors are described in the preceding subsections

5.2.1 Participants' understanding and acknowledging of SLR

Participants in both Mombasa and Lamu had varying levels of awareness/perception of climate change while also demonstrating a critical gap in awareness of SLR impacts on coastal cities. Community vulnerability to climate change is a function of the physical attributes of the climate-related event and the characteristics of the community impacted (**?**). Recent studies (**?**) have emphasised that a community that is aware of threats that they are likely to face are more inclined to develop adaptation and adaptive capacity in mitigating climate change impacts and community vulnerabilities to related threats such as SLR.

This was clearly not reflected among the participants of the two mini-charrettes. Whereas Mombasa Island participants seemed to understand the consequences of coastal disturbances, they could not link it to climate change specifically nor to SLR. Participants in Lamu were wary of the SLR and climate change debate insisting that the subject has been developed by specific individuals in need of funds for their NGOs.

Community perceptions and land ownership issues

Perceptions here are defined as the rational way in which individuals and communities understand flood risk as born out of available knowledge and previous experiences of such events. Perceptions of risk play a significant role in how people engage in current events and future risks (**???**). Risk and vulnerability to negative events are perceived differently by individuals and different sectors of society especially because the impacts of these developments are not homogeneous across urban areas, within communities, households or individuals (see Appendix C on the themes of the charrette that generated the answers).

Table 5.1: Socio-ecological changes experienced by mini-charrette participants in Mombasa and Lamu islands.

Impacted sectors	**Climate changes and effects**	**Adaptation/Mitigation response**
Fishing	• Reduced fish stock • Altered diets • Less sea foods • Loss of business • Changing fish species	• Rainfed agriculture • lobby government for local control • Provide deep sea fishing equipment • Alternative income activities • Restrict fishing rights
Tourism	• Reduced tourism visits due to changing weather • Increased coastal hotels reducing leisure time and space • Closure of some tourist hotels due to flooding • Reduced tourism business on nature trail as mangroves are reducing/increasing • Limited business gains from water sport activities	• Diversification of resources as an adaptation measure • Lobby government for local control of available resources • Coastal protection measures to be synchronized • Incorporate more conservation efforts and include the communities • Targeted government initiatives at the coast
Social issues	• Reduced tourism along the coast • Reduced livelihood options for the poor due to dwindling mangroves • Increased idle times leading to society vices as opportunities keep shifting • Increased competition over the few and stretched communal resources • Increased climate change related flooding	• Rainfed agriculture as supplement to beach activities • lobby government for local management and control of resources • Provide deep sea fishing equipment and cooling facilities to reduce dependance on Government • Alternative income activities • Improve communication and local participation in governance
Environmental issues	• Reduced forest cover as mangroves are reduced along the coast • Reduced livelihood options for the poor due to dwindling mangroves • Less mangroves (Mikoko) for building purposes • Beach changes due to increased infrastructure • Increased climate change related flooding	• Conservation and the co-management activities to be improved by the government • Resource diversification especially building materials • Protection and deliberate conservation to target specific threatened areas • Planning and development control should be effected • Improve communication and local participation in governance

As argued by **?** and **?** one's previous experience of a disaster influences the perception of future risk thus influencing immediate and long-term preparedness for responses. Mombasa Island residents have had some experiences of escalating ocean disturbances and aftermaths of Asian tsunamis that left several people dead and property destroyed. There is thus a higher sense of the dangers involved in human interactions with the sea.

A planner in Lamu Island gave an example of how, especially business people and community members, have seen the ocean advancing on them in their own lifetime. As he narrated,

> "*Some people have title deeds that are part of the sea since they were given the land its mainly under waters during the high tide*"

.

With this kind of alluding to encroachment of the sea, some participants still held their title deeds of areas covered under water assuming that it is a short-term process that will soon end. Some were convinced that the ocean interference is only possible during high water tides and will recede back to normal after some time. Some participants, however, were getting worried that the natural state of low and high tides are drastically changing and the normal thresholds are frequently being exceeded.

Evidence of encroaching sea is said to be now evident around Lamu Island as alluded to by several people who are moving inland away from their homes around the ocean due to the ocean disturbances(Appendix C gives the source of the answers). However, there was a prevailing perception that this is a short-term disturbance that will soon end. The participants believed that such events would normalize eventually and they will resume their activities and also be able to return to their homes around the coastline. During the mini- charrette, participants concurred that most of them are taking personal initiatives such as putting up sea walls to keep the "high Tides" at bay. The walls are meant to protect their properties, with little understanding that SLR impacts include an increase and continued wave strength and higher tides, and this will only increase especially under the pessimistic scenario of increased GHGs.

Engaging participants to reflect on their understanding and awareness of vulnerability to SLR and their perceptions of extreme climate events across the various fields is essential towards addressing the increased risk of SLR and

facilitating a deeper understanding and questioning of their individual perceptions towards threats associated with SLR. Communities are empowered through acknowledging their experience and social networks in the construction of locally specific solutions to external threats, risks or even shocks once unfortunate events have occurred.

? draws attention to the importance of communities and shared social responsibility. Communities in the affected areas can protect themselves from climate-related shocks especially SLR through sharing of available and relevant information and knowledge. The greater willingness of the public, especially through building social networks and structures can help them prepare for and cope with related impacts.

> "*people learn about doubtful events about hazards from intimate experience than from being provided with a description of the conceivable outcomes and their likelihood.* **?**, *.6*"

For instance, a community that has recently been affected or seen the evidence of a flood or a tsunami is more likely to take preventative action against future flooding, than people that have never experienced a flood. As a result, anticipatory adaptation efforts at the community level tends to be most effective when they are carefully referenced to the community's perceptions and priorities as the community members can more efficiently take ownership and responsibility for such actions. Planning for helpful strategies to reduce future risk is unlikely if the immediate threat to survival is high (**?**). Unless the task of addressing climate-related risks start to be viewed as a priority in a community's day-to-day lives, it is unlikely that responsive interventions will be taken by the such communities.

5.2.2 Participants' denial of SLR.

Participants in both islands were categorical that the issue of SLR is not a critical issue. They contested its existence and suggested that the subject has been coined by unscrupulous researchers and non-governmental organisations to deny them a chance of creating substantive businesses and leisure opportunities at the coastline. Instead, participants blamed the NGOs and their related networks for peddling non-existent half truths and threatening the peace and tranquillity of the community members along these coastal areas.

Another participant highlighted the lack of trust in the research organizations who

were viewed as not giving proper feedback. There was therefore concern that scientists are propagating false views and thus noted that:

> "*Why do fraudulent experts keep on repeating this story. We all know that Netherlands is below the sea level and still a powerhouse.*"

This lack of trust by the stakeholders on researchers' ability to offer proper guidance/analysis is seen as another impediment to the development of adaptation and mitigation techniques. In this scenario, however, the member was quickly responded to by another who expressed concern that the government cannot even provide essential services for a large proportion of its population in Kenya and would thus be difficult for the same government to tackle an environmental problem.

> "*Exactly it is the Netherlands, and we are in Kenya ... we are struggling in poverty as a country and hardly have enough money to guarantee proper security and education, how then do we expect to be protected from climate change effects.*"

In the light of this, governance in climate adaptation needs to ensure participatory risk analyses geared towards the prevailing perceptions of risk and resilience to related impacts (**?**). City management should therefore encompass impacts of climate variability, through participatory approaches in all phases of preparation including baseline mapping/assessment, response planning, corrective action implementation and recovery strategies/interventions.

5.2.3 Apathy and lack of community participation

Mini-charrette participants' in both case studies identified negative community attitudes as contributing towards increased local vulnerability. Some of the more localised comments included the difficulty of getting local people to participate, their inability to work together and to agree on issues that affect them and how to secure support in such circumstances. Participants demonstrated a sense of apathy through citing people's unwillingness to stand up for urgent matters and lack of conviction especially when it comes to standing for or defending a standard course or resource.

Nepotism and regionalism, as well as general disrespect for the land and natural resources, were highlighted as key factors which hampered collective effort in

understanding dangers that may be posed to them due to SLR. Such factors included the perception that it is mainly "outsiders" who are drumming up support for climate change and SLR and in most cases, it is done in the sanctity of boardrooms away from the communities. They therefore perceived the issues of climate change and SLR as an indirect method of denying the local community members from engaging in meaningful business practices. Additional factors that lead to apathy include the numerous and ongoing corruption as well as skewed information on SLR within the county government. This was identified as the main reason community leaders sometimes became oblivious when community members call for action on issues affecting them.

Continued remarks regarding nepotism within the county, coupled with the poor management of resources led to poor planning and subsequently to resource depletion. The result is that the communities who are directly threatened are no longer keen on social issues which thus reduces their resilience and also increases their anger. Several examples were cited where ordinary community members are already overwhelmed by livelihood and survival concerns while equally being frustrated by the inability of the available governance systems to protect them from the multiple threats facing them. In most cases, unforeseen eventualities like flooding leave many of these low-income households and communities suffering heavy losses on their meagre hard earned resources and assets.

Participants in Lamu expressed a different scenario compared to their counterparts in Mombasa. Whereas Mombasa Island communities are used to alternative sources of income, Lamu Island communities mainly eke out a living from the ocean waters through activities ranging from transport to fishing. The fact that Lamu communities have fewer options for adaptation due to the limited income generating activities, participants thought of them as extremely vulnerable from the effects of climate change impacts such as SLR. The lack of support, especially from the government makes it even harder for the communities to initiate and sustain their locally driven adaptation initiatives.

The situation in Lamu is almost changing, and this elicited different feelings from the participants. For example, the multi-billion dollar LAPPSET project is a government-led initiative being touted as the economic high point of the Lamu archipelago. The project aims at improving the general ability of the communities around the archipelago to be self-reliant, economically strong and thus deal with the risks facing them. However, participant views were that the communities feel

otherwise. As an example, energy options have stirred a debate on the island as the need for electricity is again eliciting negative feelings after the government signed a deal with the Chinese company to provide coal energy plant to power up the port development project.

Though completely unrelated to climate change or environmental changes, unresponsive attitudes, partisan corruption, disrespect to both regional communities and essential resources as well as a lack of cooperation between the communities and government agencies only serves to undermine inherent strengths in communities ability to manage catastrophic events and thus effectively weakens social cohesion. In turn, this erodes human capital and the effectiveness of decision-making and action within communities toward commonly shared goals and plans such as preparing for and adapting to climate change impacts.

Several initiatives by community-based organizations towards better stewardship of their resources and especially the ocean have failed to take off. **?** describes the importance of the wrong relationship between population increase, the need for urbanisation and the necessary proper development to manage the urban environment disintegrates communities and exposes them to danger. They are more vulnerable to shocks while at the same time experiencing the inability to integrate for resilience through social cohesion due to the lack of development conscious governance and in this case awareness of the impacts that may befall them.

5.2.4 Low lying areas are not at threat

The participants in the mini-charrette process were of the opinion that living next to the ocean is not a problem, as it has been done by their parents and many previous generations. Most of the Island area in Lamu have communities living adjacent to the ocean and using it as both the residential and the business premises. The situation is different in Mombasa with most of its beach front areas hosting internationally recognised hotels and luxurious apartments beside the business premises. The case in Lamu island is a little different. The participants felt that being close to the ocean is no problem at all and in the event of a high tide, children and community members get the fun out of the ocean waters next to their doorstep. Most of the participants fancied living in these areas and accessing beach fronts at any time and thus with no serious regard to the dangers that this may pose to the communities.

One on-line blog respondent succinctly claimed that *"We all know that Netherlands is below sea level, and still a powerhouse"*. The perception of risks associated with such low lying areas is still low in communities within both islands who seem to remain trapped within the normalcy bias of "business as usual" along the coastline. Whereas the environmental and government organisation respondents expressed relevant perception and awareness of climate change they face major difficulties in trying to control populations and developments on the Kenyan coast especially in Lamu Island.

5.3 Enhanced awareness and perceptions of climate change and SLR after mini-charrette

The appraisal of community awareness and attitudes demonstrated several challenges which include inadequate levels of understanding of the process of scientific knowledge production (the science) and needed/required application, to enhance community awareness. The key finding is that the integrated research process facilitates for improved levels of knowledge and understanding arising from knowledge sharing and thus facilitating innovation and readiness for adaptation and mitigation action/strategies. The section presents the ideas developed based on an improved understanding of SLR and how the participants can enhance locally based adaptation and mitigation strategies for their communities. The discussion was facilitated through the two key themes of status quo awareness and perception changes. The key findings were as follows:

- Participants acceptance of climate change and SLR was evident
- They concurred that risks related to SLR are real and planning for adaptation and mitigation needed to be prioritised
- Participants implored the government to facilitate adaptation techniques. However, they agreed that communities could better initiate community-based solutions to SLR in collaboration with the government
- The need to be sustainable through more responsive management of the coastline for the future generations was envisaged

- Participants agreed that engagements and dialogue on SLR and its implications should be sustained in order to inform response strategies on an ongoing basis

5.3.1 Acceptance of increased vulnerability to climate change and SLR.

The site of the two islands was another common theme that participants believed would contribute to local vulnerability. Lamu Island has obvious vulnerabilities arising from sole means of transport and long distance travel for goods and essential services (such as food supplies, medical care and fuel) as well as for relief and assistance during emergency situations. The island's, location on the north end of the archipelago was also believed to increase their vulnerability due to the distance and constrained access to the mainland and other related infrastructure such as the airport. The vulnerability in both islands was more pronounced for the diverse economic and culturally significant sites (with examples such as Fort Jesus, The Old Town, north and south coast star hotels and the century-old family cemeteries) which are precariously close to the current baseline sea level.

As analysed in Chapter 4, Lamu Island is severely low-lying compared to Mombasa Island. Several cultural sites that include the Lamu Old Town (one of the old and best preserved Swahili settlements), the German post office, and the Lamu Fort as well as Lamu UNESCO world heritage site are lying in the inundation zone of increased SLR. These assets are precariously located within the low-lying zones and therefore will be the early ones to be impacted by SLR and its related impacts. In the absence of any coastal mitigation measures in these islands, should a catastrophe hit these islands many participants felt that the position of the island makes it highly vulnerable to the effects of SLR. Also, Lamu Island has the old town narrow streets which consist of the main transport system based on donkeys; with no vehicular transport space and the main airport also located in low-lying zones of Manda Island. As a result, any ocean disturbance around the Lamu archipelago will mean that community members on these islands are on their own and this was well appraised by the participants. Other challenges prioritised by the participants in Mombasa and Amu island include:

- Inadequate government support to protect them from SLR-induced impacts
- Lack of community participation due to apathy of the SLR threats which are not of their own making

- Different levels of understanding and perceptions among the communities
- Problems in planning procedures and absence of altruistic behaviour/practices
- Lack of crisis preparedness programmes
- Intensification of exposure to SLR effects due to the need for livelihoods survival and exploitation of borderline resources

According to participants over dependence on government for critical systems that include transport and other essential services was another major shortcoming that increased their vulnerability. The need for community-based solutions to improve their future resilience as well as search for outside funding sources and technological solutions were commonly identified from the charrette process in Lamu Island unlike for Mombasa Island. The community members in Mombasa Island, especially on the south coast, felt segregated and more vulnerable due to the dependence on government facilitated systems including the ferry as a means of transport and business facilitation. In the event of a 1 in 100-year storm event, they are threatened by the impacts it may cause to them and their infrastructure/assets.

These ferries have been known to break down, and on April 24th, 1994, 40 metres from the port, there was a ferry accident aboard the Mtongwe ferry across Kilindini Harbour, that led to deaths of 270 of the 400 people aboard the vessel. The accident was noted as one of the worst African Maritime disasters. The ferries are run and managed by the central government, and there has been multiple complaints on the safety of the vessels. The claims that the central government does not seriously address most cases just brings to the fore the inability of the government in taking care of its residents, leave alone implementing better methods of climate change impacts adaptation along the coastline. The participants identified over-dependency issues especially such as the ferry and the exposed coastal island as key vulnerabilities for the communities to access southern communities, medical and food supplies to the mainland.

Vulnerabilities due to the connecting infrastructure is exacerbated by the fact that this single ferry crossing (at Kilindini Harbour) is the only exit route to the southern part of Mombasa. There are two main exit roads out of the island that includes the Nyali Bridge (to the north) and the Makupa Causeway crossing to Mikindani (Mombasa-Nairobi Highway). A disruption on the Kilindini as envisaged in the optimistic scenario will mean a cut-off between the island and the south coast which

is famous for tourism activities. The same applies to the Nyali Bridge, which is susceptible under the pessimistic scenario by 2060. This single means of transport to and from the island made the communities around Mombasa feel vulnerable to any unwelcome climatic events, storminess and increased SLR flooding (see section 2.8).

Other vulnerabilities on this theme included: the dependency of island communities on the government for continued funding, modern technologies (such as power generation, food production, social amenities and medical services among others), and diminishing natural resources. These ideas were linked to the changing way of life on Mombasa Island and were often associated with the dangers of over-dependency on government resources and modernization.

On the other hand, Lamu Island is entirely dependent on the government resources for both energy (especially electricity from the single diesel generator at Lamu) and transport where water transport systems are the only available transport system. No road network joins the archipelago to the mainland. These limited means of transport increases the vulnerability of the island's residents in cases where the sea is disturbed. The communities felt this dependence is increasing their vulnerability. Hence adaptation and mitigation measures are needed for the enhancement of resilience for the islands and its communities.

5.3.2 Approval of adaptation and mitigation

The role of adaptation to climate change has received increasing attention since the climate change debate begun over 15 years back. The importance of adaptation techniques is critical in the implementation of proper and sustainable mitigation measures by respective governments (**?**). The notion has however led to an increased hope in government delivery of services as well as protect the environment, which stakeholders felt have failed to materialise. The participants are left hoping against hope that nature will be forgiving, but based on the vulnerability assessment results of the study; it is a matter of time before coastal communities are affected by the effects of climate change in general as well as SLR specifically.

Growth in participatory policy option in the management of resources has increasingly led to an involvement of local stakeholders in the analysis of the areas of risk or threats and formulation of adaptive policies. This approach is appraised in this study as an option that would answer to the immediate SLR

threat to the community while taking their resource base, awareness and coping strategies into account. For example, some participants in the group responded by asking for viable strategies responding to the possible threat and adaptation options especially for SLR.

> "*The affluent industrialized countries have burned too many carbon-based fuels to the detriment of poor developing countries let them set up a coastal defence fund to help stop seaside erosion and rising sea effects.*"

Whereas, climate change adaptation funds from such developed countries may be available through several donors in Kenya, participants consistently highlighted that SLR has not been systematically prioritised to be in urgent need of such funds.

5.3.3 Dialogue on sustainability for future generations

Participants were of the view that sustaining and protecting the coastal resources and areas that are at threat will be of importance for the protection of their shoreline from further impacts such as salt water intrusion. The participants acknowledged that some information on changes at the coastal zones, especially shifts in the weather patterns and declining availability of fish species, was being passed on from the older generation who had a longer and richer memory of living in the islands. The shared information stimulated participants towards envisioning adaptation measures for their long term survival. As case in point participants who were mostly involved in fishing explained that during the *Kaskazi* wind patterns would change and this change would directly affect fishing as the wave strength gradually increases, and of late, such episodes were becoming more frequent. They emphasised the need to systematically communicate on SLR challenges to the people living in vulnerable areas and the same information to be passed to the younger generation to facilitate sustainability of the islands for the benefit of their children and coming generations.

5.3.4 Government's role in social and coastal protection

Community satisfaction with essential and vital social services and decision-making processes is an indirect measure of social cohesion as one of the key factors in social capital. Social capital can be in the form of fundamental, cognitive and relational structures. Cognitive capital refers to the social networks that human beigs rely

upon for facilitating the flow and exchange of information. For instance, social capital can facilitate an individual's access to knowledge for effective/meaningfull communication about employment, political support, adaptability and other such opportunities.

At the same time, such community and social networks help to integrate individuals into the community which fosters an exchange of information and the community's social relations as an imperative in management and response to common resources or vulnerabilities. The common way to measure social cohesion is to use involvement in collective community activities as a proxy for social coherence (**?**)

As illustrated by one of the participants from Mombasa, there is a disconnect between the planning institutions and the local communities' perceptions when it comes to the approval of development along the coastline. The participant (see **?**) insisted that planning authorities need to enforce proper development control to protect coastal areas from high-rise building and similar developments that are too close to the ocean,

> "*This is not a rocket science. Mombasa is an island and for those in planning and approval of high-rise buildings should know in long run putting more weight on the island is going to sink it. Before independence and the colonial era, the British knew this and never approved any buildings more than three storeys high. The planning laws can be checked in land/ planning registry records.*"

This demonstrates possibilities of participants negative perceptions of government supply of social services and the role of planning in ensuring the sustainability of the islands and the protection of people's enterprise and infrastructures. Besides community vulnerability, a lack of public sector preparedness in the developing world has resulted in ongoing cumulative damages in urban coastal environments.

Communities with a significant proportion of individuals who participate in community organisation, and cultural events for instance, are seen as better placed to deal with socio-economic changes and crises, including natural hazards and climate change impacts. As discussed previously (see Table 5.1), community/social challenges have led to the high levels of apathy to climate change impacts. This is coupled with a lack of information on some of these threats which in turn hinders/undermines collective adaptation and mitigation strategies.

Bureaucracy and lack of government support

In a broad perspective, the Kenyan constitution has advocated for the inclusion of local communities in the protection and management of resources within their areas in particular through devolution of governance to the county level. To an extent, this provision has increased the participation of communities in conservation as well as planning projects even though this is unfolding amidst multiple challenges such as budgets and capacity constraints.

So far the county governments have not developed systematic strategies towards the inclusion of communities in adaptation and mitigation measures in cases where their unity and livelihood is threatened. This gap leaves such communities exposed to extreme events and also left to recover from their misfortunes on their own. The participants therefore, felt that their participation in adaptation and mitigation strategies in tandem with the government officers on the ground would offer a robust solution out of the quagmire they find themselves in during the increasing extreme conditions that happen in the islands.

To reduce the centralized authority and deliver services equitably to all, the Kenyan government embarked on the current constitutional dispensation which allows for delivery of services to be brought closer to the residents, through the county governments. According to the communities in Mombasa and Lamu Island, the feeling that central government has not been taking their regional issues seriously still stands. They believe that they are vulnerable to climate extremes with Mombasa Island bearing the brunt of flooding during the rainy season and succeeding drought during the parched seasons while Lamu grapples with increased scale of tides.

They perceived themselves as already disadvantaged and disillusioned with the willingness of the central government in coming to their aid, especially now that the advancing oceans threat is real to them. The participants also noted that strategies that would allow for either climate specific adaptation strategies in the country are still in preparatory phase. However, there is a reasonable chance that when these systems are streamlined, coastal communities will demand more comprehensive measures to protect themselves and their properties from climate-related impacts. SLR vulnerability assessment studies to date have primarily focused on understanding and responding to the physical phenomena of disasters. Such a focus can be limiting, particularly because of the uncertainty of climate-change projections. Furthermore, the nature and extent of

climate-induced impacts within a community are equally influenced, among others, by social and political contexts.

Active and strategic political interactions are essential to delivering some of the adaptive and mitigative strategies. In cases where the administrative will or capacity is weak, as in most developing countries that suffer the syndrome of not rewarding opponents (which Mombasa and Lamu are deemed to be) the vulnerability realities can be dire. The analysis of the spatial assessment indicated at most a total population of 1.9 million people in Mombasa Island and a further 57,300 people on Lamu will be severely impacted by 2060 and more so by 2090. Such a population within the danger zone was viewed as a crucial point for the respective county governments to expedite adaptation strategies. The bureaucratic stalling and the related lack of public support were emphasized by one of the participants who said

> "*The people at the coast, have always been marginalized; we do not even have our pieces of land, the relevant authorities will not save us should the island be under threat from sea level changes.*"

The challenges faced by the government in providing services to the communities actually precede the growing need to offer better safety and adaptation strategies and includes financial constraints as well as the normalcy bias demonstrated by local planning agencies. Participants did not have kind words for the departments in charge of the delivery of services as well as the protection of coastal people and their properties. Table 5.2 gives a summary of participants' perception of governance and other challenges within their respective counties,

5.4 Improved and co-created adaptation and mitigation strategies

The mixed result from the mini-charette process underscores the importance of considering community interactions, locality (or geographical place) and human relations (social and environmental) in defining risks and vulnerability assessment. There are distinct social, cultural, political, and geographic characteristics that influence place-based experiences, perceptions, and vulnerabilities within and between communities of both Mombasa and Lamu islands.

Table 5.2: Sample of participants' comments on SLR governance challenges faced

Mombasa Island	**Lamu Island**
Lack of support by community members due to the issue of a compromising local government	We are excluded and farthest from development.
Government has not bothered about us for a long time	We are significant only for endorsing projects
County government is corrupt	The governor has failed to provide for basic needs
Business people have compromised government agencies on planning standards	We are waiting for planning devolution to be fully implemented
Historical interests in the Island make it impossible for community initiated and led decision-making processes	Conflicting interests in the use of resources is a problem
There is a need for the centralization of adaptation strategies with our participation	Centralization is key for meaningful community-based interventions
Lack of information dissemination on related research outputs	No one gives information to us and results implementation outcome is not forthcoming

Thus, it is critical that future steps for climate change impacts and adaptation planning consider the local characteristics and differences in identifying vulnerabilities and adaptive capacity in the development of locally relevant adaptation strategies. Considering social features does not mean, however, that a single coordinated approach, such as island flood control plans (as envisioned in the county government's plan) is not appropriate, but rather that the different characteristics (environmental and social) of diverse communities be acknowledged and factored into such schemes.

