NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE ADAPTATION AND SUSTAINABLE URBAN DRAINAGE IN TROPICAL COASTAL CITIES: A CASE FOR MOMBASA CITY

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by

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I dedicate this thesis project to my family, thesis advisor, friends, and everyone who played a role in any way throughout academic journey. I will forever be grateful.

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ABSTRACT

NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE ADAPTATION AND SUSTAINABLE URBAN DRAINAGE IN TROPICAL COASTAL CITIES: A CASE FOR MOMBASA CITY

Climate change is a reality, and its impact is being experienced all over the globe. The effects range from heat waves, raising sea levels, coastal erosion, flooding, drought, and reduction of bio-diversity among others. Urban areas are at greater risk since they accommodate the majority of the global human population exceeding 55% and are expected to be 68% by 2050. The most affected urban areas are the tropical coastal cities since most of them fall within low and middle-income countries with low levels of economic development and technological capabilities hence a low capacity to adapt.

This study focuses on exploring Nature-Based Solutions (NBS) as an affordable and ecologically sustainable approach to enhance climate change adaptability in tropical coastal cities. A case study of Mombasa is considered, a typical tropical coastal city located in Kenya. Primary data sources including pictures and key informant interviews via snowball sampling were employed to gather ground information. Secondary sources consisted of institutional data review, strategic documents, policies, and scientific journals on NBS and Climate Change adaptation in tropical environments.

The study findings depicted the climate change associated challenges in Mombasa include urban flooding, rising sea levels, coastal erosion, increasing temperatures. Rapid urbanization related challenges include inadequate infrastructure and services, poor liquid and solid waste management and inadequate housing. The study proposes NBS measures such as coastal vegetation restoration, implementing green infrastructure in the urban area, and creeks restoration could offer multi-dimensional benefits that can be replicated in other tropical coastal cities to enhance sustainability and climate resilience.

ÖZET

TROPİKAL KIYI KENTLERİNDE İKLİM DEĞİŞİKLİĞİNE UYUM VE SÜRDÜRÜLEBİLİR KENTSEL DRENAJ İÇİN DOĞAYA DAYALI ÇÖZÜMLER: MOMBASA ŞEHRİ ÖRNEĞİ

İklim değişikliği bir gerçektir ve etkisi tüm dünyada yaşanmaktadır. Bu etkilerin arasında ısı dalgaları, deniz seviyelerinin yükselmesi, kıyı erozyonu, sel, kuraklık ve diğerleri arasında biyo-çeşitlilik kaybı bulunmaktadır. Güncel durumda kentsel alanlar küresel nüfusun %55'inden fazlasını barındırdığı ve 2050 yılına kadar %68'e kadar artacağı beklendiği için daha büyük risk altındadır. En çok etkilenen kentsel alanlar tropik kıyı şehirleridir, çünkü çoğu düşük ekonomik kalkınma ve teknolojik yeteneklere sahip düşük ve orta gelirli ülkeler kategorisindedir ve bu da onların uyum sağlama kapasitesinin düşük olmasına neden olmaktadır.

Bu çalışma, tropikal kıyı kentlerinde iklim değişikliğine uyum sağlamak için uygun fiyatlı ve ekolojik olarak sürdürülebilir bir yaklaşım olarak doğaya dayalı çözümleri (NBS) keşfetmeye odaklanmaktadır. Kenya'da bulunan tipik bir tropikal kıyı kenti olan Mombasa vaka çalışması olarak ele alınmıştır. Zemin bilgilerini toplamak için kartopu örneklemesi yoluyla resimler ve önemli muhbir görüşmeleri de dahil olmak üzere birincil veri kaynakları kullanılmıştır. İkincil kaynaklar, kurumsal verilerin gözden geçirilmesi, stratejik belgeler, politikalar ve NBS ve tropikal ortamlarda iklim değişikliğine uyum ile ilgili bilimsel dergilerden oluşuyordu.

Çalışma bulguları, Mombasa'daki iklim değişikliği ile ilgili zorlukların kentsel sel, yükselen deniz seviyeleri, kıyı erozyonu, artan sıcaklıklar olduğunu göstermiştir. Hızlı kentleşme ile ilgili zorluklar arasında yetersiz altyapı ve hizmetler, zayıf sıvı ve katı atık yönetimi ve yetersiz konut bulunmaktadır. Çalışma, kıyı bitki örtüsünün restorasyonu, kentsel alanda yeşil altyapının uygulanması ve derelerin restorasyonu gibi NBS önlemlerinin sürdürülebilirliği ve iklim direncini arttırmak için diğer tropikal kıyı şehirlerinde çoğaltılabilecek çok boyutlu faydalar sunabileceğini önermektedir.