Effective adaptation and mitigation consultation and decision-making approach would include a range of stakeholders and representatives such as elected officials, municipal representatives, the local Kaya elders, business owners, regional and town planners, local communities and residents, and special interest groups. However, participation is no mean feat and requires much planning, local and meaningful involvement and dedication as well as openly soliciting different viewpoints and ideas.

Regarding implementation of such plans, the effectiveness of information and resource dissemination and uptake would vary depending on community-level and household-level socio-cultural characteristics. Communities and households experience varying levels of access to information, resources, and social support. Equally, not everyone has the same level of understanding or interprets

vulnerability in similar ways. It is, therefore, imperative that vulnerability communication is culturally appropriate (community-influenced) and prepared in collaboration with those who will be disseminating the same information and with those who would ultimately be using the information.

The results gathered in this study provide insight into various spatial vulnerability, impacts and risks associated with the past, present and future climate change and SLR (Chapter 4) as well as community experiences, perceptions of, and preparedness for these hazards. Though some aspects of sea level adaptation (e.g., perceptions and preparedness for future risks) are limited in detail, the information reveals significant insights on existing community adaptive capacity. Through the mini-charrette process, some existing strengths to counter the vulnerabilities were identified and to some extent, means to improve or build upon these strengths have been highlighted to mitigate future socio-economic and environmental impacts of climate change and resultant SLR.

From the nature and variety of responses during the mini-charrette, and the group results from the sharing sessions, it is evident that participants see awareness as a means to empowerment that will strengthen their community and plan for the future adaptation and mitigation of their vulnerability to SLR. The fact that most of the challenges were identified and listed by the participants were reasonably thought out; the improved responses show a grasp of the impacts of SLR and a positive outlook on their acknowledgement of vulnerability as well as their adaptive capacity. The envisioned response strategies after the charrette processes include:

- Coordinated collective response strategy
- The need to address poverty and improve diversification of livelihoods
- Communication of such findings to create information centres for better responses
- Robust community-led initiatives and change of mindset to mitigate current levels of apathy
- Participatory local governance should be improved

These are discussed and expounded further in the subsequent sub-sectioning.

5.4.1 The need for communal response strategy

African communities are better known in value sharing and their ability to live in active social networks/bonds. However, climate change is stressing such networks

as it impacts on several resources that are critical to the survival of such communities. These resources include fish and other food resources as described in Table 4.5, mainly as the temperatures keep shifting and the normally familiar rainfall pattern failing to hold.

Several factors influence the ability of affected communities to participate in adaptation strategies and especially the availability of resources to fall back to in the event of an emergency. The limited resource constraint is a critical vulnerability escalation factor for developing countries such as Kenya. The need to provide shelter, prevent loss of property in weather-related emergency events, such as El Nino which was recently experienced in Kenya (November 2015- April 2016) and the development of necessary infrastructure often claims priority ahead of related climate adaptation measures. Communities in the poorer neighbourhoods are also mostly and directly dependent on natural resources such as fisheries and are therefore severely affected in the event of a catastrophe. Adaptation and mitigation measures would, therefore, work best when such communities are systematically included. The participation can help such communities be shielded and protected from climate-related changes and impacts in particular through developing their unique adaptation and mitigation measures within the broader county and national climate change mitigation strategies. Participants agreed that the role of community members in evolving responses would go a long way in reducing their vulnerabilities and improving resilience as communities themselves are likely to come up with answers that are more relevant/appropriate for their contexts (socially, economically and spatially/geographically).

For communities that are heavily dependent on coastal resources and are thus sensitive to changes in climate, related risks can effectively be mitigated if community members and the leadership forge a joint response strategy. Such risks are apparent in tourism, agriculture, forestry and fisheries and several other components that constitute the livelihoods of rural and coastal populations in Mombasa and Lamu.

During the mini-charrette, participants concurred that community driven adaptation responses are likely to succeed, with communication being key to effective adaptation and mitigation response. In this case, when the vulnerable and affected communities are informed, and especially where there's systematic access to information concerning the threat at hand, a community's positive adaptation responses are enhanced.

5.4.2 Vulnerability and improved diversification of livelihoods

Daily challenges influence the capacity of individual and municipalities to cope with extreme events, and it is within a people's and the community's context that adaptation strategies are most likely to be effective (**?**). Issues of poverty constraints were mentioned during the mini-charrette where participants who have been plagued by impacts such as coastal flooding caused by large tides have no alternative housing as well as resources to bounce back when their houses are flooded or property/possessions are destroyed. For most communities and households the recovery process is often slow and painful such that another disaster is likely to strike before full recovery thus sending them back to the starting point yet again.



Figure 5.2: Lamu children in a house made of mud and plastic paper

Based on this vicious cycle of poverty which was noted (as evident through the housing materials as seen in Figure 5.2) community members felt that the responses

to adaptation and mitigation would have to include other sources of livelihoods especially through economic diversification. The diversification would help them reduce their dependence on coastal tourism and beachfront businesses for survival as well as reduce the pressure on the county government towards directly ensuring basic survival needs of their local communities.

Many developing countries can be understood to be struggling in addressing priority challenges especially those related to poverty. This also applies to Mombasa Island where 37.6% of the population lives below the poverty line which is even slightly better than the county's average of 45.9%. The effects of poor and weak communities undermine plans for adaptation and mitigation right from the household to the national level. The need is dire, and would therefore take government agencies significant attention and resources to improve community adaptation and perceptions of climate change impacts such as SLR.

5.4.3 Information sharing

During the group summary presentations and sharing session, it became evident that participants were united by a common desire to face the changes and challenges in their community based on their revitalised understanding of sea level changes and associated impacts. Communication and information sharing needs that would have to be addressed in order for this to materialise were listed and discussed under the following key sub-themes:

Internal information sharing

Participants were primarily of the opinion that both governance/policy and scientific issues that would affect them should be communicated to community members in a way they would understand. Given the nature of some of the effects that may be anticipated as illustrated in the maps, the losses would be high if no adaptation or mitigation measures are taken. This information needs to be shared with the communities and improved upon by the governance structures at community levels especially at county and ward levels as the key governance structure under Kenya's new constitution.

The call for effective communication and public participation in climate change adaptation and mitigation strategies is not only evident in specific constitutions of various countries but also in several other major international policy documents on climate change globally. Indeed, participation is identified in

Article 6 of the 1992 United Nations Framework Convention on Climate Change; ? calls for participating countries and parties to promote and facilitate "public participation in addressing climate change especially sea level rise and its effects and developing adequate adaptive responses" UNFCCC, 17).

One participant reiterated that it was important to be continually informed of climate change impacts and especially SLR as a threat to seaside sustenance and business endeavors additionally such as tourism and livelihoods on the coast of Kenya. This information is sometimes not forthcoming due to the perceived technicalities involved in information dissemination to local communities who have different levels of understanding and also where pressures and need for survival overrides the need to be constantly in meetings where such information is disseminated. He started by asking that researchers make their research simple and in more easily accessible styles and channels.

> "*The scientists write and produce hard scientific stuff, that the local community member may not understand, and sometimes this leads to misinterpretation of information.*".

Participants further debated on a need to listen more amongst groups and individuals in the communities living on these islands and also shifting towards less reliance on outside consultants/experts to solve local problems. The communication can be achieved, in part, through the hosting of events, gatherings and workshops, which would create opportunities to share knowledge, listen and learn from one another. The community also felt that the involvement of people of all ages (though calling for an individual effort) is required especially towards reminding the younger generation of the indigenous knowledge systems (IKS) existing within their communities.

Proper methods of including IKS in the community communication programs, need to be reinforced, and the former and existing cultural practices that have conserved and protected coastal communities and their resources till now be enhanced and preserved. Communication methods should be strengthened for elders to pass on traditional skills and knowledge. The village elders and heads of clans could be contact leaders; passing down history, adaptation techniques from generations and explaining what adaptations and responses are appropriate towards effective climate adaptation and mitigation.

External information sharing

A majority of the participants concurred on the view that there is a need to reclaim decision-making power and governance that was given away to outsiders (examples include the development of hotels and fishing rights). Apart from the rights, there is also, a need for better communication and voice in government and industry so that both within and outside decision makers hear and involve local inputs/expertise. Participants also expressed the need for a more robust lobby to protect both Lamu and Mombasa resources and especially their distinct culture(s). Increased media involvement and continued protests, as well as enhanced political lobbying, could facilitate for such needs.

5.4.4 Building adaptive capacity to reduce vulnerability to climate change

Adaptive capacity describes the capability of countries, households, communities and individual to deal with exposure to climate change related risks and hazards (such as sea level and storm changes, coastal erosion, flooding and landslides). Adaptive capacity thus reflects resilience, or the ability to prepare for, avoid, moderate, and recover from such risks and changes. Thus, communities that are organised to minimize catastrophic effects, while decreasing recovery times and costs that result (e.g., restoring socio-economic vitality, rebuilding damaged infrastructure) are, therefore resilient. As such, building adaptive capacity of communities living in vulnerable areas helps reduce vulnerabilities to climate changes and related natural hazards thus enhancing their resilience.

Adaptation measures are of particular importance for isolated communities with high dependence on exposed critical infrastructure and limited essential services as in the case of Lamu Island. It is also crucial to acknowledge that human activities and communities are interdependent with environmental systems, and especially for coastal systems where human activities are heavily dependent on environmental resources. As such, the adaptive capacity to climate change is influenced by the interaction between environmental exposures and modifications on the other hand and as well as socio-economic factors and perceptions that are shaped by local experiences on the other.

Whereas increased environmental exposure escalates the vulnerability levels of a community and its resources/infrastructure as well as the degree of planning and mitigation preparedness would significantly influence the overall adaptive

capacity. Decreased community resilience (via reduced social cohesion, inadequate funding to maintain infrastructure and programs, poorly implemented plans or the normalcy bias.) increases their socio-economic exposure and overall vulnerability. It is, therefore, clear that a strong relationship exists between environmental exposure and socio-economic preparedness towards addressing the vulnerability versus overall resilience of households and communities. Common indicators of community resilience and adaptive capacity (see discussion in section 1.3.2) include efficient transmission of climate change knowledge and information, economic diversification, sustainable resource use and planning. Measures towards enhancing resilience include enhancing social capital and cohesion, accessibility to financial resources and essential services, community perceptions of and preparedness for risks, and decentralized decision-making.

Participants considered short term and long term adaptation techniques through highly feasible short-term goals, as well as more long-term goals that would enhance their ability to respond and adapt to climate-related changes summarised in Table (5.1). Some of these properties emerged in community mini-charrette and survey results (see sections 3.2 and 3.3) and formed the basis for the proposed short-term and longer-term suggested strategies.

Short-term responses and adaptive capacity building

The goal of enhancing adaptive capacity to climate change is to reduce the longer-term vulnerability of communities based on the development of short- and long-term adaptation objectives and strategies to mitigate the negative impacts. The need for short responses to adaptive capacity was seen as an immediate need for the community members living in the two islands. Participants were of the opinion that there are currently no measures to protect the coastal communities from extreme events triggered by the changes in ocean storm frequency, density or increased coastal storms. They expressed concern on the ongoing flooding caused by high tides and the general increase in rainfall pattern had not provoked systematic response by communities or government structures as yet.

Research on climate change vulnerability and adaptation emphasizes on preparedness and improving quick short-term responses. Given inputs from participants communities understood that they cannot loose by preparing and planning for future climate change impacts now. Understanding the importance of action-oriented adaptation through several possible responses would build on

existing strengths of target communities such as those of Mombasa and Lamu islands.

The need for shorter term and quick adaptation measures could be incorporated into the city's daily life and activities. Some of the suggestions included the creation of revetments and drainage systems to revert water back to the ocean in the spell of high tides awaiting sea defence mechanisms to be incorporated in the protection of coastal areas from tide changes, effects and the increased inundation posed by the advancing oceans.

Participants felt that these short-term remedies should be followed by more systematic and longer term strategies. Such interventions would require the identification of exposures and highly vulnerable areas and especially critical infrastructures like roads and water systems. SLR contributes to community vulnerability as it increases the chance of damage caused by hazardous events and the possibility of extreme events due to ongoing longer-term changes. For Mombasa and Lamu islands key physical/environmental hazards as identifies in Chapter 4 would include:

- The rate of gradual SLR of up to 1.2 mm yr^{-1} and extreme annual high tidal levels of 4.1 mm yr^{-1} see Table4.6
- Coastal erosion rates and hotspots (see sections 5.7), including identified critical infrastructure that is, or could be, impacted (examples, Nyali bridge, Lamu and Manda Airports, hotels and buildings, private and public properties, among others)
- Coastal and estuarine flooding hazard extent and probabilities due to extreme events and future inundation due to SLR
- Though flood hazards are typically limited to low-lying areas, high storm surges of 0.5 to 1.0 m above predicted tides are possible as are higher tsunami waves. Tsunami prone zones could be mapped and appraised. It should also be noted that flood events may increase in frequency, and they will be superimposed on a gradually rising sea level
- Other geological risks and hazards affecting coastal regions and community infrastructure including earthquake amplification and liquefaction, salt water intrusion, landslides and wind storms

Increase public awareness of hazards, risks and future impacts

Community charette results suggest that provision of information and resources to communities and households is a critical adaptation measure. Such a strategy would include county newsletters, community seminars/workshops, displays at community cultural events and programs in school curricula.

Combined with other international and national environmental awareness initiatives such as environmental day, dissemination of information could improve understanding of climate change and related risks. The template community vulnerability maps produced in Chapter 4 could also serve as a means for communicating hazards and risks, perhaps in an accessible and updatable interactive web-based platform such as the one proposed and recommended for this study in order to improve the community's access to related information.

The development of an integrated island emergency preparedness plan with involvement from all communities and stakeholder groups would also assist in preparing for different environmental hazards. Access to information, technology and resources (and especially, finances) also varies across and within communities and could be one of the critical interventions under such a plan. Future impacts, trends, and uncertainties (in particular, the range of possible future settings) also need to be conveyed to the general public and planners. Chapter 2 of this report presents literature on a broad range of observed climate change trends and the analysed impacts for Mombasa and Lamu (Chapter 4, Section 4.4), each expressed with future impacts and uncertainties, as well as a range of possible future scenarios.

Improving household-level preparedness

Household preparedness varies greatly among and within communities represented by those who participated in the charrette. The results suggest that increased information and incentives are needed in order to enhance awareness and action towards having sufficient emergency supplies for extended periods (such as food and water supplies, fuel, heating/lighting). Communications and contingency plans at household to community levels in the event of hazards which do not currently exist and household insurance would be an additional considerations.

Preparedness programs could also consider incentives and assistance for encouraging families to participate. The plans could include community preparedness resource pools (similar to food banks) or discounts/vouchers for the purchase of emergency supplies. These measures are particularly important for

households that may not have the resources to obtain such supplies otherwise. Community workshops, similar to first aid or earthquake preparedness workshops, could be offered in order to engage and assist homeowners on ongoing improvement of their preparedness.

Improving community-level responses and planning

Ultimately it is at the community level that effective, broad-reaching programs can be developed and implemented. Households need support, whether financial, logistical, or informational, to better prepare for future eventualities. Community emergency planning is imperative regarding raising awareness, providing people with the information and tools to help themselves, and providing a coordinated approach and response to coping with emergencies and natural hazards.

The need for information sharing, coordination and planning were underscored in each of the two islands' mini-charrette. In particular, there was overwhelming support for the development of a broad, community-wide emergency plan. This procedure would apply to a wide suite of urgency and/or hazard situations and its operation details would need to be broadly disseminated.

Increased information on the linkages between such hazards and climate change (such as coastal flooding, erosion, and increased storminess) is required to build an appreciation for increasing exposure to extreme events over the longer term. This emerges from a surprisingly limited awareness of the linkages between climate change and the likely potential for increasing frequency and magnitude of extreme events and especially those related to coastal/ocean hazards.

Promoting comprehensive capacity building

As SLR is only one of many stressors that affect remote communities (with other stressors being social problems, cultural challenges, socio-economic restructuring in the wake of natural resource declines), it is important to consider not only physical but also socio-economic and cultural threats in building community adaptive capacity to climate change. Furthermore, while the technical aspects of emergency preparedness (such as household and community plans, infrastructure protection) are an important focus in adaptation to climate change, the investment in social and cultural activities and networks, as well as the safety and preservation of natural environments or resources would be also crucial.

The study results show that Lamu Island participants view their people, their culture and their natural environment as key strength-giving attributes. Thus,

investments in emergency preparedness and climate change adaptation alone are only part of the solution and could miss important local values and strengths. Investing in formal and informal education, improving access to sustainable employment, quality social services, as well as important community and cultural events would go a long way in enhancing social capital and building overall adaptive capacity in the two islands. Further to this, investments in sustainable resource development and management (such as community forests) would help sustain resource based livelihoods and local stewardship of resources toward maintaining a healthy natural environment.

Long-term adaptation strategies

Following these short-term options, several longer-term (mainly decadal scale) considerations for improving community adaptive capacity to climate change and SLR related risks were appraised.

Economic development and diversification

The development of the economy and renewal initiatives in the tourism, arts and culture sectors as well as resource stewardship could be geared to diversifying the local economy and enhancing community resilience to socio-economic impacts associated with climate change. Forest-based communities in particular, have been identified as particularly vulnerable (**?**).

Mangrove forests lace up the coastline of the two islands and with fishing as well as agriculture still hold as key livelihood resources for the island communities. The vulnerability of such natural resources especially changes in fish species and abundance, as well as shifts in the growing season due to climate change impacts, have long-term implications on the related livelihoods. Many communities who depend on environmental resources now view tourism as an economic booster after the consistent decline in the forestry and fishery sectors (**?**).

However, in Mombasa Island, a large proportion of the tourism activities is directly related to sports fishing industry. Changes in fish stocks due to both natural and human impacts would, therefore, not only directly impact on the fisheries industries but may also have trickle-down effects on the tourism sector and local businesses. Increased SLR-induced coastal erosion, sedimentation and flooding hazards will also affect the maintenance costs of transportation infrastructure, marinas, dredging, boating safety, vacation housing and resort infrastructure which are the key common characteristics of the two islands.

Diversification of the tourism industry could involve expanding and promoting the cultural and wilderness aspects of the islands, as well as other recreational opportunities such as water sports and surfing among others.

Reduce vulnerability of critical infrastructure of islanders

The communities of Mombasa and Lamu islands are geographically isolated and rely on costly critical transportation links (ferries, flights and coastal highways among others) that must withstand some of the most extreme coastal waters and stormy conditions in Kenya. At times, this geographic remoteness limits' the residents access to critical services such as better, health care facilities and results in intermittent supply interruptions. This limited access to resources due to limitations in critical infrastructure and services poses additional vulnerability to climate change-related risks, such as increasing frequency of extreme storm events.

Lamu communities are located close to 240 km by road from Mombasa. The cities are linked by an earth road awaiting to be tarmacked and in several cases being vulnerable to infiltration by the Al-Shabaab members who have been causing terror around Lamu Island. The principal modes of transport into and out of the Lamu Island is an airport adjacent to Manda Island or the jetty at Mpeketoni. The main Mombasa-Malindi road serves Mombasa Island with the Nyali Bridge thus offering connection out of and into the island.

The road is situated very close to the shoreline and portions of it have experienced increased flooding and erosion damage in recent years. With coastal erosion rates, estimated at 1m to 3 m yr^{-1}, and rising sea-levels as well as extreme water levels, this stretch of the highway is highly vulnerable and requires immediate attention with serious protection/mitigation interventions.

The current bypasses and road upgrades are a good start in creating alternative inland route reducing pressure on the available transport systems. Adaptive planning is also needed to reduce the current vulnerability of other coastal roads within and around Mombasa Island as well as exposed critical infrastructures such as low-lying buildings, airports, power and communication transmission lines and other essential services (such as sewer and water systems as well as hospitals/health infrastructure).

Re-consideration of coastal setbacks and land use rezoning along eroding and flood-prone coastal areas is now urgently needed. Future scenarios of both sea-level rise

and extreme events (storm surges) are likely to entail increased erosion and flooding damage to exposed and low-lying areas. Areas of concern within Mombasa and Lamu are mapped and discussed in Section 2.8. It is very likely that by 2060, some parts of Mombasa Port and the LAPSSET project harbour in Lamu Island will require extensive engineering efforts to control flooding and erosion.

Improved emergency preparedness

Inadequate emergency preparedness was a common theme among the charrette participants. The key issues identified included lack of knowledge on probable future environmental changes and inadequate emergency services and coordination and especially (with no backup communications). All of these ideas relate to how residents/stakeholders perceive preparedness for their community with regards to emergencies and are therefore directly relevant to climate change-related extreme events (such as storm surges and coastal erosion). Currently, there is no systematic contingency plan (for example in the case of a tsunami) for any of the islands.

5.5 Conclusions and deductions

The key findings on community member's perception demonstrate that climate changes are not news to them. They have had lived in the coastal zones and managed to generate an income and sustain their families albeit with several difficulties due to the seen changes in the coastal zone. Some of the challenges included reduced fish stock which has led to altered diets, as well as increased demand for deep sea fishing equipment to allow the community members access food from the ocean. The dwindling resources have resulted in the loss of income and an alteration of diets as most of them relied on seafood as part of nutrition.

Other factors affected by the changing climate to the coastal communities included the direct effects on tourism. The tourism sector is challenged due to the evolution of climate that includes but not limited to strong high tides, coastal flooding and sand infestation leading to closure of tourist hotels due to flooding especially in Lamu Island as well as limited business gains from water sports. These changes have indirectly led to increased competition over the little available resources, reduced livelihood options as even the forest cover that provides other essential services are affected as well thus increasing social vices within the communities as income choices in this coastal zones dwindle drastically.

As most of the participants would reckon adaptation and mitigation techniques to address impacts of a changing climate are welcome. These options would include

but not limited to a diversification of resources and livelihoods; This will greatly assist in having a steady supply of food and resources uninhibited during the changing times. Additionally, for the current and future generations benefit, enhancement of adaptation techniques will be enhanced by communication within community structures. Internal and external communication will improve perceptions and awareness thus facilitating an active participation of the local communities in aspects that affect them for example climate change and especially SLR.

Climate change especially SLR trends in coastal areas need adaptation and mitigation to facilitate the resilience of communities in case disaster strikes. Knowledge sharing and voluntary exchange of information from the government, research organizations and climate scientists to this communities will offer much-needed assistance in the changing of perceptions and invite proactive adaptation and mitigation techniques. The techniques passed on to the coastal communities who may be vulnerable to the effects of the advancing oceans, may also facilitate the development of their initiatives for sound climate change mitigation.

Chapter 6

Consolidation of findings conclusions and recommendations

6.1 Introduction and structure

The main aim of the study was to assess the extent of vulnerability and exposure to climate-change induced SLR for the island cities of Mombasa and Lamu. The hypothesis emphasised on the participation and co-production of mitigation/adaptation strategies as part of the vulnerability assessment process. The participation was hypothesized to facilitate the enhancement of awareness levels among participants and communities potentially exposed to effects of accelerated SLR. The co-production process (which included both the scientific analysis and participatory process) was prioritised as the overall approach to the study. The aim of the process was to appraise how enhanced knowledge of SLR vulnerability levels influenced related awareness and thus facilitate change in perceptions of the role of community and other stakeholders towards mitigating related SLR impacts within their neighbourhoods and cities.

This chapter presents the consolidation of sub-findings from previous chapters in order to derive the overall findings of the study, in response to the overall research question. The chapter starts with a recapture of the research question and the importance of the results of the investigation in response to the four research sub-questions. The chapter then proceeds to consolidate findings of the sub-questions followed by overall conclusions and recommendations.

6.1.1 Research objectives

The main research objectives guiding the study were as follows:

- Assess initial SLR vulnerability levels for the Kenyan coast regarding the zones, people and activities, infrastructure/assets and public services
- Use GIS-based tools and techniques to identify and map the extent of inundation risk for Kenya's coast based on regional modelling from global inundation scenario assessment up to the end of the century
- Appraise status quo vulnerability perceptions and awareness through a mini charette process in order to understand the prevailing adaptation and mitigation practices and coping strategies now in place
- Share modelled SLR findings with participants and co-produce mitigation and adaptation interventions/policy options for subsequent action and implementation
- Consolidate a vulnerability assessment manual and integrated vulnerability atlas which would be adaptable for application in similar SLR vulnerability assessment for coastal regions and cities

6.1.2 Research questions

Under the listed objectives, the study sought to address the following:

- The nature and extent of infrastructure vulnerability to SLR in the coastal areas of Mombasa and Lamu
- How the level of awareness influences response to the threat of SLR
- How participatory approaches in vulnerability assessments influence participant preparedness and empowerment to act
- How the insights from the participant experience can be incorporated into SLR vulnerability assessments methodologies/approaches

A consolidation of the main findings of the study is reported against each of the research questions, followed by the overall consolidation towards the resolution of the overall research question. This section entails the discussions of the results through merging the spatial analysis and the participants involvement based on the view that community participation plays a significant role in the cognitive ability to respond to and manage catastrophic events. Findings on the generated vulnerability maps indicating different vulnerability levels as described in Chapter 4 based on the HAT at the coast and the SLR prediction are initially summarised

and discussed. The presentation of consolidated findings are then presented as guided by the research question.

The chapter is structured into three parts: Findings on the vulnerability of people, space and infrastructure for the two islands are consolidated under the two scenarios. The analysis is followed by discussions and conclusions on the status quo awareness and preparedness of SLR and the related vulnerability. Finally, the chapter consolidates the findings on the relationship of enhanced participants' awareness and readiness to act towards mitigation and vulnerability strategies/actions.

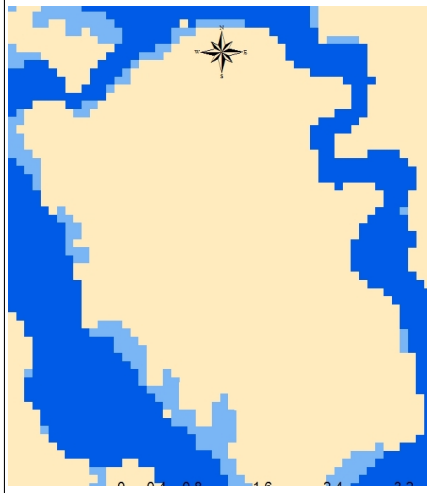
6.2 Spatial extent, infrastructure and people vulnerable to SLR

This section is structured according to the two main scenarios used in the analysis in Chapter 4. Initially, the spatial extent, infrastructure/assets and people exposed under RCP 2.6 (optimistic scenario) are addressed followed by impacts anticipated under the pessimistic scenario (RCP 8.5).

6.2.1 RCP 2.6: SLR vulnerability and exposure for Mombasa and Lamu.

The inundation-prone areas under the optimistic scenario of RCP 2.6 by the year 2030 shows that the Mombasa island's exposed assets are up to a value of US $ 1.1 billion and a land mass of up to 1.4 Km^2 by the year 2060. This exposura and vulnerability is mainly influenced by extent of low lying land-mass which is thus susceptible to ocean disturbances in the event of a severe coastal storm event clarified at 1-100 year return cycle see Table (6.1).

Table 6.1: Spatial extent and impacts on infrastructure, assets and people under RCP 2.6 by 2030

Mombasa Island	**Highlights on areas affected**	**Lamu Island**	**Highlights on areas affected**	
See Fig 4.10 for the names of exposed areas 	• The most optimistic scenario where 0.5 Km^2 is threatened • Areas around Changamwe refineries, Kilindini and Mama Ngina, could be affected by an extreme event • Under this scenario, population of 433,200 is exposed and threatened by inundation • The assets exposed in an extreme event under this scenario is US$ 1.1billion.	See Fig 4.20 for the names of exposed areas 	• The most optimistic scenario • Lamu island is more low-lying than Mombasa with an area of 36% of the island being at risk of inundation in an extreme event • Key areas under threat include the Amu division itself and areas around Matondoni being the first to be affected • Other areas affected include the Manda Island • Population under threat in this scenario add up to 21,000 persons • Assets under threat add up to US$ 54.5 million	

This low-lying inundation zone translates to almost 10% of the land mass of Mombasa under threat from accelerated SLR as indicated in Table 6.1 . The spatial extent and infrastructure within Mombasa Island that are low-lying under the RCP 2.6 include parts of Changamwe and Kilindini port, railways and the Mama Ngina Drive bordering the Kilindini Habour. As the years progress and SLR increase, other areas that are classified as low-lying include the Nyali Bridge, areas around the mixed residential area of Bondeni, Tudor Creek and the low-income residential area of Chaani. These areas are appraised further below.

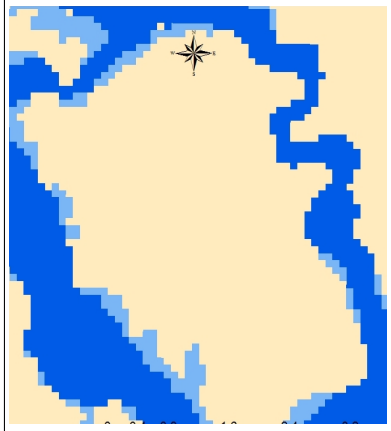
Mombasa and Kilindini port

The port of Mombasa is the main sea port of Kenya and comprises the Kilindini Harbour and administrative offices situated at Port Reitz on the eastern side of the island. The port has the additional infrastructure at the Old Port near Tudor North area of the island. Kilindini Harbour is naturally deep and well sheltered and is the main harbour where most of the sea cargo transport and shipping logistics take place. The port has recently enhanced its capacity in order to improve its service as a regional sea trade route.

The Port of Mombasa is classified by the Harlem Logistics (port infrastructure assessment company) as the second largest port in Africa, immediately after the port of Durban in South Africa. The Kenya Ports Authority (KPA) manages the port and serves as the lead operations management for the forthcoming (now under development) Port of Lamu and other small sea ports of Kiunga, Malindi, Kilifi, Mtwapa, Funzi, Shimoni and Vanga.

These critical but now vulnerable port facilities include the Kipevu Oil Terminal which is situated on the mainland around Port Reitz area. It was designed to accommodate crude oil tankers, and newly developed grain bulk handling facilities among other infrastructure. As the ports vulnerability levels rise by the year 2060, the newly developed Berth 19 becomes an additional critical infrastructure threatened by the effects of accelerated SLR.

Table 6.2: Spatial extent and impacts on infrastructure, assets and people under RCP 2.6 by 2060

Mombasa Island	**Highlights on areas affected**	**Lamu Island**	**Highlights on areas affected**
See Fig 4.11 for names of exposed areas 	• Areas around Makadara, Chaani residence, sections of the Old Town and Fort Jesus tourism attraction fall under the inundation zones • Others include the Kenya Ports Authority offices and bays, Mama Ngina Drive, Kizingo residence including Mtongwe Channel • Island area of up to 1.4Km^2 is low lying translating to 10% of the land mass falling within inundation zone • In this scenario, a population of 1.43 million is exposed and threatened by inundation • The asset exposure under this scenario adds to almost US$ 3.8 billion	See Fig 4.21 for the names of exposed areas 	• Sections of Manda Island, Lamu Airport, is slightly under threat, including the mini Manda Toto currently covered with mangroves • The archipelago area of up to 28.3 Km^2 is low lying and is susceptible to ocean disturbances in the event of a severe coastal storm • The inundation translates to 52.6% of the land mass being under threat from accelerated SLR • The number of individuals who would be living within this zone are up to 93,700 • The asset exposure under this scenario adds to almost US$ 251.2 million

Due to the ideal suitability of the Kilindini Port for harbour infrastructure given its unique depth, the Port Authority has recently invested over Ksh 5 billion in new cargo handling equipment. The new Sh5.8 billion Berth 19 project includes an additional 15-acre staking yard that adds an extra handling capacity of 200,000 TEUs per annum. Under the optimistic RCP 2.6 scenario, the port of Mombasa and the new Berth 19 would be under threat from inundation in the event of a coastal storm, under conditions of accelerating SLR.

Given that Lamu Island is relatively more low-lying compared to Mombasa Island, even under the most optimistic scenario, there are dire SLR impacts for Lamu over the 100 year period. The developers of the ongoing Lamu port project and the related infrastructure thus need to integrate mitigation/adaptation measures into these and other important infrastructure investment programs in the city. The areas under threat in Lamu Island are summarised (see Table 6.2) and in the subsequent subsections:

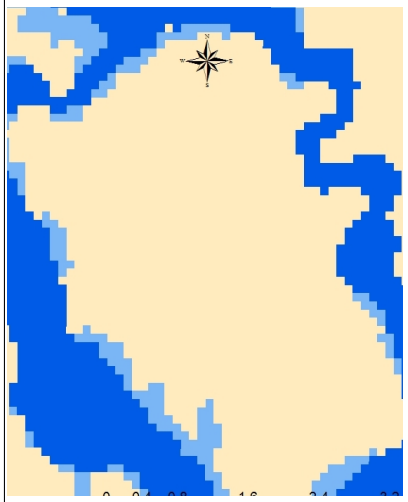
LAPSSET project

This project (involving eight African countries and budgeted at US$ 25 billion) is likely to be impaired by the effects of the SLR if adaptation and mitigation interventions are ignored. As earlier stated, the Port of Lamu is part of the LAPSSET project which constitutes of both transport and tourism infrastructure projects linked to it. Such important Kenyan and African related infrastructure should have been assessed for its suitability in the face of the changing climate and SLR, and also in order to ensure that appropriate protection and adaptation measures are factored into its planning, design, construction and operation over its entire life-cycle.

Lamu hotels and residences

The Lamu archipelago, and especially Lamu Island, hosts some of the internationally renowned hotels such as the Majilis, Kizingo, Kijani and the Peponi. These hotels constitute critical tourist attraction infrastructure during most holidays and festivals such as the Lamu Maulidi festivals (Lamu cultural festivals).

Table 6.3: Spatial extent and SLR impacts on infrastructure, assets and people under RCP 2.6 by 2090

Mombasa Island	**Highlights on areas affected**	**Lamu Island**	**Highlights on areas affected**
See Fig 4.12 for the names of exposed areas 	• Areas affected include the railways area, the administrative unit of Mombasa City, sections of the Old Town and Fort Jesus • Others include the State House premises on Mama Ngina Drive, the Kizingo Residence, The Nyali Bridge, Tudor Creek and Mtongwe Channel • Island area of up to 2.3 Km^2 is low lying translating to 12.1% of the land mass, totalling to 22.6%. • Under this optimistic scenario by the year 2090, a total population of 2.6 million people will be living within the inundation range • The asset exposure for the scenario is US$6.4 billion	See Fig 4.22 for the names of exposed areas 	• Lamu Airport is among the exposed infrastructure under threat; Manda Toto will be completely be submerged. • The island area of up to 35 Km^2 is low lying and is susceptible to ocean disturbances in the event of a severe coastal storm event • The inundation translates to 60.4% of the land area under threat • Others include the site for the LAPSSET project offices and bays, the hotels around Shella as well as the business district of Lamu • Under this scenario, a projected population of 166,500 will be living within the exposed/vulnerable zone • The exposed assets will be towards US$ 435.8 million.

Most of these hotels are lined along the coastline and are therefore extremely exposed to both inundation and storm surges as a result of SLR. The threat of SLR will thus severely impact on the economy of this island county given its significant dependence on tourism for economic development.

Kenyan and international investors own properties on the island including a private residence under ownership of the British monarchy. Besides the business premises and related investments, the island also hosts households whose livelihoods as fishermen, boat makers and repairers as well as beach assistants will be equally impacted by SLR.

Manda Airstrip

The Lamu Airstrip (also known as the Manda Airstrip) is the only air-flight gateway to Lamu island from other cities through domestic and chartered flights. Most Kenyan commercial airlines have flights twice a week to Lamu from Mombasa, Malindi or Nairobi. Even under the optimistic RCP 2.6 scenario, Manda Airstrip shows escalating inundation by the year 2060 and will be almost entirely immersed by the year 2090.

Changamwe Oil Refinery, Mombasa

The Changamwe Oil Refinery site falls under the LECZ and is thus within the area under threat from sea level changes and inundation. The refinery earns an average monthly revenue of US$ 99 thousand for handling LPG, petrol, diesel, dual purpose kerosene and fuel oil, even though the station is currently underutilised due to the government's policy changes to crude oil processing, and the reduced role of the facility from refining to storage of crude oil.

Under the optimistic scenario, this infrastructure is classified to be in the inundation zone by 2060. The severity and extent of inundation for Changamwe and Kipevu Oil Refinery facilities increases substantially under the pessimistic scenario (RCP 8.5).

Five and three-star hotels in Mombasa Island

Mombasa is known to host internationally recognised five and three-star hotels that have enhanced the city's niche as a tourist destination. Travel and tourism contribute close to US $2.5 billion to the Kenyan economy annually, with the tourist hotels in Mombasa as the critical centres of travel and tourism. Climate change,

and especially SLR will thus impact this important sector of the economy which is second only to agriculture in contribution to GDP. Some of the low-lying coastal hotels include the English Point Marina and the Tamarind Hotel in Mkomani.

Fort Jesus-National Museum of Kenya

The Portuguese built Fort Jesus in 1593 over a sharp edge of the coral rock on the southern boundary of Mombasa Island and kept it under their control for more than a century. Joao Batista, an Italian Architect, was the designer of the Fort. In its structures and subsequent transformations, the Fort bears material witness to the trade and change of cultural values between and among peoples of African, Arab, Turkish, Persian and European origin who fought to gain and maintain control over this strategic infrastructure and its related city of Mombasa as a whole.

The Fort is located along the coastline neighbouring the Old Town zone and, close to the culturally valued Muslim-based Cemetery (burial place of eminent coastal/Muslim personalities such as Prof Ali Mazrui). The Fort attracts numerous tourists keen to learn the history and changes as perceived through the long fight and trade through this city. Under RCP 2.6 scenario, the port is at risk of inundation by 2060 as it is within the low-lying zone. In the case of an extreme event in the coastal zone, this is one of the critical infrastructures that will be negatively impacted by accelerating SLR.

Chaani and Kizingo residences

The Chaani settlements an informal high-density residential area close to the Kilindini Harbour and Makupa Causeway is one of the low-income residential areas that will be negatively impacted due to the accelerated SLR. Unplanned settlements, with hardly any formal infrastructure, are known to escalate the vulnerability of residents. The informality of the settlements makes the inhabitants suffer more devastating damage, and their homes become uninhabitable faster in the event of a storm or a flood. Their shanty town level of risk is exacerbated by small road networks and inadequate storm-water drainage systems that are a hindrance to quick response in case of an emergency thus reducing the resilience of communities living in such areas.

On the other hand, the suburb of Kizingo, an upmarket low-density residential area along the coastline is also at risk of inundation by the year 2060. Kizingo is a low lying area which attracts the affluent residents as it is close to the Mtongwe Channel and enjoys excellent views as most houses face the ocean.

6.2.2 RCP 8.5 SLR vulnerability for Mombasa and Lamu

This scenario shows extremely severe impacts in each of the islands based on IPCC prediction of increased SLR under this scenario. The scenario rests on the assumption that climate change will go on unabated, and the use of fossil fuels will still continue unchecked. Under this scenario, low-lying areas under threat from inundation include cultural and religious sites in both islands, residential areas, transport and infrastructure such as airports and bridges as well as hotels that were adequately elevated under the previous scenario (RCP 2.6).

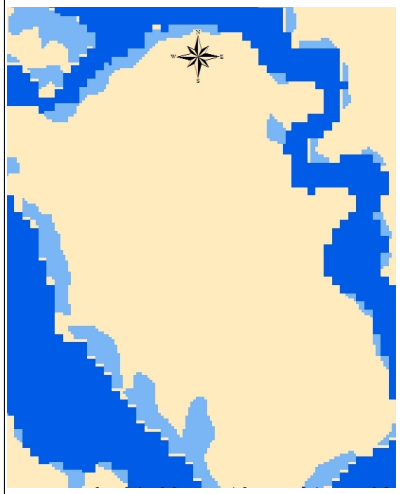
Important UNESCO cultural sites

Lamu Island (fondly called the Amu City) is a UNESCO world heritage site, and the city's built environment is under the management of the National Museums of Kenya. Some of the protected areas include the German Post Office as seen in Figure 6.1. Under this protection, only minimum architectural and design changes can be allowed on selected buildings and sites in Amu in order to ensure that the island maintains its heritage face and design. The city is famous for leading tourism and fisheries resources and the residents highly depend on the ocean for business and transport. The island has no road network connecting the island to the mainland. The only means of travel to the mainland and the nearest airport at Manda is by boat.



Figure 6.1: Heritage protection site: German Post Office in Amu City.

Table 6.4: Spatial extent and SLR impacts on infrastructure, assets and people under RCP 8.5 by 2030

Mombasa Island	**Highlights on areas affected**	**Lamu Island**	**Highlights on areas affected**
See Fig 4.13 for the names of exposed areas 	• The most pessimistic scenario with no commitments to targets on global temperatures • A bigger proportion around Changamwe Refineries, Kilindini and Mombasa State House site would be affected by an extreme event • Other vulnerable areas include Nyali Bridge, the only exit to the North Coast as well as the multi-billion new hotel enterprise (English Point Marina) • The area of the island under threat translated to 2.0 Km^2 equivalent to the 8.2% extending out of Mombasa Island. • Population of 453,000 is exposed and vulnerable to inundation • The asset exposure under this scenario adds to almost US$ 1.2 billion	See Fig 4.23 for the names of exposed areas 	• The scenario completely disintegrates the business city and most areas in Lamu Island • All the areas within the island, with exception of the Shella sand-dunes will be frequently inundated • Key areas under threat include the Amu division itself, areas around Matondoni and Mokowe will be under water most of the time • Other areas affected include the Manda Island • Populations under threat under this scenario will be about 29, 000 people • Assets under threat will be US$ 76.1 million

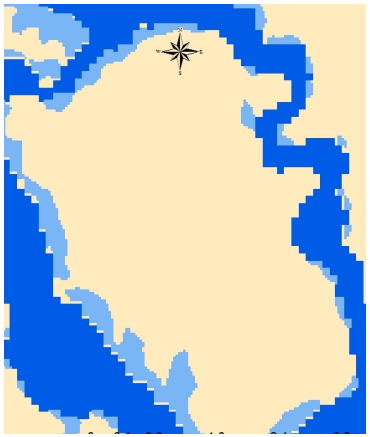
Under the RCP 8.5, most of Lamu Island falls within the inundation zone, except the Lamu Sand Dunes next to Shella residential area Table 6.4. As earlier described, a seasonal high tide in Lamu has already flooded the central business district and destroyed property and homes. Most of these homes close to the coastline are inhabited by fishermen and business people who live and work along the main Lamu highway.

Lamu Island travel

The Lamu community depends on the ocean channels for almost all their transport services. Such transport services facilitate the movement of food, fuel for the generator that supplies electricity to the whole island as well as commuting from the Island to the mainland. Disturbances on the coastal waters will leave the community completely stranded.

By the year 2060, island area of up to 28.3 Km^2 is low lying and is susceptible to ocean disturbances in the event of a severe coastal storm, clarified at 1-100 year return cycle. The inundation translates to 52.6% of the land mass being under threat from accelerated SLR. This includes the sections of Manda Island that host the Lamu Airport which will be slightly under threat. The mini Manda Toto, currently covered with mangroves, will be completely submerged under this scenario.

Table 6.5: Spatial extent and SLR impacts on infrastructure, assets and people under RCP 8.5 by 2060

Mombasa Island	**Highlights on areas affected**	**Lamu Island**	**Highlights on areas affected**
See Fig 4.14 for the names of exposed areas 	• Important infrastructure is under threat from inundation under this scenario • The areas around Makadara, the Chaani residential area in Changamwe, the Old Town and Fort Jesus tourism attraction sites are increasingly vulnerable • Others include the Nyali Bridge, Mama Ngina Drive, the Kizingo Residential area as well as well as the English Point Marina • Island area of 20.5% falls under threat of inundation • Population of 1.97 million people will be living within the inundation range • Asset exposure for the scenario is estimated at US$ 5.2 billion	See Fig 4.24 for the names of exposed areas 	• Sections of Manda Island, Lamu Airport, is slightly under threat, including the mini Manda Toto currently covered with mangroves • Archipelago area of up to 28.3 Km^2 is low lying and susceptible to ocean disturbances in the event of a severe coastal storm • The inundation zone translates to 52.6% of the land mass • A population of up to 138,300 will be living within the inundation zone • Asset exposure is estimated at US$ 362 million

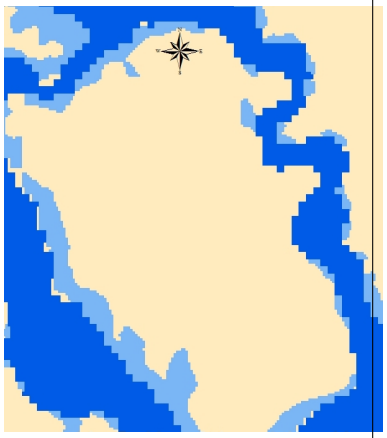
Population and socio-economic exposure

The exposed assets of Lamu Island at the elevation of up to 6m above sea level, under RCP 8.5 puts the county losses to around US$ 648 million and an exposed population of 248,000 people by the year 2090. The total asset exposure at Mombasa Island stands at US$ 9.2 billion by the year 2090 and a population of about 3.5 million by the same year. When the value of the property and infrastructure valuation that is based on the US$ 25 billion LAPSSET project, the total asset exposure is in the range of US$ 7.6 billion. At the 10m LECZ, the asset exposure in Lamu by 2090 increases a value between US$ 180 million to US$ 284 million in assets. The asset exposure increases when people and properties living within the 8m to 10m range (the LECZ) are included.

Effects on natural resources

Studies have shown a general impact on natural resources around coastal areas as a result of climate change induced SLR. Some of the changes are due to salt water intrusion and the physiological changes of plants due to the prolonged temperature and changes in rainfall pattern. SLR may be affecting the flora and fauna of coastal mangrove systems in ways that are yet to be studied and determined. A case in this study is the Manda Toto that is between the Manda Island and the Lamu Island. This natural resource that produces the mangrove poles (known as *Mikoko*) in the local dialect and used for the building of homes and other infrastructure) is under threat under the pessimistic scenario. The loss of such natural resources not only impacts the communities who depend on them directly for the production of goods and services, but also on the wildlife that uses the related eco-systems for food and nesting sites.

Table 6.6: Spatial extent and SLR impacts on infrastructure, assets and people under RCP 8.5 by 2090

Mombasa Island	**Highlights on areas affected**	**Lamu Island**	**Highlights on areas affected**
See Fig 4.15 for the names of exposed areas. 	• All the critical infrastructure on the Island is under threat • Areas affected include the railway's area, Makadara, a large percentage of Chaani area, the Old Town, cultural graves at the Old Town and Fort Jesus • Others include the Bondeni Estates, Tudor Creek, Kenya Ports Authority offices and bays, the State House area along Mama Ngina Drive, the Kizingo residence including Mtongwe Channel in Likoni • Total area of up to 3.1 Km^2 is low lying translating to almost 21.9% of the land mass under threat from accelerated SLR • The total population living within the exposed zone is about 3.5 million people • The asset exposure for this scenario id estimated at US$ 9.1 billion	See Fig 4.25 for the names of exposed areas 	• Under this scenario Manda Toto completely disintegrates from the influence of SLR • Manda island is separated into different portions as the area is inundated • Other areas under threat include the Amu division itself and transport from the island will be disrupted • Other areas affected include the Manda Island • Populations under threat in this scenario add up to 247,500 persons • Assets under threat add up to US$ 648 million

Exposed populations under threat

The increased migration of rural populations to coastal towns has led to urbanisation and population growth for coastline cities compounding the future impacts of climate change and especially SLR. Both Mombasa and Lamu islands have an increasing number of people living on the coast now coming under threat from accelerated SLR. Many of the participants living within the two coastlines appreciated that residing within the coastal areas for recreation, food and livelihood opportunities was attractive.

The total population living within the 8m sea level threshold for Mombasa Island is estimated to be 9.1 million by the year 2090 and 305,800 people in Lamu. This estimate is based on the standard annual population increase. The exposed population in the two islands grow to a total of 25.6 million individuals when the current urbanisation trends are factored into the model.

Summary finding on exposed infrastructure assets and people

Under the optimistic scenario of RCP 2.6, by the year 2090. Mombasa Island area of up to 23.3 Km^2 is low lying and is susceptible to inundation following ocean disturbances in the event of a severe coastal storm. The vulnerable land mass translates to 22.4% of the island area under threat from accelerated SLR. Under the pessimistic scenario (RCP 8.5 where the world population is increasing and no adequate efforts are made to mitigate GHG-emissions and increase in temperatures, and the use of fossil fuels is not abated). The inundation-prone areas for Mombasa Island by 2060 goes up to 25 Km^2. This translates to 22.6% for 2060 and a cumulative total of 44.9% of the land mass under threat from accelerated SLR.

Critical infrastructure for Mombasa and Lamu islands, especially the five and three star rated hotels, along with important port city development initiatives that serve central and eastern African countries, are faced with inundation as a result of accelerated SLR, under both the optimistic and the pessimistic scenarios. SLR impacts, especially on the services of Mombasa port as described, will impact not only the Kenyan economy but also the neighboring countries that use and depend on the coastal city for transport and the daily exchange of goods and services including tourists. The county and national government thus need to implement plans and programmes to protect these critical infrastructure from the impacts of the advancing oceans and especially the slow and gradual SLR. As of now, neither

Kenya's climate change strategy nor the Mombasa and Lamu county development strategy explicitly/systematically factor this challenge into their planning processes or programmes. The adaptation and related financial management for all the climate-related disturbances are lumped in one disaster preparedness budget that still lacks systematic preparedness measures for the specific impacts related to threats such as SLR.