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NOMENCLATURE

Abbreviations

AT	Alternative Techniques
BI	Blue Infrastructure
BMPs	Best Management Practices
CBD	Central Business District
CC	Climate Change
CIDP	County Integrated Development Plan
CIDP	County Integrated Development Plan
CO_2	Carbon Dioxide
CSE	Catchment Systems Engineering
DDR	Disaster Risk Reduction
EBA	Ecosystem Based Adaptations
EE	Ecological Engineering
ESA	Ecosystem Services Approach
FEMA	Federal Emergency Management Agency
GDP	Gross Domestic Product
GHG	Green House Gases
GI	Green Infrastructure
ISUDP	Integrated Strategic Urban Development Plan
ITCZ	Inter Tropical Convergence Zone
IUCN	International Union for Conservation of Nature
IUWM	Integrated Urban Water Management
JICA	Japan International Cooperation Agency
KNBS	Kenya National Bureau of Statistics
LID	Low Impact Development
LIUDD	Low Impact Design & Development
MCA	Member of County Assembly
NBS	Nature Based Solutions
NC	Natural Capital
NGOs	Non-Governmental Organizations

SC	Source Control
SCMs	Storm Water Control Measures
SDGs	Sustainable Development Goals
SUDs	Sustainable Urban Drainage Systems
SWMM	Storm Water Management Model
UN	United Nations
UNFCC	United Nations Framework Convention on Climate Change
UN-HABITAT	United Nations Human Settlements Programme
UNICEF	United Nations Children's Emergency Fund
USGS	United States Geological Survey
WSUD	Water Sensitive Urban Design

CHAPTER 1

INTRODUCTION

1.1 Background

Climate change is becoming a reality that is being manifested in different parts of the globe. Its consequences result in rising global average temperatures, changing patterns of rainfall, and incidences of extreme weather events, among others. The United Nations Framework Convention on Climate Change (UNFCC) defines climate change as, "a change of climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods" (UNFCC, 1995, p. 7). Thus, the phenomenon encompasses natural and human-driven factors. Climate change effects have brought significant changes in the environment, livelihoods, and the general urban landscape in different parts of the globe.

The areas significantly vulnerable to climate change are the towns and cities situated within the tropical region of the globe and particularly human settlements concentrated along the coastal regions. The warm climate and geographical context of these regions increase their vulnerability. Correspondingly, most cities within these regions are characterized by middle to low levels of economic development and technological capabilities. This further exacerbates climate change adaptation and mitigation capabilities of these areas. Among the climate change challenges anticipated and already experienced in the tropical coastal cities include raising sea levels, coastal and urban flooding, erosion, storm surge, typhoons, loss of biodiversity among other effects (Balica et al., 2012). This calls for an urgent need in adopting mitigative and adaptive measures that could reduce the climate change vulnerability of these areas while improving the livelihoods and environmental quality. Hence the need for ecosystem-based approaches and NBS interventions.

Nature-Based Solutions (NBS) have experienced growing popularity in different corners of the globe as a possible ecosystem-friendly and economical intervention able to lessen climate change effects. It is explained as a variety of environmental restoration solutions that enhance environmental resilience while creating economic opportunities and social benefits to the respective communities (Curran & Hamilton, 2020). Thus, NBS solutions can provide multiple benefits ranging from environmental, social, and economic gains. These solutions are characterized by their ability to support and mimic natural processes, cost-effectiveness in implementation and maintenance, and ability to offer simultaneous benefits to the ecosystem and the community. Other related ecosystems friendly approaches towards climate change adaptation and mitigation as identified by Nesshöver C. et al., (2017) include Ecological Engineering (EE), Catchment Systems Engineering (CSE), Green and Blue Infrastructure (GI & BI), Ecosystem-Based Adaptations (EBA), Ecosystem Services Approach (ESA) and Natural Capital (NC), among others. These concepts are all considered environmentally friendly interventions in creating resilient ecosystems, however, Nature-based solutions are considered more holistic and comprehensive solutions offering multiple benefits (Nesshöver et al., 2017).