Spatial and assets exposure for Lamu Island seems to be on the severe side even though in relation to the population exposed, lower population levels in the Island translates to lower number than for Mombasa. The exposure indices for Lamu increase substantially because the island's growth and development make the community rely on the coastal resources and businesses for survival. This is highly increased by the lack of alternatives, regarding transport, building materials and livelihoods. SLR-induced impacts will put a more severe strain on the growing economy of Lamu and its people unless adaptive and mitigation procedures are planned and executed. The LAPPSET project, which is set to become in the long-term part of the Lamu's development strategy lies within the inundation zone and is one of the significant infrastructures both to the economy of Kenya and Lamu. Other critical infrastructure under threat from inundation include the Lamu Airstrip at Manda Island as well as the hotels and business premises that line the island's coastal zone.

Whereas the study focussed on inundation vulnerability for the low-lying areas and focussing on infrastructure, assets and people under threat, inundation impacts will severely affect other areas beyond those that are directly inundated, especially when local and bulk infrastructure networks are rendered dysfunctional. These networks include storm water, sewage systems, electricity, vehicular transport and access and waste removal among others. Equally, the second-order (indirect) socio-economic appraisal of such indirect impacts has not been factored into the study.

6.3 Status quo vulnerability awareness, perceptions and readiness to act

The appraisal of community awareness and perceptions demonstrated several challenges, which include inadequate levels of understanding of the process of scientific knowledge production (the science) and needed/required application to enhance community awareness. The key finding is that the integrated research process facilitates for enhanced levels of knowledge and understanding arising from knowledge sharing, and thus facilitating innovation and readiness for adaptation and mitigation action/strategies. This section consolidates the key findings on this dimension of the study, across the three key themes of status quo awareness and perception, changes in perception and awareness together with the proposed/co-created adaptation and mitigation strategies.

6.3.1 Status-quo awareness of climate change and related SLR impacts

Coastal planning by planners and communities is mainly based especially on the mean high water mark which has served as the reference for coastal cities and the basis for planning the built environment together with the socio-economic initiatives/programmes within coastal settlements. Anticipated changes in climatic patterns, as now becoming evident in the present century through climate and weather changes, will rapidly raise the high water mark, and therefore the assumption of a stable sea-level will cease to serve as a reliable reference. Most coastal households derive their incomes from related maritime trade, fishing industry, and tourism. Any climate-induced disturbances to related coastal patterns will negatively impact on such livelihoods of coastal cities, as well as national and regional economies if not adequately understood and systematically mitigated.

Table 6.7 captures the key insights on status quo awareness and perceptions as reported by the mini-charrette participants from both islands. The key highlights are elaborated further in subsequent sections as a process towards resolution of research sub-question two on awareness and responses to the threat of accelerated SLR.

Table 6.7: Initial SLR awareness for mini-charette participants in Mombasa and Lamu

Status quo SLR awareness in Mombasa and Lamu	
Mini-charrette Mombasa	**Mini-charette Lamu**
• Participants had an idea what SLR is but had not experienced vivid evidence as yet • Participants had varying perceptions of the 'SLR' debate • Climate change is a far fetched idea that does not really exist • The fishing group participants did not seem to understand the influence of SLR and changes in fish stock • Need to survive now deemed a more critical priority than that of addressing future risks • Planners and environmental agencies had an idea what SLR is. However, sense of immediate serious threat was not evident	• Participants were of the idea that climate change is not happening. • Participants did not understand SLR and its effects. • The need to live and survive now is a more critical priority compared to adaptation for future vulnerabilities • Some believed SLR is an NGO agenda to solicit funds from donors • Planners and the NEMA environmental officers did know about SLR • Some participants were of the view that in some areas the sea was advancing while in some regions it was receding

Consolidated highlights on status quo SLR awareness

- Participants from both islands seem to have different levels of awareness/perception of the SLR threat
- Planners from both islands had different experiences with sea disturbances and perturbations
- Participants from both islands expressed a bias towards prioritizing present needs and thus discounting/downplaying adaptation/mitigation needs
- SLR threat is not viewed as probable or likely by participants from both islands
- Participants expressed good understanding of respective communities' dependence on the sea for nourishment and business/economic activities
- The urge to live off the coastline/ocean and its resources was evident
- IKS is critical in transfer of knowledge and enhanced adaptation
- Feedback from within both groups of participants arrived at the insight that changes at the coast are happening and are being experienced

Diverse understanding of climate change and SLR

Participants in both Mombasa and Lamu had varying levels of awareness/perception of climate change while also demonstrating a critical gap in awareness of SLR impacts on coastal cities. One of the subsequent on-line respondents was aware of climate change and SLR and insisted that "Mombasa is an island and that those in planning and approval of high-rise buildings should know in long run putting more weight on the island is going to sink it. Before independence/colonial era the British knew this and never approved any buildings more than three storeys high. The approval standards can be checked in land/planning registry records". In particular, participants did not understand the relationship between climate change and accelerating SLR, with some participants insisting that scientists are fictitiously creating the story of climate change this is reflected by a a frustrated response by one of Lamu participant who observed as follows "Why do fake experts keep on repeating this story".

IKS usefulness in adaptation to coastal problems

The application of local IKS knowledge was identified as one of the methods participants and local communities could use and share information towards understanding a changing climate and preparing for adaptation strategies. Participants from Lamu and Mombasa islands appreciated the knowledge shared by the older generation on how to assess changing climates and offering methods of adaptation to the changing weather/climate systems. Some of the knowledge passed on includes awareness of changes in fish abundance and species as well as changes in vegetation patterns which can be a sign of siltation or a sign of temperature changes as some fish species diminish or increase. This knowledge could be explored and integrated then transferred to the younger generation for an evolving/improved understanding of SLR.

Apathy and lack of collective interest in SLR

The participatory process was able to highlight some of the fears related to climate change adaptation in particular by some participants who felt out rightly helpless. One participant, for example, went as far as wondering "who cares! I am 46 by now 2015 + 60years= 2075 most likely I will not be there". A general concern was noted where the government, now struggling with business and community demands, must also start factoring in coastal protection because of SLR, and thus opening a new push-and-pull in the socio-political frontier.

Some participants went further and insisted that being low lying is not an issue with one member claiming "We all know that Netherlands is below sea level, and still a powerhouse". To the contrary, others felt that the comparison was hollow, as Kenyan government cannot even provide the essential services to Kenyans. "Exactly it is the Netherlands, and we are in Kenya ... we do not even have enough money to guarantee proper security and education, so how will the government protect the coastline as the Netherlands government does?". Many of the community participants appreciated the significance of being informed about climate change and in particular the SLR threat to tourism and livelihoods on the coast of Kenya.

Summary of finding towards resolution of sub question 2 on participant awareness and perception

The difference in understanding by the planning/administration officials and the participants with regard to issues of climate change made it a challenge to discuss the current climate change trends especially SLR with local community members and the planning authorities in both cities. The absence of any adaptive measures is evident at the county government's planning laws that are still based on a stable coastline. Unmitigated action/development of buildings and hotels at the coast as evidenced in Lamu, after the dredging for the port contributed to the creation of new land mass, was highlighted as one example. The "business as usual" approach exhibited by participants from communities and the planning authorities in both islands, and there seems to be systematic discounting of risks and challenge posed by the accelerated SLR.

Given that local planning authorities continue with the development without climate change informed mitigation strategies at the coastline, participants were are not keen on planning a response. The lack of enthusiasm is mainly due to insufficient information on the impacts of SLR, which induces communities to be less proactive in coming up with community-based initiatives of their own in order to prepare for impacts of SLR. As indicated during the mini-charrette the laxity of participants may be due to lost faith in the ability of different levels of government to deliver services in an accountable manner. Besides the challenges of participation within communities, a lack of collective interest was also evident during the mini-charrette as no individual was willing anymore to champion any initiatives. The reason given for the noted level of disempowerment was the scanty information passed to them with regards to climate change and related

SLR impacts.

On a positive note, participants acknowledged that some information on changes at the coastline, especially shifts in the weather patterns and declining availability of fish species, was passed on from the older generation who had a longer and richer memory of living in the islands. The shared information stimulated participants towards envisioning adaptation measures for their own long term survival. A a case in point, participants who were mostly involved in fishing explained that during the *Kaskazi* changes in wind patterns directly affected fishing as the wave strength gradually increased, and of late, such episodes were becoming more frequent. They emphasized the need to systematically communicate on SLR challenges to the people living in vulnerable areas, and the same information to be passed to the younger generation in order to reinforce their understanding of threats and vulnerability levels due to climate change.

6.3.2 Climate change and SLR awareness and perceptions after mini-charrette

Participants in both islands agreed on interventions that can be used to improve on the currently low level of SLR awareness as reflected under the status quo appraisal. The renewed understanding of climate change and SLR by the participants initiated a discussion on reasons why and how global warming will cause negative impacts for them even though they are not the contributing polluters through GHG-emissions. The discussions focussed on the "denial and the blame game" that goes on between communities, their leaders and the GHG-emission polluters who are mostly from the developed countries.

Participants agreed that governments and the planning authorities in Kenya should focus on adaptation techniques, and also pursue the developed world to support these initiatives. This should also translate to mitigation of escalating vulnerability of local communities when partnering with international organisations in negatively perceived development projects as was evident in Lamu over the dissatisfaction of the coal plant approved by the government. As lamented by one of the participants in Lamu "If SLR is true, it is graceless that the government can get into deals to develop coal mining projects in Lamu, such countries should instead set up a coastal defence fund to help adaptation for coastal communities directly impacted by SLR". Improved awareness from the dialogue on the vulnerability of local communities became evident when participants implored planning agencies to keep coastal areas

under protection from high-rise building developments and investments located too close to the sea.

As illustrated in Table 6.8 the participatory mini-charrette technique created awareness along SLR and climate change and participants were willing to get involved in adaptation through the following enhanced awareness strategies:

- Enhanced awareness through information sharing
- Enhanced awareness and increased willingness to act in adaptation and mitigation
- Enhanced awareness and the need for diversification of livelihoods
- Enhanced awareness and the need for ongoing capacity building among individual residents, communities and organisations.

Enhanced awareness underpinning dialogue on information sharing

The participants expressed a need to reclaim decision-making power and governance that was given away to outsiders such as developers of hotels and owners of fishing rights and beach fronts. A need was also expressed for better communication and voice in government and industry so that both "within" and "outside" decision makers can hear and involve local inputs/expertise in climate-change based planning and decision making. Participants also expressed the need for a more robust lobby to protect the resources of both Lamu and Mombasa as well as their unique/distinct culture(s). Increased media involvement was suggested hand-in-hand with continued protests, and enhanced political lobbying to improve information dissemination in support of initiating for adaptive strategies.

As expressed by participants (see appendix D), household preparedness varies greatly among and within resident communities in both islands. The results suggest that increased information and incentives are needed to enhance household awareness and action on sufficient emergency supplies of basic needs such as food and water supplies, fuel and heating/lighting for extended periods. Participants further noted that communication and contingency plans in the event of hazards (at household to community levels) do not currently exist and were thus urgently needed. Household, level insurance programmes were also considered as supplementary mitigation/adaptation interventions.

Table 6.8: Change in SLR vulnerability perceptions and awareness through mini-charrette process.

Change in climate change and SLR vulnerability perceptions and awareness	
Mini-Charrette Mombasa Island	**Mini-Charette Lamu Island**
• Climate change is real and SLR is understood to be causing changes at the coastline (IKS guided insight)	• Lamu participants felt more at risk from impacts of accelerated SLR
• The need to be vigilant and engage with peers on mitigation was envisaged	• Participants agreed that an NGO that has been in the forefront fighting for environmental safety should include SLR as a subject
• Participants agreed that the future is equally as important as the present, especially for the benefit of their children	• Participants were for the idea of a collective response towards the protection of coastal resources
• Participants also agreed that information on SLR should be systematically shared with them for timely action	• The need for conservation today in order to secure future benefits was also highlighted and accepted by the members
• As an example, they accepted it as their responsibility to proactively initiate adaptation and mitigation solutions	• Participants were of the opinion that information and communication of SLR findings was a critical starting initiative
• Participants perceptions/awareness had improved and this facilitated dialogue on planning for adaptation,	• Participants concurred on the need for communities to create their adaptation and mitigation strategies within networks of other stakeholders/actors

Consolidated highlights on changes in SLR vulnerability perception and awareness

- Participants in both mini-charrettes appreciated and perceived as important the shared information on SLR
- They also concurred that plans towards adaptation as well as mitigation should be championed by themselves among other actors
- The participants agreed on robust community-led initiatives and that change of mindset is important to mitigate current levels of apathy
- They agreed on the enhancement of participatory local governance especially in relation to SLR
- They were cognisant of the fact that the assets exposed within the coastal zone will negatively impact on their communities well-being and livelihoods
- Participants concluded that capacity building for preparedness is a critical component in planning for resilience to SLR in both islands

Enhanced awareness underpinning dialogue on willingness to act on adaptation and mitigation

Adaptation is the ability of communities households and individuals to deal with exposure to climate-change related risks and hazards (such as sea level and storm changes, coastal erosion, flooding and landslides). As such, enhanced adaptive capacity enhances resilience (the ability to prepare for, avoid, moderate, and recover from related risks and shocks). During the mini-charrette, participants in both islands became fully cognisant of the critical threat of accelerating SLR and agreed on participation in the community-led initiatives towards enhanced adaptation and mitigation capabilities.

It is at the community level that efficient and broad-reaching adaptation programs can be developed and implemented. Households need support (in forms such as financial, logistical, or informational) in order to become better prepared for escalating levels of vulnerabilities. Community emergency planning was suggested as a strategy to improve adaptation and reducing apathy to SLR threats. The participatory processes for Mombasa and Lamu concurred that awareness creation on vulnerability levels and providing people with the relevant information and tools of adaptation will help communities engage in providing a coordinated approach and response to coping with emergencies and natural hazards arising from escalating SLR.

Enhanced awareness underpinning dialogue on diversification of incomes and livelihoods

Enhanced awareness of climate change and impacts of accelerated SLR underpinned the dialogue on the need to diversify sources of revenue as a key adaptation strategy. The diversification will come in handy in the event of interruptions due to increases in intensity and frequency of coastal storms and related disturbances. Development of the general economy complete with diversified initiatives in tourism, arts, culture, and resource stewardship could further enhance community resilience to socio-economic disruptions associated with climate change and escalating SLR. Forestry-based communities have been identified as particularly vulnerable. The diversification of the tourism industry could involve diversifying and promoting cultural and wilderness aspects of the islands, as well as other recreational opportunities such as water sports and surfing, among others.

Enhanced awareness underpinning dialogue on capacity building for communities

Capacity building and preparedness programs could consider incentives and assistance in support of households to be proactively engaged in adaptation and mitigation strategies for SLR. These responses could include community preparedness donations/banking (similar to food banks) or discounts/vouchers for the purchase of emergency supplies. Such measures are particularly critical for households who would otherwise be unable to obtain such supplies. Other suggestions underpinned by the enhanced awareness included community workshops as a way of improving community-based capacity for action and response. Such workshops could include first aid training or tsunami preparedness as well as responses aimed at engaging and assisting homeowners and community towards ongoing improvement in their emergency preparedness.

Summary on enhanced perception and awareness

The impacts of climate change and especially SLR for the coast of Mombasa and Lamu as assessed will put a severe strain on the economies and the populations living on the islands. The pressure will include the disruptions of transportation systems especially in Lamu due to the dependence on the sea for transport, and in Mombasa where main Nyali Bridge and the Makupa Causeway which serve as the only entry and exit points of the islands. The juxtaposition on the dire consequences and impacts on the communities is in contrast to the absence of community led initiatives and local government prioritisation of this matter regarding awareness creation and planned emergency responses.

The argument is that the complacency by the central government with regard to offering reliable solutions to communities is affecting the ability of community members access to information on such phenomena like climate change and SLR and therefore directly affecting the communities perception and awareness in dealing with such kinds of disasters. During the mini-charrette in the two islands, the communities generated their adaptation techniques that can be adapted to their different islands, as the island of Mombasa and Lamu have varying levels of vulnerability, and this required participants from each community develop strategies towards their specific adaptation needs.

In general, participants from both islands felt that capacity building for community members as well as the diversification of income sources, is a priority

for the communities to be resilient in the case of impacts of accelerated SLR. As earlier mentioned in Chapter 5, and summarised in Table 6.8 the need for capacity building, planning and executing strategies in order to enhance resilience is an important milestone in the appreciation of awareness, changing attitudes and planning proactive implementation strategies.

6.3.3 Enhanced awareness and co-created SLR adaptation options

In 2010, the Kenyan Government launched the National Climate Change Response Strategy which was meant to enhance understanding of global climate change and its impacts within the local context. The strategy was Kenya's first climate change agenda guide which provided a basis for focusing governmental action towards adaptation and mitigation interventions. In the development of this plan, the procedure failed to provide for involvement of local communities due to logistical and costs implications of the necessary participatory processes. Another major gap in the strategy is that SLR and related vulnerabilities of coastal communities were not specifically addressed in the strategy.

The participatory vulnerability analysis undertaken in this study demonstrated the critical role of stakeholder participation in both the analytical as well as the response strategy formulation stages. The positive outlook on adaptation and mitigation was ascertained as the participants enjoyed the benefits of new insights from each other as well as the researcher concerning climate change and its relation to SLR for coastal areas. An important outcome of the study was to demonstrate the benefits of scaling down scientific SLR knowledge in order to support information sharing with local community members at different levels. This awareness and information sharing process empowered participants towards generating approaches for enhancing their adaptation and related levels of resilience given their unique SLR vulnerability.

Changes in perceptions and awareness of climate change and SLR underpinned participants discussions on the adaptation techniques that could be implemented to mitigate impacts on lives, resources, infrastructure and assets from the consequences of climate change and related SLR. These proposed interventions include

- Improve on locally based communication on SLR impacts and adaptation

- Engage in community led initiatives for adaptation interventions
- Participate in local governance to articulate climate change and SLR adaptation initiatives for varying levels of actors
- Consider a proper community based local planning forum/platform to protect vulnerable areas and communities

Table 6.9: Change in awareness and SLR adaptation/mitigation measures envisioned

Change in perception and SLR adaptation interventions prioritized	
Mini-charrette Mombasa Island	**Mini-charette Lamu Island**
• Improved communication of SLR and its impacts across various community levels (individuals, households,neighbourhoods) • Poverty alleviation and improved diversification of livelihoods for survival • Engage in community led initiatives on adaptation and mitigation strategies • Internal and external information sharing on responsive resilience and adaptation measures • Initiate efforts to engage with various levels of government especially on decision making on developments along the coast • Seek for home grown solution to this global threat based on IKS	• Participants agreed on means of building adaptive capacity in face of accelerated SLR and climate change • Participants prioritised increased awareness of climate change and adaptation strategies available • Participants agreed on encouraging both household and community level response planning especially in cases of emergencies • Mitigation of vulnerability of critical infrastructure of Lamu Island was also prioritised • Community-based solutions to coastal protection and especially conservation techniques was also identified • Engaging support from local community members and leaders to build resilience through mitigating apathy

Consolidated highlights on SLR adaptation interventions prioritized

- Improved communication and shared information on SLR and its impacts on the community and overall economy
- Enhance capacity-building especially towards poverty alleviation and improved diversification of livelihoods
- Engage in community-led initiatives on adaptation and mitigation strategies
- Enhance internal and external information sharing on resilience and adaptation measures considered
- Participate in efforts to engage with government especially on developments along the coast
- Seek for a home-grown solution to this global threat based on IKS

Facilitate local based communication on SLR impacts

As mentioned under Section 4.22 and Table 6.8, participants were of the view that the current inadequacies in information sharing on the effects of climate change on coastal residents are a matter of concern which should be systematically addressed. The information can be shared using both the IKS during cultural festivities and should be coupled with ongoing improvements to systematically raise awareness to facilitate the evolution of effective adaptation and mitigation strategies in the short to medium term.

Engage in community-led initiatives for adaptation policy and programmes

Participants felt that community driven adaptation responses are likely to succeed when effective communication is emphasized as the core for effective adaptation and mitigation response. When vulnerable and potentially affected communities or stakeholder groups get better informed, their response is most likely to be enhanced. Ultimately it is at the community level that effective, broad-reaching mitigation and adaptation programmes can be developed and implemented. Households need support (whether financial, logistical, or informational) to better prepare for future eventualities. Community emergency planning is one of the critical imperatives regarding raising awareness, providing people with the information and tools to help themselves and providing a coordinated approach and response to coping with SLR related emergencies and natural hazards.

Participate in local governance for posterity

Participants concerned that consultation on decision-making would include a range of stakeholders with representatives such as elected officials, towards strategic adaptation and mitigation municipal representatives, the local Kaya elders, business owners, regional and town planners, local communities and residents, and special interest groups. However, useful and meaningful participation/empowerment requires systematic preparations coupled with resources to ensure ongoing dedication as well as pro-actively attracting/integrating different viewpoints and ideas.

Collective planning and management of common resources

The need to allow community members the "rights" to access communal resource-base and co-jointly diversify their resources was reiterated as a policy

and adaptation priority. The right to manage was particularly highlighted in both Mombasa and Lamu where participants were of the view that government and communal properties on the coast need to be vested and co-managed by the local community groups. Such initiatives were suggested as a method of mitigating the illegal exploitation and development on critical ecosystems that increase the vulnerability of the communities to the impacts of SLR. Such spaces include the beach areas which should be free from development and the zones that are covered with mangroves as a natural shelter and protection of the local communities as well as both flora and fauna from the impacts of SLR.

Summary on community based adaptation and mitigation strategies

Community satisfaction with necessary and vital social services and decision-making processes is an indirect measure of social cohesion as one of the key factors in social capital (fundamental, cognitive and relational structure). For instance, social capital can facilitate an individual's access to knowledge about employment, political support, adaptability for resilience and other resources. When a community's ability to participate in solutions to their problems is compromised, social cohesion is disrupted thus escalating their vulnerabilities to risks/threats such as SLR impacts. These vulnerabilities are further exacerbated by the dependency of local communities on the various levels of government for their basic amenities and services. The need for community-driven solutions (which are better adapted to the local community conditions) cannot be overemphasized.

Lack of emergency preparedness was a common theme among the charrette respondents. The key issues identified include, lack of knowledge on probable future environmental changes, lack of clear inventory in local stores and government offices, and inadequate emergency services and coordination systems and especially absence of backup communications. All of these ideas depend on how residents/participants perceive preparedness for their community in the event of emergencies and is therefore directly relevant to climate change-related extreme events (for example storm surges and coastal erosion). Contingency plans can be developed and adopted by community members when information is shared across generations and co-management of available resources is vested in such communities. Adaptive and mitigation strategies are best implemented through a cohesive and well-informed community.

The need for short-term responses to adaptive capacity was seen as an immediate

need for the community members living in these two islands. They were of the opinion that there are currently no measures to protect the coastal communities from extreme events triggered by the changes in ocean storm frequency, density or increased coastal storms. They reiterated that flooding caused by high tides and the general increase in rainfall pattern had not yet received systematic response from the communities, respective county or national county levels.

6.4 Overall conclusion and recommendation

The study hypothesized that an integrated vulnerability assessment process could improve vulnerability appraisal and additionally highlight several issues that are key in sustenance and protection of coastal communities from the impacts of climate changes and especially SLR. The conclusion of the research is based on the objective of co-production of knowledge for vulnerability awareness and change in perceptions on the related vulnerabilities and regions strategies. The hypothesis thus envisaged that an integrated process could positively influence awareness and thus lead to changes in perceptions that would in turn become vital for adaptation and mitigation efforts that are unique and focused to the context. Three research questions facilitated the substantiation of the hypothesis as summarised in the subsequent sub-section

- The vulnerable assets, spatial extent and populations within the two Islands, and the importance of co-production of this data
- Importance of collaborative vulnerability assessment in awareness and perception improvement
- The need for collaboration with the community in co-production of vulnerability atlas and the development of adaptation and mitigation strategies

6.4.1 Vulnerability of coastal infrastructure problems and the need for adaptation and mitigation

The spatial analysis in vulnerability assessment for Mombasa and Lamu islands showed advanced effects on both the community and critical infrastructure apart from displacing populations in these islands. Accelerated SLR can impact the GDP of Kenya where essential infrastructures such as the Nyali Bridge, the Mombasa Port and the LAPPSET project are rendered vulnerable and thus

mitigation and adaptation techniques need to be in place to protect threatened assets and communities. Integrated SLR analysis in coastal planning would thus facilitate new centres of knowledge and stretching out of the typical horizons of time and centuries. Such knowledge should be nationally included in the planning and implementation of sustainability interventions for coastal cities such as Mombasa and Lamu whose residents and infrastructure are under threat from impacts of accelerated SLR.

The essence and advantages of including local community in the assessment of the vulnerable areas are to explore uniquely relevant alternative methods of adaptation and mitigation. Through the co-production of the vulnerability atlas understanding and sharing experiences on the assets and people threatened ensured that community can be implored to explore and protect their land and property from destruction, or at most be able to become resilient and bounce back from the effects of such events.

Climate change impacts and especially SLR threats to coastal communities' ability to be resilient through adaptation strategies can reverse the trend toward adequate protection and mitigation of significant resources that support families and businesses in these coastal regions. The science of climate change and related impacts calls for radical shifts in mindsets. It would therefore not be or even surprising if it takes decades or even centuries, for concerned governments to accommodate and agree on meaningful climate change adaptation strategies/measures where reliable data remains inadequate towards facilitating meaningful protection of state infrastructure, and vulnerable communities from impacts of climate change such as SLR.

Table 6.10: Summary of SLR impacts on infrastructure/assets and people in Mombasa and Lamu

Item	Scenario	Mombasa	Lamu	Overall
Area	• 8.5	• 8.0 Km^2 equivalent to the 51.6% of land area threatened	• 103.5 $Km^2$of land under equivalent to 71.5% threat	• Between 25% to 50% of Mombasa and 36.5% to 71% of Lamu land mass is vulnerable to inundation. The significance contrasts drastically with the total absence of perception/awareness of SLR
	• 2.6	• 4.2 Km^2 under threat	• 81.1 Km^2 under threat	
Assets	• 8.5	• The asset exposed adds to US$ 14.5 billion	• The asset exposure is estimated at US$ 1.2 billion	• Total exposure between US$ 6.4 billion to 14.5 billion in Mombasa and 435 million to 1.2 billion in Lamu
	• 2.6	•The asset exposed adds to US$ 6.4 billion	• Asset exposure is estimated at US$ 435 million	
People	• 8.5	• 9.7 million people exposed	• 452 thousand people exposed	• Total population of up to 9.7 million in Mombasa and 452 thousands in Lamu threatened
	• 2.6	• 6.1 million people exposed	• 248 thousand people exposed	
Infrastructure	• 8.5	• Mombasa Port, Nyali Bridge and English point Marina	• Amu city, Manda Airport, LAPPSET site under threat	• Important infrastructure both in Mombasa and Lamu under threat, adaptation is crucial
	• 2.6	• Chaani and Mama Ngina drive is under threat	• Manda Toto, Shella residence under threat	

6.4.2 Information sharing and co-production of knowledge a precursor to awareness on SLR

Climate change vulnerability assessments can not be presumed as an independent activity devoid of the participation of the people living and eking a life in these vulnerable areas. The co- production and sharing of information on such issues that affect community members, constitute an effective strategy towards advancing the knowledge as well as preparing for the adaptation techniques that could be pursued.

For example, participants in Lamu Island noted that the participatory process was enriching in understanding the concept of climate change and SLR as well as in defining their vulnerability levels. The shared knowledge on SLR generated dialogue on how community members in Lamu and Mombasa can be prepared for adaptation and mitigation in the event of severe coastal effects due to accelerated SLR as illustrated in Table 6.8.

6.4.3 Participation and co-creating adaptation and mitigation strategies to SLR for Mombasa and Lamu

The complexities of building resilience to impacts of climate extremes in a developing context are comparatively unexplored. Daily challenges influence the capacity of individuals communities and municipalities to cope with extreme events and it is within the person and day-to-day context that adaptation is most likely to be effective. Participants in Lamu and Mombasa islands are not exempt from the inadequate facilitation by local governance and as such climate change adaptation is not given the priority it deserves. The articulation and understanding of perceptions and the range of risk were evident in both communities during the mini-charrette and participants suggested adaptation measures that can be locally incorporated to protect them from climate-induced SLR impacts. The understanding of the complexity and problems related to community vulnerability and perceptions in SLR was a necessary precursor to building effective structures and behaviors to reduce vulnerability and build resilience, adaptation, as well as mitigation of the related risks, Table 6.9.

Politically, climate change cannot be subsumed purely within the knowledge and decision-making routines of even the most scientifically advanced nation-states or validated following any single nation's independent scientific or administrative

practices devoid of the affected communities. Many states and their governments, especially in the developing world, are daily faced with the dilemma of the provision of the essential services to their communities versus initiating adaptation/mitigation of long-term threats such as SLR. The important role of co-production of SLR information as illustrated in this research regarding community vulnerability is again, a significant step towards enhancing the role of the community in demanding and advocating for adaptation strategies, based on the understanding of the threats and the critical areas that are vulnerable and valuable to them.

Devolving planning roles to county levels is a sure way to fast track county led initiatives that can address environmental as well as urban and regional planning challenges. Climate change impacts such as SLR are unique to specific geographic areas, and political structures such as the counties of Mombasa and Lamu and strategies that directly include the county governors in these areas may yield better planning and implementation outcomes. Vulnerability studies based on physical and mathematical models for SLR without actively involving communities nullifies the opportunity/potential for a holistic approach towards the management of climate change related threats. This is evident from the limited application of findings from such stand alone studies as governments and communities take their time to access and integrate the findings into their plans. As an example, Kenya has never had comprehensive and integrated vulnerability assessment studies for the coastal communities in relation to the impacts of climate change and especially SLR.

Table 6.11: Summary of awareness and perception changes in Mombasa and Lamu

SLR awareness	**Mombasa/Lamu**	**Overall**
Status quo	• Awareness is scanty, future not important • Participants from both islands expressed a motivation bias to prioritize present needs and thus discounting/downplaying adaptation/mitigation needs	• The urgency for SLR realisation not evident • Planners and environmental agencies had an idea what SLR is However, sense of immediate serious risk was not evident
Mini-charrette	• Awareness increased and need for adaptation envisaged • The need to be vigilant and engage with peers on mitigation was envisaged	• Future sustainability and available options considered • Local adaptation plans engaged
Adaptation and Mitigation strategies envisaged	• The need to get involved in adaptation reinforced • Future involvement/participation in plans for the development of the coastline agreed upon	• Plans to improve communication, engage the government in poverty alleviation and economic diversification was suggested • Participants level of awareness improved drastically from the previous stances

6.4.4 Key conclusions and recommendations for future studies

Key conclusions

As seen in Table 6.10 even under the most optimistic scenario, close to 25% of Mombasa island and almost three quarters (75%) of Lamu Island are at threat from inundation. Under the pessimistic scenario, almost 50% of Mombasa Island and its critical infrastructure is under threat. The protection of this two coastlines is therefore critical even though this may be well beyond the capabilities of the Kenyan government capacity and resources at the moment. A method that is sure to reduce the number of people and the asset exposure will be adaptation techniques that are locally based and can be replicated within the various communities in both islands.

Key recommendation

This study dealt with the methodology for the assessment of vulnerability in an area where there is hardly any little-integrated assessment studies to date. Most of the assessments undertaken to data globally are biased towards the stand-alone scientific approach. The scientific approach that is conventionally used explains the apparent lack of different data to compare with the findings of an integrated study as applied in this study. The participatory procedure and analysis employed in this research method faced critical challenges some of which are stipulated in the participatory approach section in Chapter 3. The participatory method using mini-charrette is thus authentic and enriching especially for the sharing and discussions of the scientific based findings.

Given the findings of the study, it is recommended that the sustainability and protection of these two islands is important to the economy of Kenya, with specific Deliberate policies on adaptation, coastal planning and protection with SLR in mind. Action plans included in the county development plans that are meant to protect the environment and enhance the protection of critical infrastructure in these areas, should be considered. Since the climate action plan for the country is salient on the matter of SLR and coastal protection, its recommended that an addendum is added to the legislation for adaptation and mitigation of SLR impacts to the coastal cities of Mombasa and Lamu

For further research and expansion of knowledge, it is recommended that other methodologies, such as the involvement of well established community and youth

groups in similar studies is investigated for a sustainable and continual process. The available community-based groups would help to understand and to determine which groups can form an open forum for use as a practical method of climate-change vulnerability analysis. The involvement of climate-change threat prone sectors which are diverse is best achieved when the stakeholders are consulted on an ongoing basis. Climate-change related remote-sensed data in Kenya is still at a rudimentary level. Highly remote sensed data through Lidar data for example should be enhanced and made available to improve scientific monitoring and analysis of climate-change trends ad related changes in levels of vulnerability for different zones and regions of the country.

References

Appendix A

Supplementary information

Table A.1: Mombasa elevation and population exposure by 2090

Elevation	2009	2030	2040	2050	2060	2070	2080	2090
Less than 2m	133,456	417,289	585,497	753,705	921,913	1, 090,121	1,258,329	1,426,537
Between 2 - 4m	5,113	15,988	184,197	352,405	520,613	688,821	857,029	1,025,237
Between 4 - 6m	6182	19,328	187,537	355,745	523,953	692,161	860,369	1,028,577
Between 6 - 8m	6278	19,628	187,837	356,045	524,253	692,461	860,669	1,028,877
Between 8 - 10m	9213	28,806	197,015	365,223	533,431	701,639	869,847	1,038,055
Totals 0 - 10m	160,242	501,039	1,342,083	2,183,123	3,024,163	3,865,203	4,706,243	5,547,283

Table A.2: Lamu elevation and population exposure by 2090

Elevation	2009	2030	2040	2050	2060	2070	2080	2090
Less than 2m	6 134,38	19 180,98	31 315,98	43 450,98	55 585,98	67 720,98	79 855,98	91 990,98
Between 2 - 4m	530,49	1 658,74	13 793,74	25 928,74	38 063,74	50 198,74	62 333,74	74 468,74
Between 4 - 6m	2 622,75	8 200,83	20 335,83	32 470,83	44 605,83	56 740,83	68 875,83	81 010,83
Between 6 - 8m	12 114,31	37 879,03	50 014,03	62 149,03	74 284,03	86 419,03	98 554,03	110 689,03
Between 8 - 10m	6 535,86	20 436,34	32 571,34	44 706,34	56 841,34	68 976,34	81 111,34	93 246,34
Totals 0 - 10m	27 937,79	87 355,92	180 602,26	208 705,92	269 380,92	330 055,92	390 730,92	544 651,28

Appendix B

A process manual for integrated vulnerability assessment of SLR along coastal island cities



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B.1 Preface and Introduction

Stand alone scientific analysis has been the primary approach to climate change and SLR vulnerability assessments around the globe. This is then followed by the dissemination of the results to the affected communities and governments to solicit adaptation measures in several fields such as agriculture and food security. The key challenge of this approach has been the neglect and discounting of such findings by the target communities who may be affected as they do not always fully comprehend the significance of such findings especially in terms of implied impacts, or how to strategically respond with effective mitigative and adaptive strategies.

Since the Rio Earth summit in 1992, participatory processes have been hailed as methods that can offer better management towards sustainability especially for resources that support livelihoods and well-being of affected communities. This management approach provides for a more efficient protection of resources as well as communities. The need for adaptive socio-ecological systems has initiated a necessity of community oriented management and co-production of environmental and ecological strategies for resilience.

This manual is designed around sharing an understanding of both physical and social impacts of coastal SLR, and how various types of knowledge could be applied towards guiding communities to change and respond to oceans and sea related perturbations emanating from climate change. The manual focusses on an integrated vulnerability assessment approach through an initial analysis of the physical infrastructure and human activities, at risk from the impacts of escalating SLR, combined with a participatory process towards enhanced awareness-raising and dissemination. The initial stages of the process involve the use of spatial, statistical and quantitative analysis of exposure inundation data from annual climatic forecasts and global SLR-induced inundation scenarios.

In order to enhance spatial and social analysis, it is essential to include inputs from supplementary documents such as government policy and reports, coupled with focus group appraisal processes with the affected stakeholders and communities as well as planners and managers among other interest groups. This process can be enhanced through a mini-charrette process aimed at co-production of the vulnerability atlas. The results of the synthesized investigations are subsequently integrated towards overall findings and addressing the primary objective of conceptualizing mitigation and adaptation strategies for implementation.

B.1.1 Organization of the manual

The process manual has been structured as follows. Section 1 and 2 covers the initial and preparatory stages of the process and the critical data needs for the process. Section 3 includes the processing of raw data from primary and secondary sources to make it suitable for ArcGis process and segmentation by creating raster datasets from LiDAR or other available data. In Section 4 the mini-charrette process is discussed and how to ensure it runs successfully as well as to optimise its goals and objectives. Section 5 includes the actual estimation of SLR vulnerability inventory results for the area under assessment, as well as coalescing of the data and report writing.

B.1.2 Objectives of the manual

The key objectives of the manual are as follows:-

- Understand the different criteria used in selecting a vulnerability assessment methodology
- Assessing initial climate change and SLR vulnerability levels for coastal city or island regions, with factors such as zones, assets, people and activities, infrastructure and services under threat
- Use of GIS-based tools and techniques to identify and map the extent of inundation risk for coastal zones based on adaptation of regional modelling to global inundation scenarios
- Appraise status quo vulnerability perceptions and awareness through a participatory process and conceptualise/develop the adaptation and mitigation practices and coping strategies in place
- Share research report on the modelled SLR findings with affected communities and relevant stakeholders
- Co-produce vulnerability atlas as well as mitigation and adaptation interventions/policy options for subsequent action and implementation
- Empower communities and stakeholders in responses to evolving risk levels by prioritizing defensive resources and manage ongoing vulnerability events
- Reflect on process and necessary improvements for subsequent interactions based on insights from this initial implementation cycle

B.1.3 Manual description and content

The integrated vulnerability assessment process entails four key components in SLR studies as follows:

- Climate change induced SLR and its relation to coastal vulnerability
- The main conceptual frameworks underpinning SLR vulnerability assessment approaches
- Field research and assessment of SLR vulnerability
- The role of community participation in co-production of adaptive and mitigation responses to the vulnerability related to SLR

The four components are described in detail under two steps and processes as follows:

- The Geographical Information System (GIS) process
- The Participatory Action Planning (PAP) process based on the mini-charrette technique

These processes are described in Digram B.1 below.

B.2 The GIS process

This section introduces the GIS datasets and tools employed in the process. Some datasets are prepared beforehand so that the process itself could be more focused on the inventory. All the data sets for the process should be kept in an easily accessible folder. The GIS Data would preferably be prepared beforehand for use in the practical session. All the results of the different phases are stored in the same folder which could be named "Results". During the GIS processing, the applicable map coordinate system should be used to avoid map distortions which could lead to inaccurate results.

B.2.1 Literature review

It is important to read and understand the concept of climate change, vulnerability assessments, coastal planning and design and the issues of adaptation and resilience responses/strategies. Studies on these topics will offer insights into the process of climate and environmental vulnerability assessments.

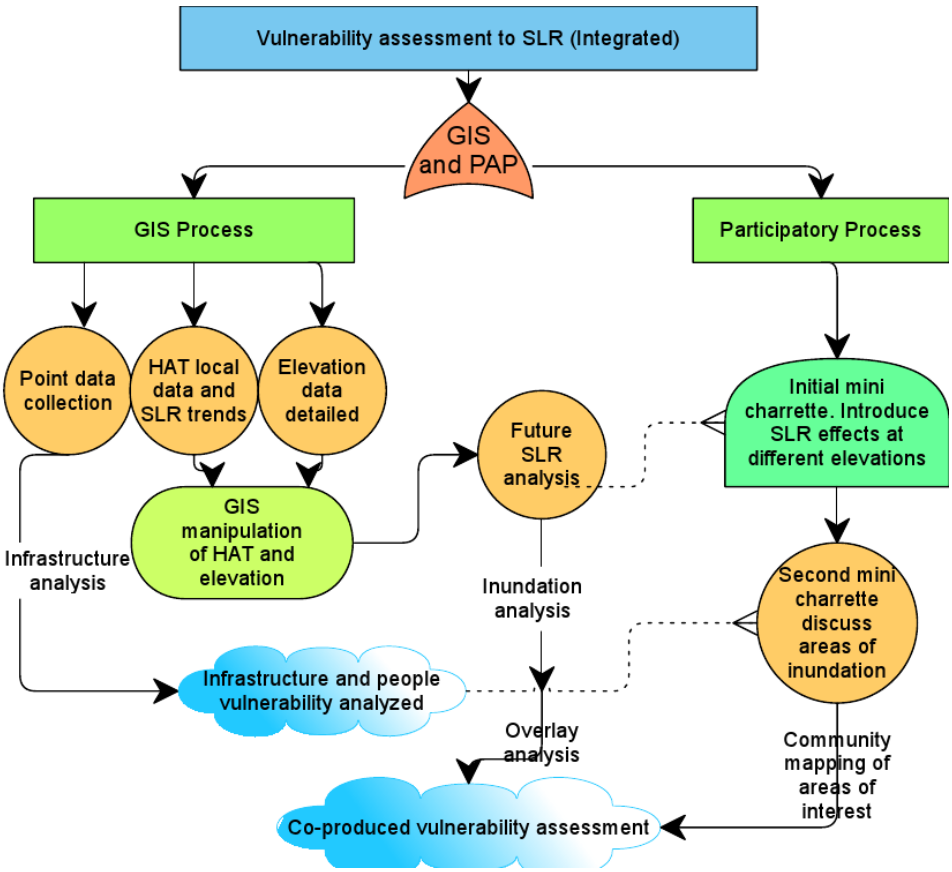


Figure B.1: Integrated SLR analysis process.

B.2.2 Data sources and GIS maps

The data sources include primary data sources from the field as well as important secondary sources.

Primary data sources

Such data can be solicited from several online sources including; Shuttle Radar Topography Mission (SRTM), ASTER or other airborne sensors which are available in most cases free of charge. Applicable point data for infrastructure analysis, population, and planning data are also required to facilitate at risk population analysis. The data can be collected from the field in your area of interest.

Secondary sources

These data include 20m contours and spot heights images from 1:50,000 scale topographic maps. Also required are the 5m contours or LIDAR data for the area of the study. In order to add on the topographical map and the spot images available, other secondary data required for GIS analysis include:

- LiDAR data for the study site if possible
- Accurate digital elevation model (DEM)

- Reference areas and their validation
- Inventory configuration file

The data types are described in detail below.

LiDAR data

Usually, LiDAR data is processed by the LiDAR vendor. The processing of the laser scanning data can also be done by Arbonaut or other parties if necessary. The most common procedures which are done by Arbonaut are classifying the points (usually under three classes: Default, Ground, and Error) and deleting the overlaps between the flight lines. Before the LiDAR data can be used in the inventory process, the Z (height) values of the LiDAR point cloud has to be changed to be the altitude from datum surface instead of the altitude from the approximate point of sea level of the projection.

Digital elevation model

Satellite imagery containing elevation information DEM is an important aspect of the GIS analysis. Remotely sensed data (such as satellite imagery) with the description of the ground elevation is important in facilitating the analysis of the predicted changes viz-a-viz the elevation of necessary infrastructure and people at the coast. Image analysis information is invaluable in the conduction of targeted ground-truthing or actual verification of information on the ground. Data files that contain the height above sea level of the terrain, the land use and the current utilization over a specified area, are critical in the analysis of population and infrastructure exposure. The point and raster intervals between each of the grid points should always be referenced to some geographical coordinate system. (such as latitude-longitude and Universal Transverse Mercator (UTM)). The key points to note in this process are:

- The closer together the grid points are located, the more detailed the information is in the file. The particulars of the peaks and valleys in the terrain is better analysed and modelled using small grid spaces than when the grid intervals are significant. Elevations other than at the specific grid point locations are not contained in the file. As a result, the high and low points (Peaks and Valleys) not coincident with the grid should not be recorded in the archive.

- The DEM file also does not contain public infrastructure information such as hotels, roads or buildings. It is an elevation data set and not a scanned image of the paper map (graphic). Neither is it a bitmap. The DEM does not contain elevation contours, only the specific elevation values at specific grid point locations. However, contours can be generated from the DEM if necessary.

Reference areas and their validation

The positioning of the sample sites for the analysis is crucial for the success of the inventory and analysis process. Usually, the locations of the areas of interest are predefined, but the exact locations are always measured in the field and differentially corrected afterwards. The study area data inventory of the land uses and subdivisions needs to be collected. Accurate GPS positioning sources and systems will help to locate and position the important infrastructure and business assets intended for analysis and assessment of vulnerability to SLR.

Inventory configuration file

A complete and detailed data inventory of the critically exposed assets and resources (land, population and urban extent) should be collected from the relevant ministry of planning in the country. For qualitative analysis, extrapolation of the inundation zones should be projected for a current 1-in-100-year storm surge. Spatially-disaggregated data sets can be sourced from various public sources, including the KEMFRI, among other sources. Online data sources include National Aeronautics and Space Administration (NASA), Regional Centre of Survey of Resources in Kenya, the US Geological Survey (USGS), The DIVA tool or the World and Wildlife Fund (WWF) among others. Access to the data typically requires on-line registration.

B.2.3 Processing and preparation for GIS analysis

This section provides a guide to the preparation for the inventory and analysis process. At this stage, the GIS data, aerial images, and reference sample plots are ready to use, but some modifications are needed. The rasters created from the DEM are used for analysis. The GIS inventory process consists of the following steps:

- Acquisition of input data (remote sensing data and reference plots from either primary or secondary data sources as described in section B2.2)

- Refining/adapting and cross checking of input data into an available GIS system/software
- Running the analysis based on automatic segmentation
- Derivation of initial estimates
- Cross checking and reporting of tangible research results

Refining data for GIS analysis

GIS tools needed for refining and analysis

Necessary tools for the analysis include GPS for the selected sites for infrastructure mapping, a computer loaded with ArcGis and or Global Mapper with the relevant extensions especially the "Spatial Analyst" extension of the ArcGIS. The DEM maps and other land use maps should be considered as images that can be manipulated. Population and economic data including the countries GDP and the particular county per capita GDP are also necessary.

Software and hardware

The process requires the following software: ArcGIS 10.2 for Desktop (ArcView, ArcEditor, or ArcInfo) as well as global mapper. The manual processes focuss on data needed for the analysis. The data is compressed for faster download. For the hardware, a desktop or laptop with enough memory is required for analysis as GIS files are usually cumbersome and can take time to load and analyse if the hardware cannot support heavy documentations and complete computing processes.

Global Mapper

Global Mapper is an affordable and easy-to-use GIS application that offers access to a variety of several spatial data and provides just the right level of functionality to satisfy the needs of both experienced GIS professionals and beginners. The software is equally well suited as a standalone data management tool including as an integral component of a wider application in a GIS system. The software is affordable and available at low-cost as compared to many GIS-based softwares which are expensive and beyond reach for many. The softwares advantage it is easy-to-use GIS solution which supports a broad range of data formats including an optional LiDAR module equivalent to Idrisi cloud softwares for point cloud processing and advanced projection management using GeoCalc library.

Global Mapper free extensions

COAST 11 - This tool also known as the Coastal Adaptation to SLR Tool, facilitates the modelling of cost/benefit analysis for adaptation strategies for SLR and coastal flooding from storm events like hurricanes. These extensions are available in the Global Mapper package.

Running spatial GIS analysis processes

After the collection of the refined data and the loading of the appropriate software onto the system, GIS analysis of the selected areas in the vulnerability assessment can now commence.

Satellite imagery and analysis

Selection of the required satellite data is quite important. This should be based on diverse criteria such as on the available data formats, the ability to manipulate this information, the hardware and software capability for data acquisition and manipulation. The quality of information on satellite images is also important and there will be cases where cloud correction is necessary. In cases using landsat and spot images, they do have their global grid references which are applicable while a country's, coordinate systems can be used to reflect data in the correct places.
Figure B.2 provides an overview of how to solve and analyse data either using remote sensing tools or generating appropriate tools to solve the problem at hand. In this case, the analysis using remotely sensed data by a GIS process, you need to specify the images and image analysis required based on the primary and the secondary data collected and refined.

The process will then require that a comparison of the cleaned raw data is done in relation to the results and the characteristics of the vulnerability and inundation analysis envisaged. In the event that the data is available and sufficient for analysis the data can then be processed and analysed using the GIS software available in order to assess the inundation areas and population on the spot images or the topographical maps earlier collected.

SLR inundation analysis using GIS + HAT process

Before the inundation prone areas can be developed from the DEM of the site of study, the probability of future effects of SLR is calculated from the formula developed by Nicholls. The calculation of storm surges (extreme sea levels), would be based on the method outlined by **?** as applied by several researchers **??**. The Highest Astronomical Tide (HAT) of the coastal region is included within the

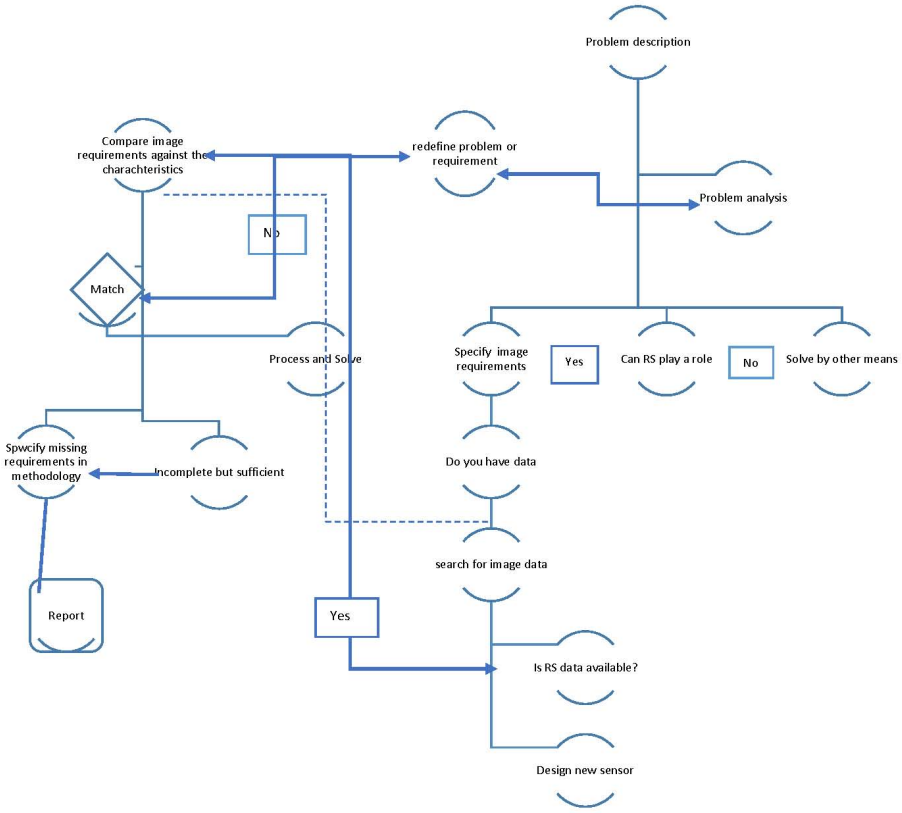


Figure B.2: Remote sensing data manipulation process: Adapted from (**?**).

formula and must be calculated beforehand. The formula for the calculation of storm surges is as follows:

$$\text{FSS} = S100 + SLR + \left(\frac{\text{UPLIFT} * 100yrs}{1000}\right) + \text{SUB} + (S100 * x), \tag{B.2.1}$$

Where

- FSS= $S100$=1-in-100 years surge height(m),
- SLR=sea-level rise (based on the IPCC Prediction),
- UPLIFT=continental uplift/subsidence in $mm/year$,
- SUB=0.5mm (applies to deltas only) as they are prone to subsidence,
- x=0.1, or increase of 10% applied only in coastal areas currently prone to tsunamis and tropical cyclones.