Flooding and storm water management in coastal cities is among significant climate change risks. According to Diez et al., (2011), climate change has caused a growing risk of intense flood and damages in coastal cities thus necessitating the need for appropriate flood resilience systems. This, therefore, calls for a Sustainable Urban Drainage System (SUDs) to enhance efficient handling of water and improve flood resilience in coastal urban areas. Sustainable drainage systems can be explained as "Singular, or series of management structures and associated processes designed to drain surface runoff in a sustainable approach to predominantly alleviate capacities in existing conventional drainage systems in an urban environment..." (Butler and Davies, 2000; CIRIA, 2000; SEPA, 1999). The systems tend to imitate natural drainage by incorporating measures that slowing down runoff thus reducing the overwhelming of traditional drainage systems. The SUDs enable the collection, storage, and cleaning of surface water runoff before it goes back to the environment. These systems are preferred due to their environmental friendliness and relatively low cost of implementation making them feasible in middle and low-income economy cities.

1.2 Scope and Rationale

The study evaluates the climate change-related effects on coastal cities within the tropical region of the globe and proposes appropriate Nature-Based Solutions that could reduce climate change vulnerability and foster climate mitigation and adaption of Tropical Coastal Cities including enhancing Sustainable Urban Drainage. The concept of NBS favours the tropical coastal cities due to its relatively affordable cost compared to other structural engineered solutions. It correspondingly provides multi-faceted benefits to these cities including both socio-economic well-being, environmental and ecosystem restoration and protection and the general urban aesthetics among other benefits. Most tropical coastal cities have low to medium levels of economic development with relatively insufficient technological capacities to implement expensive engineering solutions that would ensure climate resilience. Thus, nature-based solutions present a more realistic, cost-effective and sustainable approach towards climate adaptation and sustainable drainage in these cities.

1.3 Problem definition

Climate change termed as a 'defining crisis of our time' by the UN is having significant negative effects all over the globe including degradation of the environment, frequent occurrence of natural disasters, weather extremes, food insecurity, water scarcity, disruption of the local economy, sea levels rising, reduction in biodiversity, and acidification of oceans, among others. These effects are anticipated to be paramount in the tropical regions of the globe. This is due to lower levels of economic development, rapid urbanization, and inadequate technological advancements of most cities within the world's tropical zone making them more susceptible to climate change adversities. However, the low cost, ecological sustainability, and multiple rewards of Nature-Based solutions provide an opportunity for intervention measures that could reduce the effects of climate change while fostering adaptability of tropical coastal cities. In this thesis research, Mombasa city is evaluated as a typical tropical low-income coastal city. Mombasa city is experiencing several climate-related challenges such as rising sea levels, coastal erosion, urban flooding, environmental degradation, food insecurity, water scarcity, and loss of biodiversity and mangrove species, among others. These challenges, therefore, advocate for urgent intervention to enhance adaptability and reduce the adverse ramifications of climate change within the city. Thus, NBS solutions could serve as a crucial innovative intervention to enhance the sustainability, resilience, and adaptability of Mombasa City.

1.4 Aim of the study

The study aims to identify appropriate Nature-Based Solutions for tropical coastal cities like Mombasa to enhance resilience and climate change adaptability while fostering sustainable urban drainage.

The specific objectives include:

- To identify the climate change challenges facing tropical coastal cities
- To identify NBS & SUDs practices ideal for tropical coastal cities
- To evaluate Mombasa city based on climate challenges and Risks.
- To propose appropriate NBS measures suitable for Mombasa City.

1.5 Methodology

The thesis answers the question on what the best nature-based solutions for tropical coastal cities are, and specifically Mombasa city, to enhance climate adaptability and sustainable urban drainage. The research sub-questions are as follows:

- What are the climate change challenges facing tropical Coastal Cities?
- What are the NBS & SUDs interventions for these cities?
- What are the climate change challenges faced by Mombasa city?
- What are the best NBS & SUDs solutions ideal for the City?

The research primarily involved a qualitative approach. It consisted collection of both primary and secondary data. The methods of data collection utilized included:- Secondary data review, Case studies review, Interviews, Surveys, and Satellite Images and Photographs. Primary data sources consisted of photographs and interviews done through snowball sampling. The interviews included key informants drawn from Governmental departments, NGOs, Community Organizations, and the Private sector. The primary data was useful in depicting the current situation of the city, the severity of challenges, and measures put in place to mitigate the challenges. Secondary data sources on the other hand included satellite imagery, website reviews, institutional data reviews, policy reviews, and journal reviews. This data was instrumental in depicting challenges and characteristics of tropical cities, NBS & SUDs interventions in explaining the different sustainable drainage practices, design and implementation requirements, space, and infrastructure needs (Figure 1.1).