Starting GIS and loading elevation data

The starting point for inundation scenario analysis (after the collection of the targeted inundation areas using Nichols formula as described in Formula B.2.1, is the loading of the data on your project and preparing for analysis. The Global

Mapper or Arc Gis software in use should be registered for ease of manipulation of the data.

Part 1 of the process is to learn how to start ArcGIS or Global Mapper and display related geospatial datasets about the analysis in question, such that one can see the effects of displaying the data sets.

Part 2 involves the manipulation of the data sets using the corrected projected SLR derived from the Nicholls formula to create the future SLR location map showing areas of inundation under selected scenarios.

Starting Global Mapper

The first step is to open up the GIS software in use. As an example, the Global Mapper version 16.2 and ArcGis version 10.2 for desktop is used for the rest of this manual.

Step 1: Open the Global Mapper and allow the software to load, if properly done the following page will be displayed.

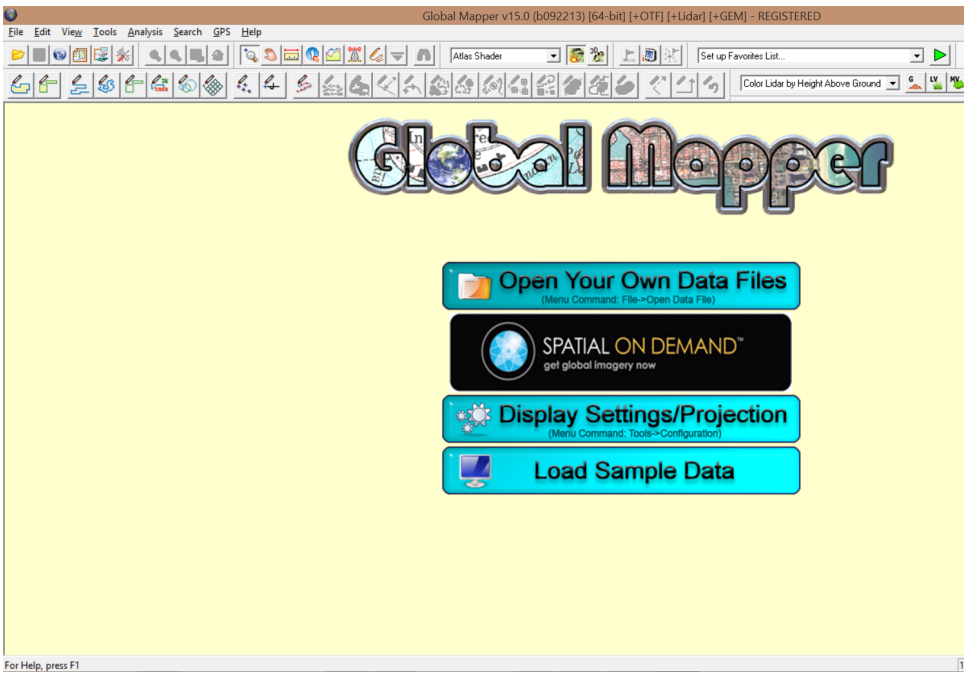


Figure B.3: Loading data on Global Mapper

Add a dataset to Global Mapper

When the software is open, you can add datasets (as well s layers or themes) to the project. Click on the folder "open the data files", to access the data images stored on the computer, browse to the folder where the data is saved bear in mind that the data should not be in a compressed format.

If the data is compressed use FireFox as the selected browser to download any

zipped files, choose the "save" button (not the 'open' button) and extract the contents of the zipped folder to a home directory where project data will be manipulated. Keep the working directory clear and readily available to avoid losing data or confusing the software when searching and executing commands based on the directory.

Locate the required DEM for analysis

Locate and open the DEM or LiDar available data into the open browser. The wizard should default directly to the directory or the database of the data as shown in the example below (see Figure B.4).

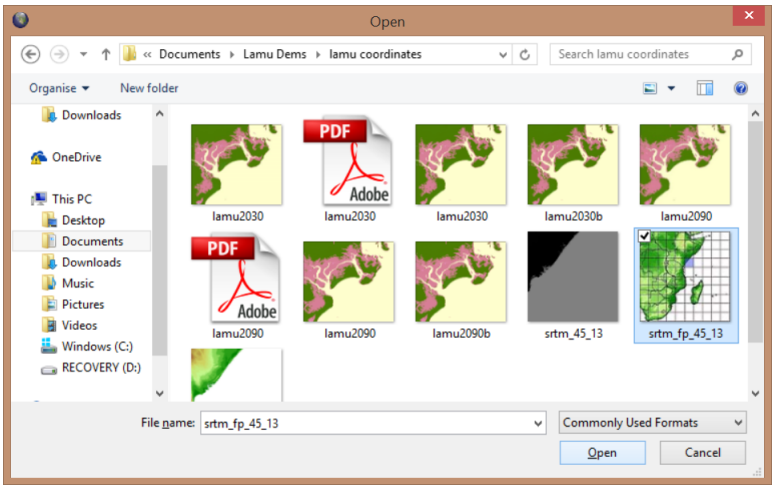


Figure B.4: Selecting your data from the home directory on Global Mapper.

Open the required DEM for analysis

For viewing and manipulating the datasets, it is important to add data to the project. The addition is done by opening the required data file (be sure to correct the reference system to the study site and to match with the documents and for proper analysis). For this case the DEM of Lamu Archipelago is loaded on the project and is displayed as seen in Figure B.5 showing the different elevations of the selected data.

Creating area bounds for easier analysis

To facilitate easy and efficient creation of inundation zones based on calculated values, its better to define the extent of the analysis as seen in Figure B.6.

Since the raster tile may be thick and thus delay the analysis, the process is easily facilitated by the digitizer tool of the Global Mapper as illustrated. During the analysis click on the dialogue box on "crop to selected area features". This is important to avoid the analysis running on the whole area DEM and thus taking longer than needed (see Figure B.7 for a screen shot illustration).

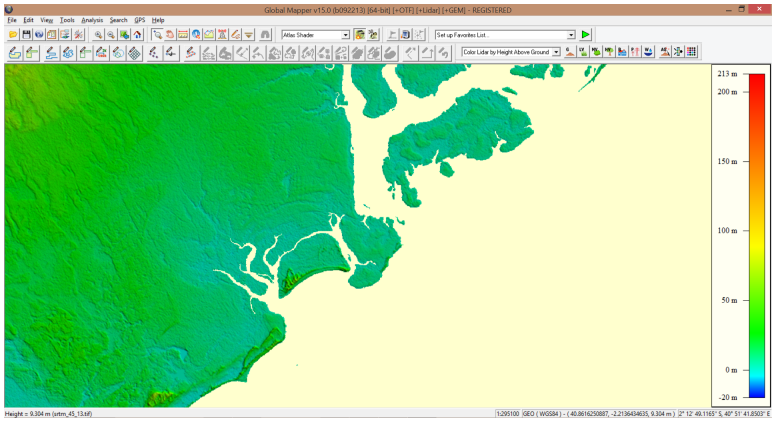


Figure B.5: Loaded data and the sequences of flood analysis.

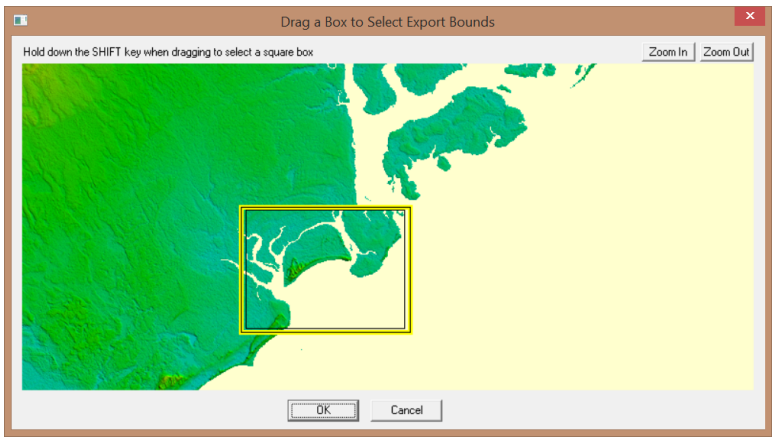


Figure B.6: Creating area bounds for quicker analysis.

Running the inundation areas on the map

After selecting the bounds of the prioritised areas for analysis, proceed to define the water levels (generated from Nichols formula) in metres or millimetres. Keep the base elevation as 0 m at zero, this will enable the generation of an inundation map based on the different scenarios and selected years to the area of study.

Figure B.8 gives a screen shot of the level of SLR increase in this case (3.8m), with the selected X and Y axis defined based on the selected bounds, and the depth of terrain that needs to be filled. Note that for the dialogue box check ocean elevation at zero.

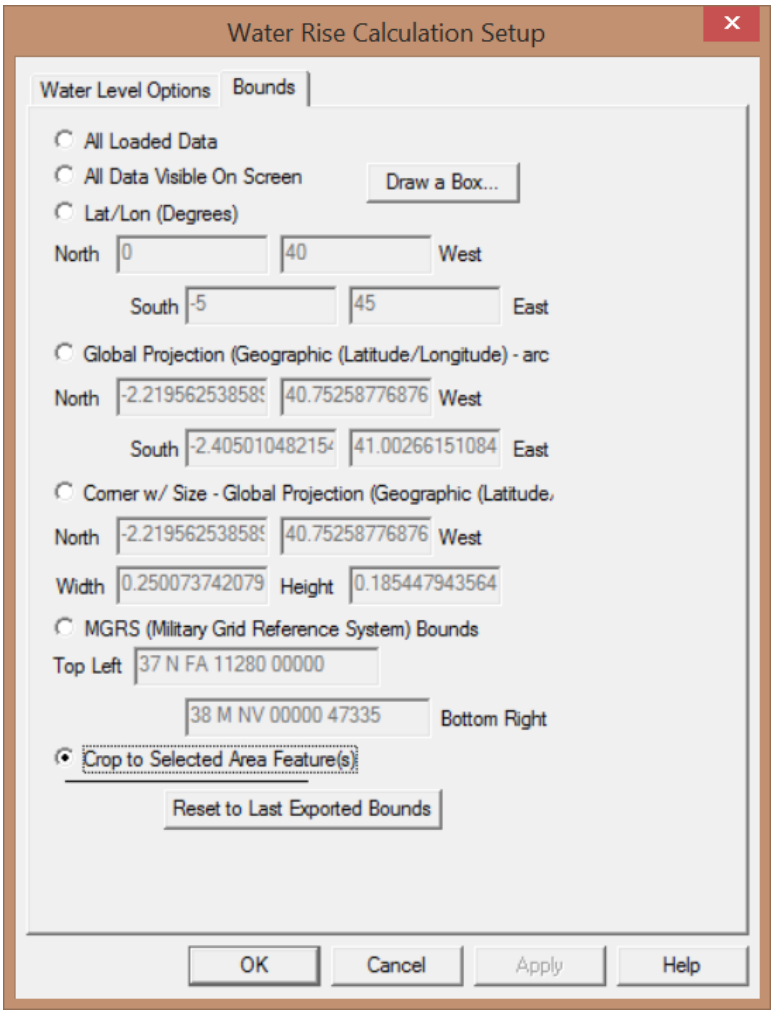


Figure B.7: Analysis within the selected area bounds.

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Overlay analysis and initial vulnerability map

The exported map from the inundation scenario analysis is then used for this step. Overlay analysis is achieved using the ArcGIS software as compared to Global Mapper. In this step add all the point data of the critical infrastructure selected for your coastline, (including the inundation area data) to the project. Using the "spatial extent" analyst of ArcGIS, run an overlay of the two maps and generate a single map of infrastructure exposure within the inundation area.

The raster calculator can be used to define further details of the areas falling within specified distances along the elevations that may be prone to flooding on the map. Procedures for spatial analysis are given in the references at the end of this manual. Prepare the complete vulnerability map ready for the mini-charrette by adding the necessary annotation which includes the legend, scale and North point. Annotation is better done in data frame view following the wizard and appropriately tidying

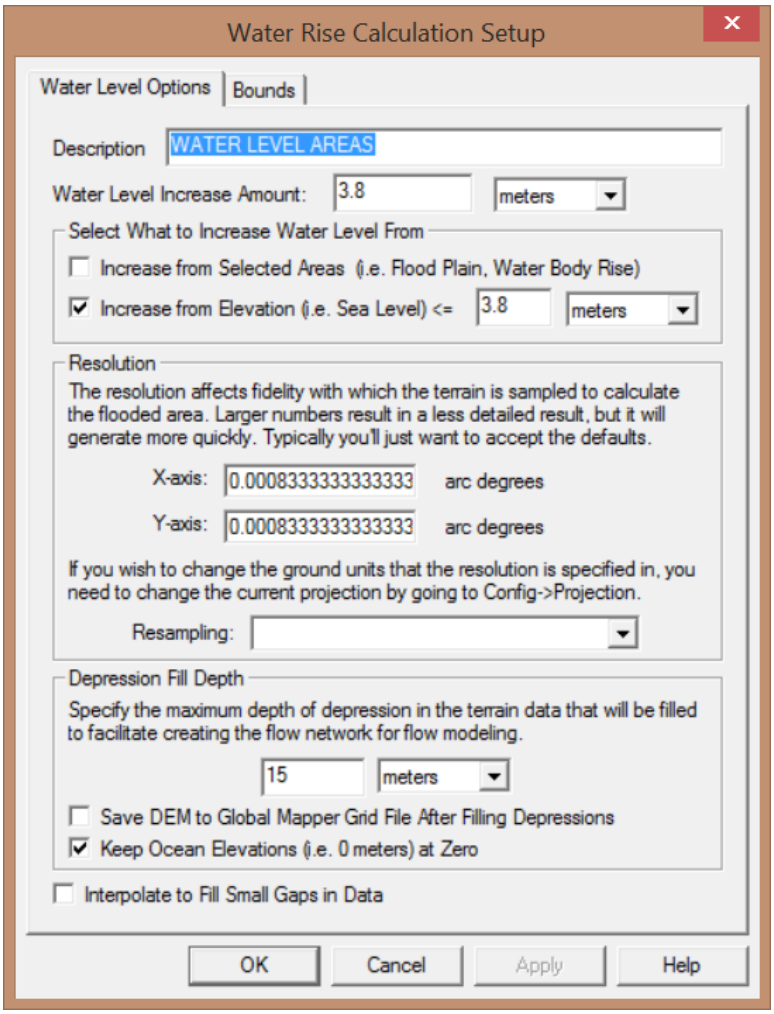


Figure B.8: Flood and inundation analysis scenario on Global Mapper.

up and presenting the final map.

Results and Summary

By the end of this exercise you a variety of inundation maps for different scenarios and different years (if involved in the future simulations of your study area) will have been generated. The maps can then be exported using the "export" dialogue box and saved for further analysis using ArcGIS. When saving and exporting the maps, use the .PNG or .JPEG or .EPS to allow the maps to be loaded onto another programme. Do not export maps in .TIFF as this will make it difficult to manipulate them using another software subsequently.
In summary the following are the key GIS steps be followed

- Start ArcMap or Global Mapper software
- Create a connection between the data in the project directory and the software to facilitate easier loading and unloading of data
- Add data to the project and make necessary data projection changes to reflect the correct ground positioning
- Select appropriate data bounds to fasten analysis of the specific areas
- Run the analysis and identify the inundation areas on the map and export the data for further analysis on other available software platform
- Display your inundation data on corrected projection ready for the mini-charrette process
- Perform an overlay to merge inundation areas and the critical infrastructure and annotate the map for Mini charrette

B.3 Participatory planning and mini-charrette

B.3.1 Introduction to PAR

This conceptual framework relied on *the Handbook of participatory planning* (**?**) as well as research reported in **?**, for the literature on the typologies of participation and on the concept of empowerment through the participatory process. A key objective in the process is the co-learning and co-production of understanding on climate change impacts and experiences with the communities within the selected city or islands.

Although the participatory research process is adopted from participatory planning processes, the conceptual framework of the study should emphasise co-creation of knowledge and empowerment about climate change mitigation and adaptation strategies. In such an approach social empowering and learning is understood as a contributor to relational and cognitive changes that happen as a result of experiences within group settings. Thus, PAR oriented research should be able to synergise across social and individual learning.

The social and environmental learning should emerge from the different perceptions during the mini-research-charrette (participatory) process. The various community members who can participate in the process should largely be people who make a living around the coastal areas and could include, beach management units, fishing, conservation activists, investors and entrepreneurs and public sector entities.

During the mini-charrette, the double-loop learning process is prioritised over the single loop process as the single-loop learning process entails mere acceptance of the available and new ways of adapting to climate changes instead of the mere fundamental changing of mental models. Double-loop learning, in contrast, "occurred when the existing world-views, research, underlying and current knowledge on climate change and the community values were challenged and narrowed down to the individual region of study" (**?**). In particular, proper application of the Indigenous Knowledge Systems(IKS) is enhanced through the double loop system.

B.3.2 Importance of charrettes

Most importantly, SLR and participatory climate change based charrettes can save time and money and improve co-production of knowledge for adaptation purposes

as well as create awareness on the current threats facing communities living around the coastline. The participatory process should:

- Provide a forum those who can participate in climate change and SLR effects would understand and make decisions to enhance responsiveness and action towards mitigation efforts
- Encourage agreement about the status of the threats and the extent of SLR and climate change induced changes at the coast where they eke a living from
- Kick off the planning for adaptation and mitigation strategies for responsive action planning
- Save time and money by soliciting ideas, issues, and concerns of the communities living around coastal areas on the protection of their resources from climate related changes especially SLR
- Promote enthusiasm for any suggested adaptation and mitigation strategies for the communities, as well as address apathetic tendencies to participatory management of large communal resources

A successful charrette promotes joint ownership of solutions and attempts to defuse typical confrontational attitudes between residents and the research team. Although charrettes would of necessity, involve small groups. Participants should not be viewed as representatives of all the residents nor to have the moral authority to represent them.

Consent forms for participation in the mini-charrette process should be done early enough and thus allow for members to freely agree to participate in the focus group discussions. The discussion should include the initial modelling results (inundation results) and participants understanding and perceptions of climate change especially SLR around their communities. In order to mitigate and reduce bias in participant selection and participation, it is essential to engage a process that attracts members' interest by selecting from different categories such as gender, age groups and economic interests among others.

B.3.3 Preparation for mini-charrette field work

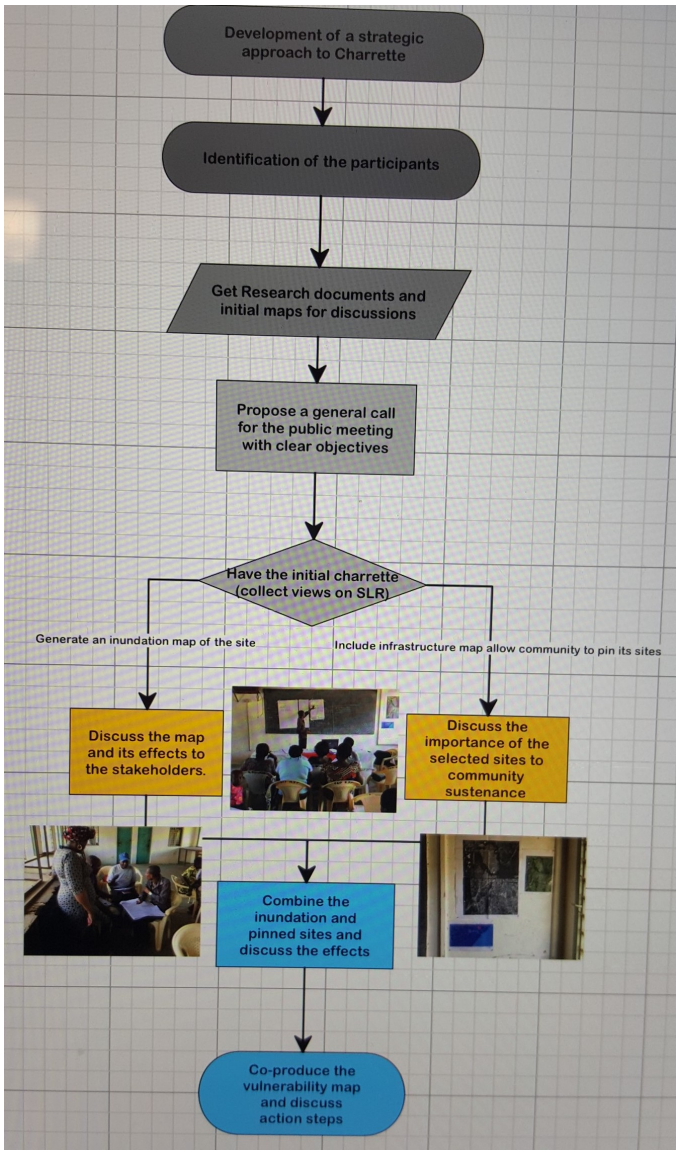


Figure B.9: Mini charrette field procedure. Source: Adopted from **?**

The following steps highlight the process of the mini-charrette and how to implement it in the field.

- Develop a strategic approach/plan on how to identify and approach participants
- Identify and make initial approach to potential participants
- Finalise the required consent and other preliminary documents, including consent forms and local permission, letters as well as venue selection and commitment to the area

- Prepare the inundation and infrastructure maps.
- Solicit participants through diverse channels such as public call through the community organizations and local leaders
- Execute the charrette with both the inundation scenarios and community interest areas within the site
- Co-produce the vulnerability map and discuss adaptation techniques

B.3.4 Development of a strategic approach to the charrette

The strategic planning involves the initial analysis for the execution of the charrette process. Factors such as the list of targeted participants intended for the process and the announcement of an on-line blog system for on-line participants engagement and motivation for areas prioritised for the mini-charrette should be planned in advance.

B.3.5 Identification of community members

Before embarking on the study site, it is important to identify the key participants who will participate in the physical participatory process. The on-line participation process through a blog should be open to anyone within the island area or the country, who would be willing to contribute to the process. A deliberate effort should be made to involve the local communities in the selected research sites to discuss and develop the map collaboratively. In particular, a public notice would be required for the community-based groups living and eking a living around the coastline.

B.3.6 Initial planning and research documents for the charrette

Before embarking on the participatory process, the collection of base data for the charrette is critical to the success of the process. This includes the land use patterns at the coastal area, the people living within low elevation areas around the coast, significant public infrastructure within the coastal site and the planning regulations rules as well as the economic indicators that are unique to the coastal zone.

It is also important to have necessary permission and documents from the relevant research and government organizations. This includes the research

permits and active consent forms for interviews, audio, and video recording. During the preparation, the objectives of the research must be clearly indicated in the documents and presented to the participants before initiating the charrette process.

Keep in mind that stakeholders must be treated with respect at all times and assured that a co-created outcome is to be delivered back to them either in the form of maps or seminars on their input into the process.

B.3.7 Preparation of inundation and infrastructure maps

For the process to be efficient, early preparation of the required plans is necessary. This is to be done during the data collection phase. All data needed for the mini-charrette process must be collected and structured in advance. The maps necessary for the process includes:

- The key infrastructure/asset map of the area
- A well-annotated inundation map based on a selected scenario for display purposes
- Land use maps that delineate different planned uses within the study area
- Population density map to identify the number of people who are living within the selected area

B.3.8 Call for the charrette

A general call for the participation in the mini-charrette should be done using the community networks. The general meeting request should be made to community members living around the selected site to participate in the meeting. The objective and the time of the meeting should be clearly stated, and if snacks/refreshments are to be provided. As far as possible financial remuneration should be avoided in order to mitigate bias and facilitate a creative dialogue.

B.3.9 Executing the mini-charrette

A full score charrette would last four to seven days. However, a mini-charrette can four days, but would require to adhere it is important to adhere to the strict rules of a complete charrette in order to optimise the outcome. As a first process in the mini-charrette, the introduction of general climate change should be done before

getting into the specific SLR and coastal areas. Facilitate for in-depth analysis within smaller groups under each cluster aided by an experienced facilitator.

It is recommended that provision be allowed for feedback from the previous day discussions to ensure continuity and sustain participant interest in the process. The vulnerability map for the selected area is important to serve as the tool to trigger the implementation process. The implementation charrette begins not more than six weeks after the initial charrette to allow for discussions and conclusions as well as formulating action plans adaptation and mitigation strategies.

The process largely involves the use of mini-charrette plus interactive exercises which take between 1 to 4 days, where the researcher serves the following roles:

- Provide basic exposure on the issue of climate change, SLR and the modelling of related data to understand vulnerable areas, sectors and people. The process is conducted in charrette format and important background information to the study appraised and finalised
- Encourage participation in the research project, generate enthusiasm on issues of climate change and SLR and develop initial maps and materials to guide the participatory process
- Set the group and performance goals expected for the discussions on IKS that has been used to protect coastal areas from climate change and SLR changes identified
- Identify community members who can be of assistance in terms of managing groups and facilitate breakout group sessions

Inclusion and exclusion criteria

During the anticipated field work, community members living within the area are eligible for inclusion based on their ability to participate and availability for the sessions. It is also necessary to include the participation of the local government officials in order to enhance input into planning processes at municipal or national levels. In most participatory processes a participant's level of expertise on the matter should be considered. In most cases, especially with climate change awareness, most members are rarely experts in the scientific analysis of the issues except for their experience-based knowledge which is often identified as indigenous knowledge systems (IKS), which is equally crucial for a start.

Use of video and photographic recording

Ensure proper ethical standards and only engage such tools when appropriate consent has been sought and confirmed. Video and photography can be utilized as part of the method to facilitate an interactive approach on e-based platforms where stakeholders are invited to add value to the uploaded data and hence increase the ability of several additional members to participate in the study.

B.3.10 Co-production of vulnerability map

Point data collected for infrastructure identification should serve as input into a GIS to facilitate the identification of infrastructure/assets and service areas within the research area and generate infrastructure and asset maps. The DEM data collected from USGS and STRM should be analysed to provide flood risk maps either with the help of Global Mapper (GIS software) or ArcGIS software.

Using a printed topographical map of the study area, encourage the community members to pin up their prioritised areas of importance and business interests such that the process allows them to associate well with the printed map. A few of the critical areas should have been recorded as point data on your GPS. During the charrette meeting, practically run flood risk areas using the map described and show the community members the simulated results, these will enable them to better sense/understand the areas and the concept of flood vulnerability index.

The simulated flood inundation map and the land use maps are to be integrated into the GIS for further analysis. The integration of the qualitative data into the action-based model to be developed should facilitate the compilation of the comprehensive SLR atlas for the Kenyan coast. Combined with GIS-based land use maps, population maps as well as urban extent maps, the "Spatial Analyst" extension of the ArcGIS 10.1 TM software of the ARC GIS tool is handy for combining the areas and displaying as well as rank the most vulnerable portions. Further scenarios can then be done later and the co-produced map shared with the participants.

B.4 Writing the field reports

Any systematic study would require submitting of on-going reports on the research performed in a field notebook. The deadline for submitting rugged (observation notebook) and final drafts (research paper) are as instructed by the

Table B.1: Summary of application of mini-charrette process

Pre preparation process	**Executing mini-charrette**	**Post charrette analysis**
Develop a strategic approach to identify and approach participants	Prepare the inundation and infrastructure maps	Evaluate the results and feedback from the charrette
Make initial approach to potential participants	Discuss general climate change and specific SLR	Initiate dialogue on appropriate adaptation and mitigation techniques
Collect research documents, including consent forms and local permission, letters	Subdivide participants into manageable discussion groups with a facilitator	Initiate further participatory analysis between the participants and policy makers
Solicit participants through diverse channels such as public call	Co-produce the vulnerability map	Disseminate the results of the map to the participants

leader of the study. Considerable effort should be directed towards the production of a systematic and coherent/reflective report.

As a general rule, the final research document should contain the following key items

- Introduction
- Literature and secondary data sources appraised
- Methodology (with primary and secondary data needs/sources systematically highlighted
- Results and key findings
- Conclusions and recommendations
- References consulted

Figure B.10: Mombasa island inundation areas by 2060 under RCP 2.6

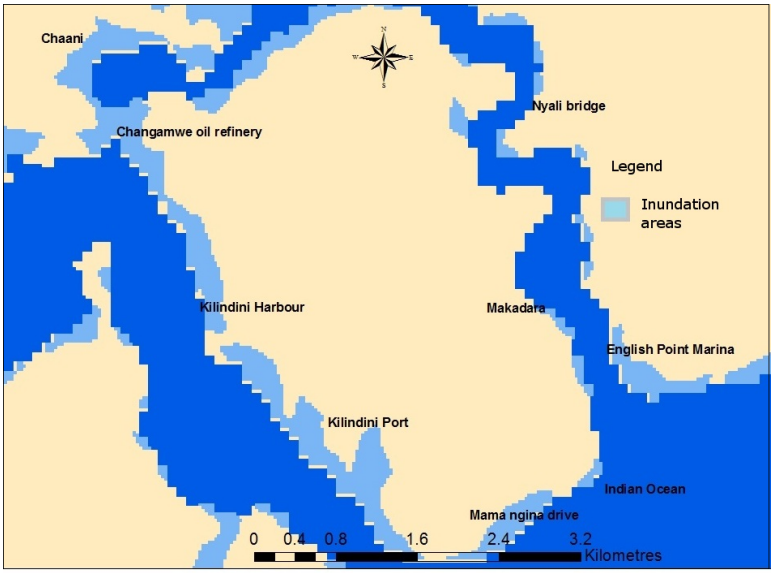


Figure B.10 shows the severity of inundation impacts under scenario 2.6 escalates drastically by 2060. The two main highways (Makupa Causeway and The Nyali Bridge) connecting to the mainland, as well as the oil refinery and the port facilities (part of the backbone of Mombasa and Kenya's economy at large), would be prone to inundation. The area under threat would be approximately 26.8Km^2, which translates to 11.6% thus leading to a total of 22.58% (including the 10.9% inundation area by 2030).

Appendix C

Vulnerability Atlas



Figure C.1: Mombasa Island aerial view

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University of The Witwatersrand Johannesburg

2016.

C.1 Preface and Introduction

The atlas visually provides a final vulnerability assessment for Mombasa and Lamu islands due to the impacts of climate-change induced SLR with regard to people, spatial extent and infrastructure/assets of the islands. The aim of the atlas is to facilitate knowledge sharing with the affected stakeholders including businesses, communities and public role players with a view towards initiating the process of developing adaptation measures.

Different approaches have been used to define how storms and other coastal disasters have affected a range of communities and how such communities have responded to these hazards. The atlas gives an indication of the physical infrastructure and human activities, at risk from the effects of SLR. The Atlas defines the affetced areas based on the IPCC predictions of SLR and the combined HAT for the coastline of Mombasa and Lamu.

The spatial and social analysis is enhanced through inclusion of inputs from supplementary documents such as government policy and reports, coupled with focus group appraisal processes with the communities and interviews with planners and managers among other stakeholder groups. The development of this atlas was enhanced through a mini-charrette process and the production of a co-produced vulnerability atlas itself.

C.1.1 Atlas organization

The Atlas has been structured in the following order. Section 1 covers the introductory and preface stages followed which Section 2 describes the content. Section 3 presents the infrastructure, assets and spatial extent of vulnerability. Section 4 is dedicated to the extent of the effects under the RCP 2.6 and 8.5 scenarios (optimistic and pessimistic scenarios respectively).

C.1.2 Objectives of the atlas

The objectives of the atlas are as follows:-

- Visually present vulnerability levels in terms of spatial extent, people and infrastructure under threat in Mombasa and Lamu islands.
- Facilitate knowledge sharing and communication with stakeholders in order to facilitate responses/preparedness towards mitigation and adaptation strategies.

C.1.3 Atlas description and content

The Atlas components include the three main processes that facilitate integrated assessment in SLR studies which are

- Climate change and SLR and its relation to coastal vulnerability and related populations.
- Mapping of main vulnerable areas and infrastructure/assets within the LECZ under threat from accelerated SLR.
- Role of stakeholder participation in encouraging participatory mitigation and adaptation strategy to SLR.

C.1.4 Socio-economic characteristics of Mombasa and Lamu

Mombasa county as a tourism-based city needs to put in place robust plans to protect the island and its resources from the effects of accelerated sea-level rise. As indicated earlier, the inundation-prone areas under the optimistic scenario of RCP 2.6 by the year 2060 shows that the island land mass of up to a quarter is low lying, and is susceptible to ocean disturbances in the event of a severe coastal storm event clarified at 1-100 year return cycle.

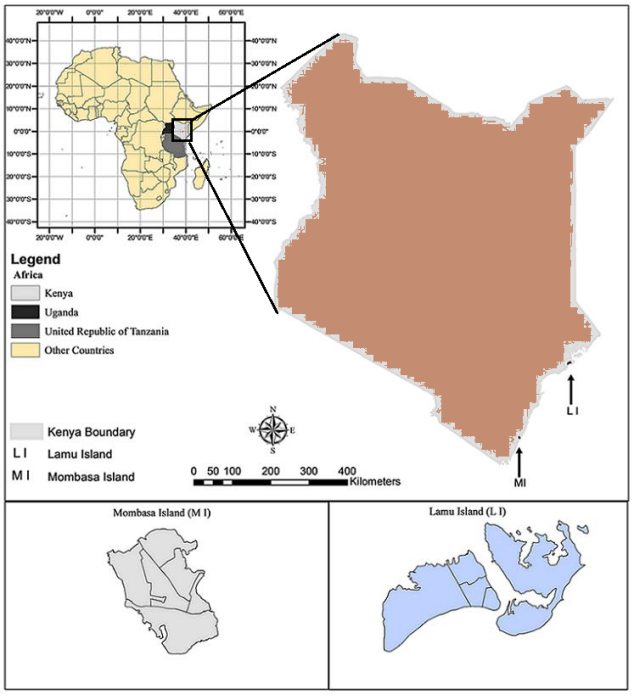


Figure C.2: Study sites, Mombasa and Lamu islands

Mombasa population distribution

Mombasa County is situated in the south-eastern part of the former Coast Province. The county government of Mombasa and the town is the smallest of the other county regions and cities within the former seven districts in Coast Province. The county covers an area of 294.6 km^2. The borders around Mombasa county include Kilifi to the North, Kwale to the South and West and the Indian Ocean to the East. The county lies between latitudes $4^0 2' 12'$ South of the Equator and between longitudes $39^0 0' 10'$ East of the Greenwich Meridian, with most of the city lying at 5m below sea level. TableC.1 shows the administrative units and municipal electoral Wards by Division.

Table C.1: Population distribution (2009) for Mombasa county and its six subcounties.

Division	Population(thousands)	% Population	Area(Sq kms)
Changamwe	147,613	15.7	16
Jomvu	102,566	10.9	29
Kisauni	194,065	20.7	88.7
Nyali	185,990	19.8	22.88
Likoni	166,008	17.7	41.10
Mvita	143,128	15.2	14.80
Mombasa county	939,370	100	222.8

Mombasa population density and projections

Population distribution and settlement pattern in the county is influenced as in many cases by infrastructure networks especially the main roads. Other factors that have affected distribution include the availability of clean water services, as salt water intrusion is a problem in the county, access to electricity, availability and accessibility to gainful employment activities especially along the beaches, availability of suitable housing, security and land tenure systems.

High population densities and infrastructure are found in the Island Division and along the major highways such as Mombasa Lunga-Lunga roads in Likoni Division, Mombasa-Nairobi road in Changamwe Division and Mombasa-Malindi road in Kisauni Division. The Sparsely populated areas are found on the outskirts of the county as they the least developed regarding infrastructures; these areas include Mwakirunge the location of the main city dumpsite, the areas around Maunguja, Mkupe Jetty, and Mwangala.

The population density pattern for the various areas around the island and the administrative units are illustrated in Table C.1 and Figure C.3. The population is set to increase to about 1.3 million individuals in 2017 based on the county projections.

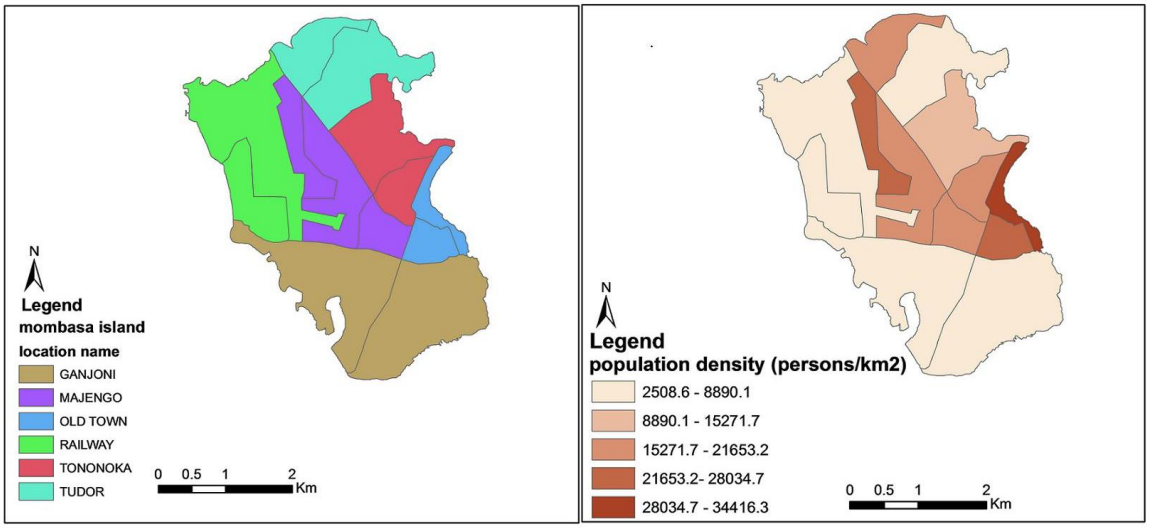


Figure C.3: Mombasa County population density.

Mombasa elevation and characterisation of LECZ

Mombasa Island is classified as a low-lying ecological area with 21.9% of the area falling between the range of 0 to the 10m above sea level. The sectors that are at most within this zone includes the railways, parts of the Nyali bridge the only main road exit from Mombasa Island to the mainland North of the coast.

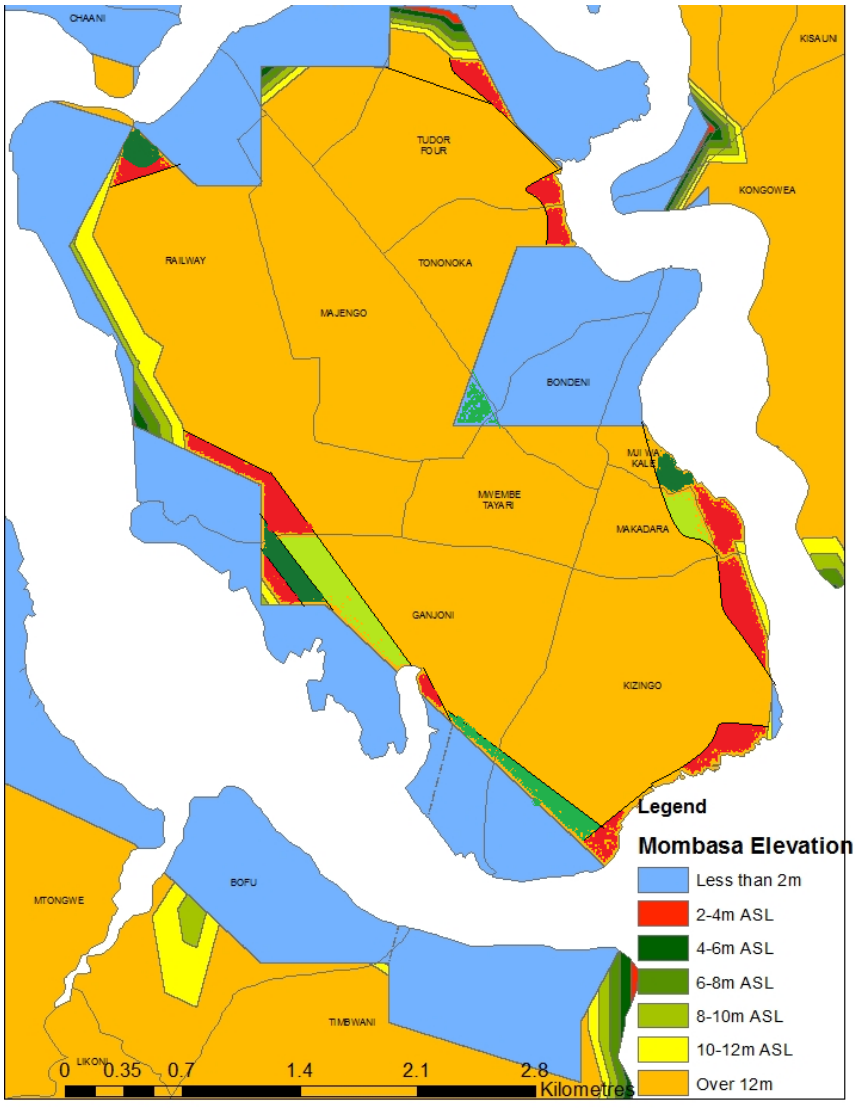


Figure C.4: Mombasa County elevation based on LECZ definition.

Lamu population

Lamu island is less populous than Mombasa island, the archipelago has several islands that include Pate, Manda and Manda toto with a mainland comprising of small towns of Mokowe, Hindi, Mpeketoni, Witu among others as described in

Table C.2.

Table C.2: Population distribution (2009) for Lamu county and its seven divisions.

Constituency	Division	Population	% Population	Area In Km^2
Lamu WEST	Amu	22,366	22	99.7
	Hindi	10,700	10	1150.8
	Mpeketoni	13,105	36	1727.7
	Witu	13,105	12.9	975.4
Lamu EAST	Kizingitini	8,346	8.2	79.2
	Faza	6,577	6.5	17.7
	Kiunga	3,918	3.9	2222.6
	Total	101,539	100	6,273.1

Lamu population density

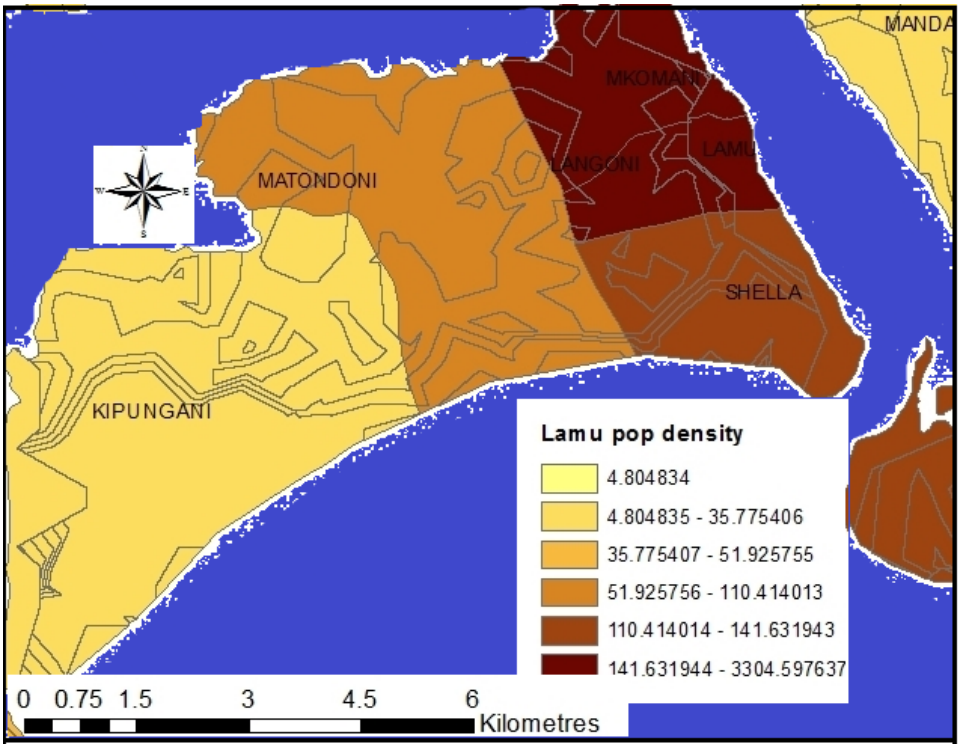


Figure C.5: Population density for Lamu County.

The Lamu Island see Table C.2 and Figure C.5 is located between at $2^0 16'$ South and longitude $40^0 54'$ East. Lamu island has a total land area of about 50 km^2. About 19 km^2 of the island is covered by a double row of sand dunes located along the entire length especially from Shella covering the southern coastline. The

primary source of water for the whole Island is the Shela aquifer, whose unconfined section lies underneath these sand dunes.

Lamu elevation and LECZ classification

Lamu island is classified as an LECZ island. The island is thus vulnerable to effects related to climate change, especially SLR. The vulnerability includes the impacts of temperature/tide variations and the probability of heavier coastal storm surges as a factor of global climate change. The increase in the effects of the high tide has been experienced recently. The ocean wave along the island created a flood on the main road and the jetty along the island used as a transport point.

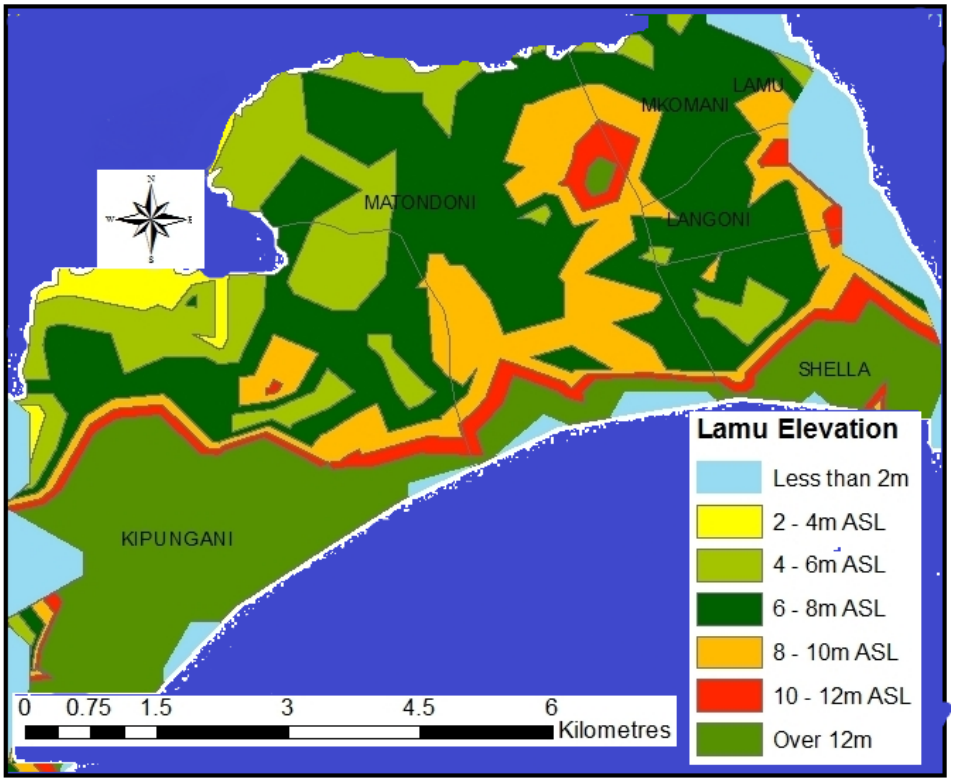


Figure C.6: Elevation and LECZ classification for Lamu Island.

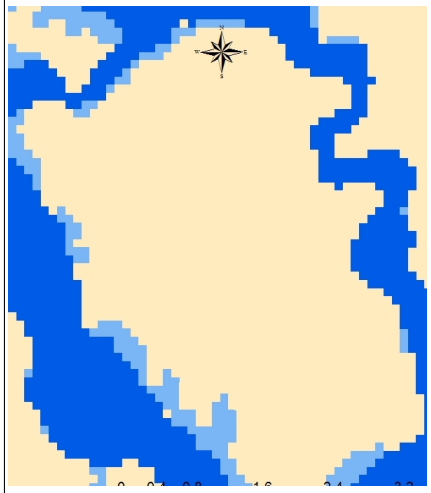
C.2 RCP 2.6 vulnerability for Mombasa and Lamu to SLR

This low-lying inundation zone translates to almost 10.87% of the land mass of Mombasa under threat from accelerated SLR as indicated in Table C.3 . The spatial extent and infrastructure within Mombasa Island that are low-lying under the RCP 2.6 include parts of Changamwe and Kilindini port, railways and the Mama Ngina Drive bordering the Kilindini Habour. As the year's progress and SLR increase, other areas that are classified as low-lying include the Nyali Bridge, areas around the mixed residential area of Bondeni, Tudor Creek and the low-income residential area of Chaani. Table C.3 gives a summary of the anticipated impacts.

C.2.1 Summary and areas prone to SLR impacts by 2030

The inundation-prone areas under the optimistic scenario of RCP 2.6 by the year 2060 shows that the Mombasa island exposed assets are up to US $ 1.1 billion and a land mass of up to 1.4 Km^2 is low lying by the year 2060, and thus susceptible to ocean disturbances in the event of a severe coastal storm event clarified at 1-100 year return cycle see Table (C.3).

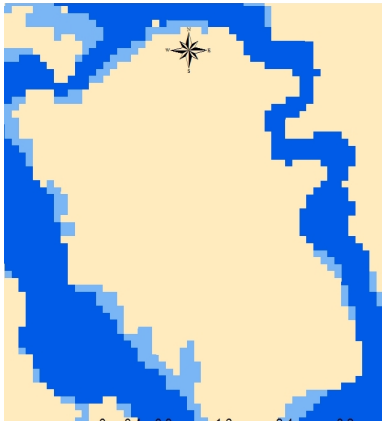
Table C.3: Spatial extent and impacts on infrastructure, assets and people under RCP 2.6 for 2030

Mombasa Island	**Highlights on areas affected**	**Lamu Island**	**Highlights on areas affected**	
See Fig 4.10 for the names of exposed areas 	• The most optimistic scenario • Areas around Changamwe refineries, Kilindini and Mama Ngina, could be affected by an extreme event • Under this scenario, population of 434,000 is exposed and threatened by inundation • The assets exposed in an extreme event under this scenario is US$ 1.1billion.	See Fig 4.20 for the names of exposed areas 	• The most optimistic scenario • Lamu island is more low-lying than Mombasa with an area of 36% of the island being at risk of inundation in an extreme event • Key areas under threat include the Amu division itself and areas around Matondoni being the first to be affected • Other areas affected include the Manda Island • Population under threat in this scenario add up to 21,000 persons • Assets under threat add up to US$ 54.5 million	

C.2.2 Summary and areas prone to SLR impacts by 2060

By the year 2060 critical port facilities including Kipevu Oil Terminal which is situated on the mainland around Port Reitz area, designed to accommodate crude oil tankers, and newly developed grain bulk handling facilities, among other infrastructure. As the ports vulnerability levels rise by the year 2060, the newly developed Berth 19 becomes an additional critical infrastructure threatened by the effects of accelerated SLR. Table C.4 gives a summary of the areas and populations under threat.

Table C.4: Spatial extent and impacts on infrastructure, assets and people under RCP 2.6 for 2060

Mombasa Island	**Highlights on areas affected**	**Lamu Island**	**Highlights on areas affected**
See Fig 4.11 for names of exposed areas 	• Areas around Makadara, Chaani residence, sections of the Old Town and Fort Jesus tourism attraction fall under the inundation zones • Others include the Kenya Ports Authority offices and bays, Mama Ngina Drive, Kizingo residence including Mtongwe Channel • Island area of up to 1.4Km^2 is low lying translating to 10% of the land mass falling within inundation zone • In this scenario, a population of 1.43 million is exposed and threatened by inundation • The asset exposure under this scenario adds to almost US$ 3.8 billion	See Fig 4.21 for the names of exposed areas 	• Sections of Manda Island, Lamu Airport, is slightly under threat, including the mini Manda Toto currently covered with mangroves • The archipelago area of up to 28.3 Km^2 is low lying and is susceptible to ocean disturbances in the event of a severe coastal storm • The inundation translates to 52.6% of the land mass being under threat from accelerated SLR • The number of individuals who would be living within this zone are up to 93,700 • The asset exposure under this scenario adds to almost US$ 251.2 million

C.2.3 Five and three-star hotels in Mombasa and Lamu Island

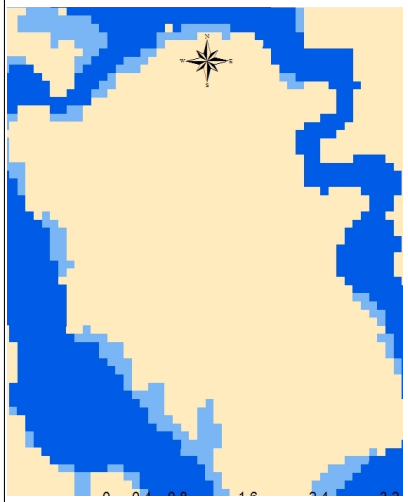
Mombasa is known to host internationally recognised five and three-star hotels that have enhanced the city's niche as a tourist destination. Travel and tourism contribute close to US $2.5 billion to the Kenyan economy annually, with the tourist hotels in Mombasa as critical centres of the travel and tourism. Climate change, and especially SLR will thus impact this important sector of the economy which is second only to agriculture in contribution to GDP. Some of the low-lying coastal hotels include the English Point Marina and the Tamarind Hotel in Mkomani.

Lamu Island is relatively more low-lying compared to Mombasa Island. Even under the most optimistic scenario, there are dire SLR impacts for Lamu Island across the 100 year period. The developers of the ongoing Lamu port project and the related infrastructure thus need to integrate mitigation/adaptation measures into these and other important infrastructure investment programs in the city. The areas under threat in Lamu Island are summarised (see Table C.4) and in the subsequent subsections:

C.2.4 Summary and areas prone to SLR impacts by 2090

Under this scenario as earlier stated Mombasa island will have almost 25% of its land mass under threat from severe inundation. This translates to almost a quarter of the island. The summary of the effects are described in Table C.5.

Table C.5: Spatial extent and SLR impacts on infrastructure, assets and people under RCP 2.6 for 2090

Mombasa Island	**Highlights on areas affected**	**Lamu Island**	**Highlights on areas affected**	
See Fig 4.12 for the names of exposed areas 	• Areas affected include the railways area, the administrative unit of Mombasa City, sections of the Old Town and Fort Jesus • Others include the State House premises on Mama Ngina Drive, the Kizingo Residence, The Nyali Bridge, Tudor Creek and Mtongwe Channel • Island area of up to 2.3 Km^2 is low lying translating to 12.1% of the land mass, totalling to 22.6%. • Under this optimistic scenario by the year 2090, a total population of 2.6 million people will be living within the inundation range • The asset exposure for the scenario is US$6.4 billion	See Fig 4.22 for the names of exposed areas 	• Lamu Airport is among the exposed infrastructure under threat; Manda Toto will be completely be submerged. • The island area of up to 35 Km^2 is low lying and is susceptible to ocean disturbances in the event of a severe coastal storm event • The inundation translates to 60.4% of the land area under threat • Others include the site for the LAPSSET project offices and bays, the hotels around Shella as well as the business district of Lamu • Under this scenario, a projected population of 166,459 will be living within the exposed/vulnerable zone • The exposed assets will be towards US$ 435.8 million.	

Kenyan and international investors own properties on the island including a private residence meant for the British monarchy. Besides the business premises and related investments, the island also hosts households whose livelihoods as fishermen, boat makers and repairers as well as beach assistants will be equally impacted by SLR.

C.2.5 Population and infrastructure under threat

The Lamu Airstrip (also known as the Manda Airstrip) is the only air-flight gateway to Lamu island from other cities through domestic and chartered flights. Most Kenyan commercial airlines have flights twice a week to Lamu from Mombasa, Malindi or Nairobi. Even under the optimistic scenario, Manda Airstrip shows escalating inundation by the year 2060 and will be almost entirely immersed by the year 2090.

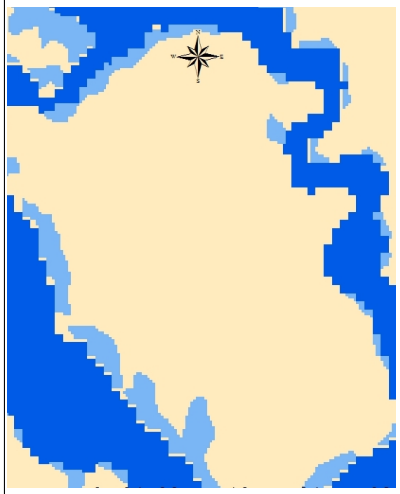
The Changamwe Oil Refinery site falls under the LECZ and is thus within the area under threat from sea level changes and inundation. The refinery earns an average monthly revenue of KSh10 million for handling LPG, petrol, diesel, dual purpose kerosene and fuel oil, even though the station is currently underutilised due to the government's policy changes to crude oil processing, and the reduced role of the facility from refining to storage of crude oil.

Under the optimistic scenario, this infrastructure is classified to be in the inundation zone by 2060. The severity and extent of inundation for Changamwe and Kipevu Oil Refinery facilities increases substantially under the pessimistic scenario (RCP 8.5).

C.3 RCP 8.5 SLR vulnerability for Mombasa and Lamu.

This scenario shows extremely severe impacts in each of the islands based on IPCC prediction of increased SLR under this scenario. The scenario rests on the assumption that climate change will go on unabated, and the use of fossil fuels will still continue unchecked. Under this scenario, low-lying areas under threat from inundation include cultural and religious sites in both islands, residential areas, transport and infrastructure such as airports and bridges as well as hotels that were adequately elevated under previous scenario (Rcp 2.6).

Table C.6: Spatial extent and SLR impacts on infrastructure, assets and people under RCP 8.5 for 2030

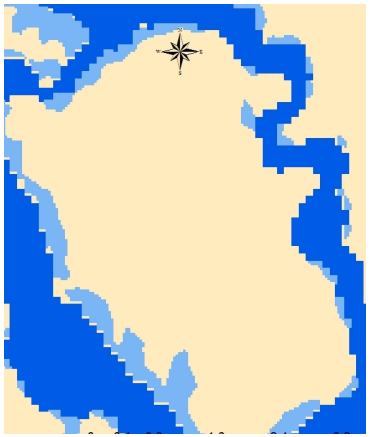
Mombasa Island	**Highlights on areas affected**	**Lamu Island**	**Highlights on areas affected**
See Fig 4.13 for the names of exposed areas 	• The most pessimistic scenario with no commitments to targets on global temperatures • A bigger proportion around Changamwe Refineries, Kilindini and Mombasa State House site would be affected by an extreme event • Other vulnerable areas include Nyali Bridge, the only exit to the North Coast as well as the multi-billion new hotel enterprise (English Point Marina) • The area of the island under threat translated to 2.0 Km^2 equivalent to the 8.2% extending out of Mombasa Island. • Population of 453,000 is exposed and vulnerable to inundation • The asset exposure under this scenario adds to almost US$ 1.2 billion	See Fig 4.23 for the names of exposed areas 	• The scenario completely disintegrates the business city and most areas in Lamu Island • All the areas within the island, with exception of the Shella sand-dunes will be frequently inundated • Key areas under threat include the Amu division itself, areas around Matondoni and Mokowe will be under water most of the time • Other areas affected include the Manda Island • Populations under threat under this scenario will be about 29 000 people • Assets under threat will be US$ 76.1 million

Under the RCP 8.5, most of Lamu Island falls within the inundation zone, except the Lamu Sand Dunes next to Shella residential area (see Table C.6. As earlier described, a seasonal high tide in Lamu has already flooded the central business district and destroyed property and homes. Most of these homes close to the coastline are inhabited by fishermen and business people who live and work along the main Lamu highway.

C.3.1 Summary and areas prone to SLR impacts by 2060

By the year 2060 island area of up to 28.3 Km^2 is low lying and is susceptible to ocean disturbances in the event of a severe coastal storm, clarified at 1-100 year return cycle. The inundation translates to 52.6% of the land mass being under threat from accelerated SLR. This includes the sections of Manda Island that host the Lamu Airport which will be slightly under threat. The mini Manda Toto, currently covered with mangroves, will be completely submerged under this scenario.

Table C.7: Spatial extent and SLR impacts on infrastructure, assets and people under RCP 8.5 for 2060

Mombasa Island	**Highlights on areas affected**	**Lamu Island**	**Highlights on areas affected**
See Fig 4.14 for the names of exposed areas 	• Important infrastructure is under threat from inundation under this scenario • The areas around Makadara, the Chaani residential area in Changamwe, the Old Town and Fort Jesus tourism attraction sites are increasingly vulnerable • Others include the Nyali Bridge, Mama Ngina Drive, the Kizingo Residential area as well as well as the English Point Marina • Island area of 20.5% falls under threat of inundation • Population of 1.9 million people will be living within the inundation range • Asset exposure for the scenario is estimated at US$ 5.2 billion	See Fig 4.24 for the names of exposed areas 	• Sections of Manda Island, Lamu Airport, is slightly under threat, including the mini Manda Toto currently covered with mangroves • Archipelago area of up to 28.3 Km^2 is low lying and susceptible to ocean disturbances in the event of a severe coastal storm • The inundation zone translates to 52.6% of the land mass • A population of up to 138,300 will be living within the inundation zone • Asset exposure is estimated at US$ 362 million

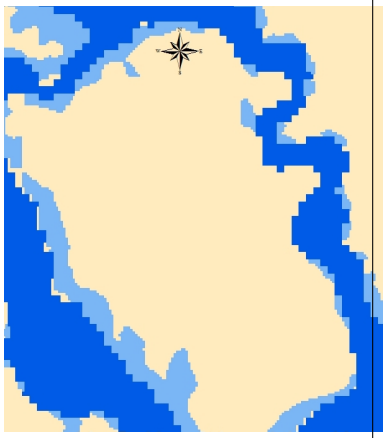
C.3.2 Population and socio-economic exposure

The exposed assets of Lamu Island at the elevation of up to 6m above sea level, under RCP 8.5 puts the county losses to around US$ 648 million and an exposed population of 248,000 people by the year 2090. The total asset exposure at Mombasa Island stands at US$ 9.2 billion by the year 2090 and a population of about 1.1 million by the same year. When the value of the property and infrastructure valuation that is based on the US$ 25M LAPSSET project, the total asset exposure is in the range of US$ 764 million. At the 10m LECZ, the asset exposure in Lamu by 2090 increases a value between US$ 180 million to US$ 284 million in assets. The asset exposure increases when people and properties living within the 8m to 10m range (the LECZ) are included.

C.3.3 Summary and areas prone to SLR impacts by 2090

The areas people and infrastructure prone to inundation by the year 209 is summarsed in Table C.8.

Table C.8: Spatial extent and SLR impacts on infrastructure, assets and people under RCP 8.5 for 2090

Mombasa Island	**Highlights on areas affected**	**Lamu Island**	**Highlights on areas affected**
See Fig 4.15 for the names of exposed areas. 	• All the critical infrastructure on the Island is under threat • Areas affected include the railway's area, Makadara, a large percentage of Chaani area, the Old Town, cultural graves at the Old Town and Fort Jesus • Others include the Bondeni Estates, Tudor Creek, Kenya Ports Authority offices and bays, the State House area along Mama Ngina Drive, the Kizingo residence including Mtongwe Channel in Likoni • Total area of up to 3.1 Km^2 is low lying translating to almost 21.9% of the land mass under threat from accelerated SLR • The total population living within the exposed zone is about 3.5 million people • The asset exposure for this scenario id estimated at US$ 9.1 billion	See Fig 4.25 for the names of exposed areas 	• Under this scenario Manda Toto completely disintegrates from the influence of SLR • Manda island is separated into different portions as the area is inundated • Other areas under threat include the Amu division itself and transport from the island will be disrupted • Other areas affected include the Manda Island • Populations under threat in this scenario add up to 247,500 persons • Assets under threat add up to US$ 648 million

C.3.4 Exposed populations under threat

The increased migration of rural populations to coastal towns has led to urbanization and population growth for coastline cities compounding the future impacts of climate change and especially SLR. Both Mombasa and Lamu islands have an increasing number of people living on the coast now coming under threat from accelerated SLR. Many of the participants living within the two coastlines appreciated that residing within the coastal areas for recreation, food and livelihood opportunities was attractive.

The total population living within the 8m sea level threshold for Mombasa Island is estimated to be 9.1 million by the year 2090 and 305,800 people in Lamu. This estimate is based on the standard annual population increase. The exposed population in the two islands grow to a total of 2.6 million individuals when the current urbanization trends are factored into the model.

Appendix D

Mini-charrette process and programme

Figure D.1: Data collection process during mini-charrette.

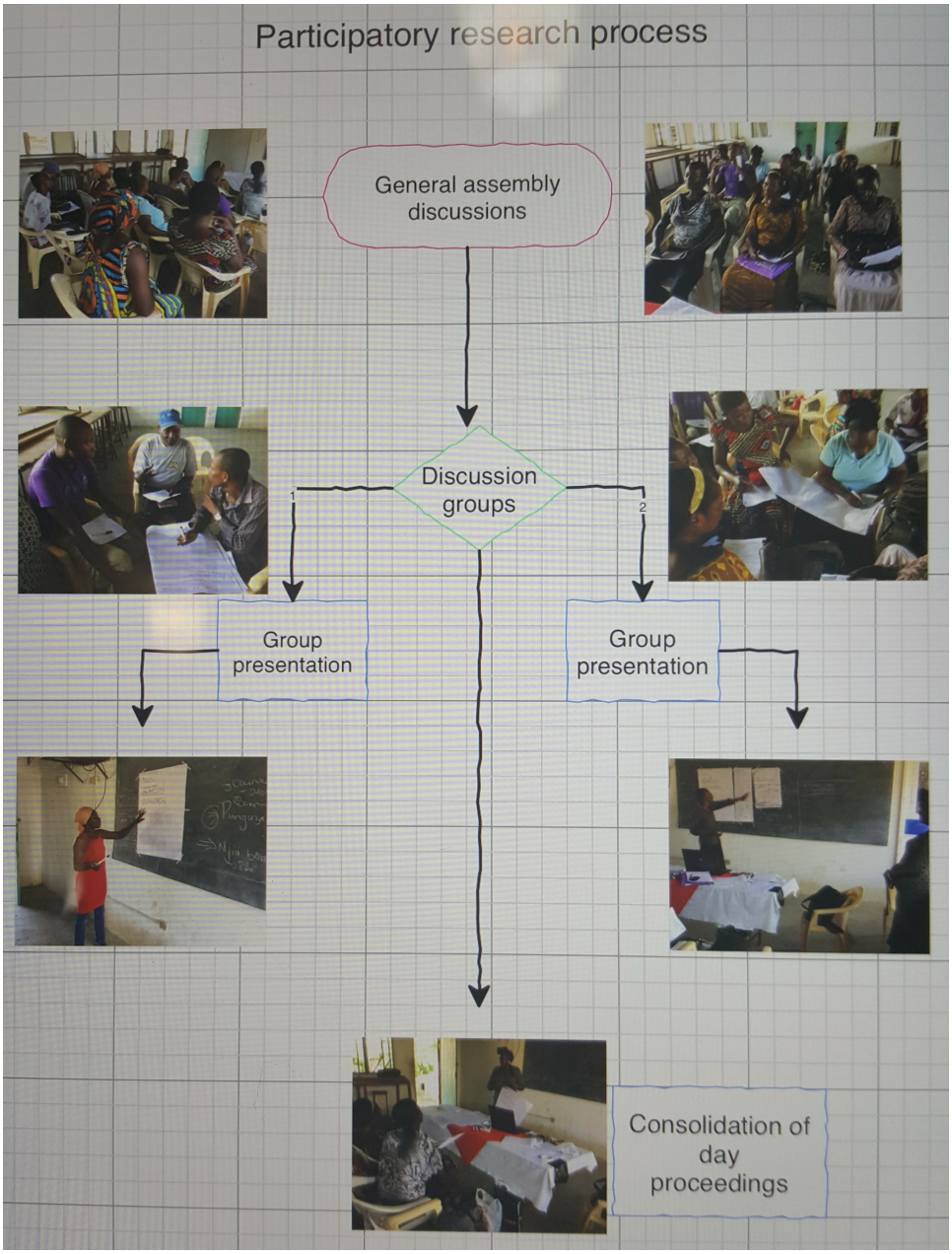


Table D.1: Programme and themes for Mombasa mini-charrette

WEDNESDAY, 29TH APRIL 2015			
Time	**Agenda Item**	**Responsible Person**	**Notes**
09:00 09:15 am	Registration	Researcher	Registration
09:15 09:45 am	Introduction and Welcome Remarks	Introduction by participants and expectations	Opening/Welcome Remarks
		Representative of researcher and team	Contextualizing the mini-charrette within the ongoing climate change issues and effects.
		Representative from Mombasa county office on environment.	Official Opening
09:45 10:15 am	**Overview of the mini-charrette project.**	Valentine Ochanda/Victor Kapiyo - WITS	A brief about the project, the thematic areas it intends to address and its approach it intends to use in its implementation; gaps it intends to address
10:15 11:45am	**Status of climate change knowledge and adaptation techniques in Mombasa**	Charrette groups assisted by the researcher and assistants	Highlight the current status of climate change and shared knowledge. Local climate change challenges affected by the community. Challenges in relation to knowledge and information on adaptation of identified climate change role of the various stakeholders in promoting sustainability in a changing climate.
11:45 12:40 pm	**HEALTH BREAK**		
12:50 14:00 pm	**Climate Change Adaptation and Mitigation in the Coastal Region (Mombasa County)**	The mini charrette groups	Overview of the current climate change challenges unique to the region; Impacts of climate change on the livelihoods of the local communities; gaps in addressing climate change; opportunities under climate change; Role of the County in addressing Climate change

Table D.2: Programme and themes for Mombasa mini-charrette

WEDNESDAY, 29TH APRIL 2015			
Time	**Agenda Item**	**Responsible Person**	**Notes**
2:00 3:45 pm	**Identification & Prioritization of gaps, key critical issues, challenges & Opportunities linked to SLR and Climate Change**	Panel of at least 5 Representatives from Government Department; CSO; Community Rep.	Identification of key issues, challenges and opportunities in Mombasa County related to climate change Governance and Climate Change. Building Consensus on key interventions
DAY TWO 30TH APRIL			
08:45-10:15	**Overview of the mini-charrette project and findings from the last engagement**	Valentine Ochanda,	Sharing of experiences on the best approach to strengthening the platform aimed at promoting climate change and SLR adaptation and mitigation techniques in Mombasa County
10:15 10:45 am	**PLENARY SESSION**		
10:45 11:30 am	**Group Work**		Aimed at creating consensus on the most sustainable framework of engagement
12:45 1:00 pm	**Closing Remarks by:** 1.County Officer, 2.CFA Representative 3.CSO Representative 4.Researchers **END OF THE CHARRETTE**		

Table D.3: Programme and themes for Lamu mini-charrette

THURSDAY, 11TH JUNE 2015			
Time	**Agenda Item**	**Responsible Person**	**Notes**
09:00 09:15 am	Registration	Researcher	Registration
09:15 09:45 am	Introduction and Welcome Remarks	Introduction by participants and expectations	Opening/Welcome Remarks
		Representative of researcher and team	Contextualizing the mini-charrette within the ongoing climate change issues and effects.
		Representative from Lamu county office on environment.	Official Opening
09:45 10:15 am	**Overview of the mini-charrette project.**	Valentine Ochanda/Victor Kapiyo - WITS	A brief about the project, the thematic areas it intends to address and its approach it intends to use in its implementation; Gaps it intends to address
10:15 11:45am	**Status of climate change knowledge and adaptation techniques in Mombasa**	Mini-charrette groups assisted by the researcher and assistants	Highlight the current status of climate change and shared knowledge. Local climate change challenges affected by the community. Challenges in relation to knowledge and information on adaptation of climate change role of the various stakeholders in promoting sustainability in a changing climate.
11:45 12:40 pm	**HEALTH BREAK**		
12:50 14:00 pm	**Climate Change Adaptation and Mitigation in the coastal region (Lamu County)**	The mini-charrette groups	Overview of the current climate change challenges unique to the region; Impacts of Climate change on the livelihoods of the local communities; Gaps in addressing climate change; opportunities under climate change; role of the County in addressing Climate change

Table D.4: Programme and themes for Lamu mini-charrette

FRIDAY, 12TH JUNE 2015			
Time	**Agenda Item**	**Responsible Person**	**Notes**
2:00 3:45 pm	**Identification & Prioritization of Gaps, key critical issues, challenges & Opportunities linked to SLR and Climate Change**	Panel of at least 5 Representatives from Government Department; CSO; Community Rep.	Identification of Key issues, challenges and opportunities in Lamu County related to climate change governance. Building Consensus on key interventions
DAY TWO 12th JUNE			
08:45-10:15	**Overview of the mini-charrette project and findings from the last engagement**	Valentine Ochanda,	Sharing of experiences on the best approach to strengthening the platform aimed at promoting climate change and SLR adaptation and mitigation techniques.
10:15 10:45 am	**PLENARY SESSION**		
10:45 11:30 am	**Group Work**		Aimed at creating consensus on the most sustainable framework of engagement
12:45 1:00 pm	**Closing Remarks by:** 1.County Officer, 2.CFA Representative 3.CSO Representative 4.Researchers **END OF THE CHARRETTE**		

Appendix E

Ethics clearance

Figure E.1: Ethics clearance form from University of The Witwatersrand.

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Khasenye Ochanda

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER H14/11/02**
PROJECT TITLE	A participatory and integrated approach towards vulnerability assessment of sea level rise along the coastal strip of Kenya
INVESTIGATOR(S)	Ms V Khasenye Ochanda
SCHOOL/DEPARTMENT	Architecture and Planning
DATE CONSIDERED	21 November 2014
DECISION OF THE COMMITTEE	Approved Unconditionally
EXPIRY DATE	07/12/2016
DATE 08/12/2014	**CHAIRPERSON** (Professor T Milani)

cc: Supervisor : Prof I Irurah

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10000, 10th Floor, Senate House, University.

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

_____ **Signature**

_____/_____/_____ **Date**

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES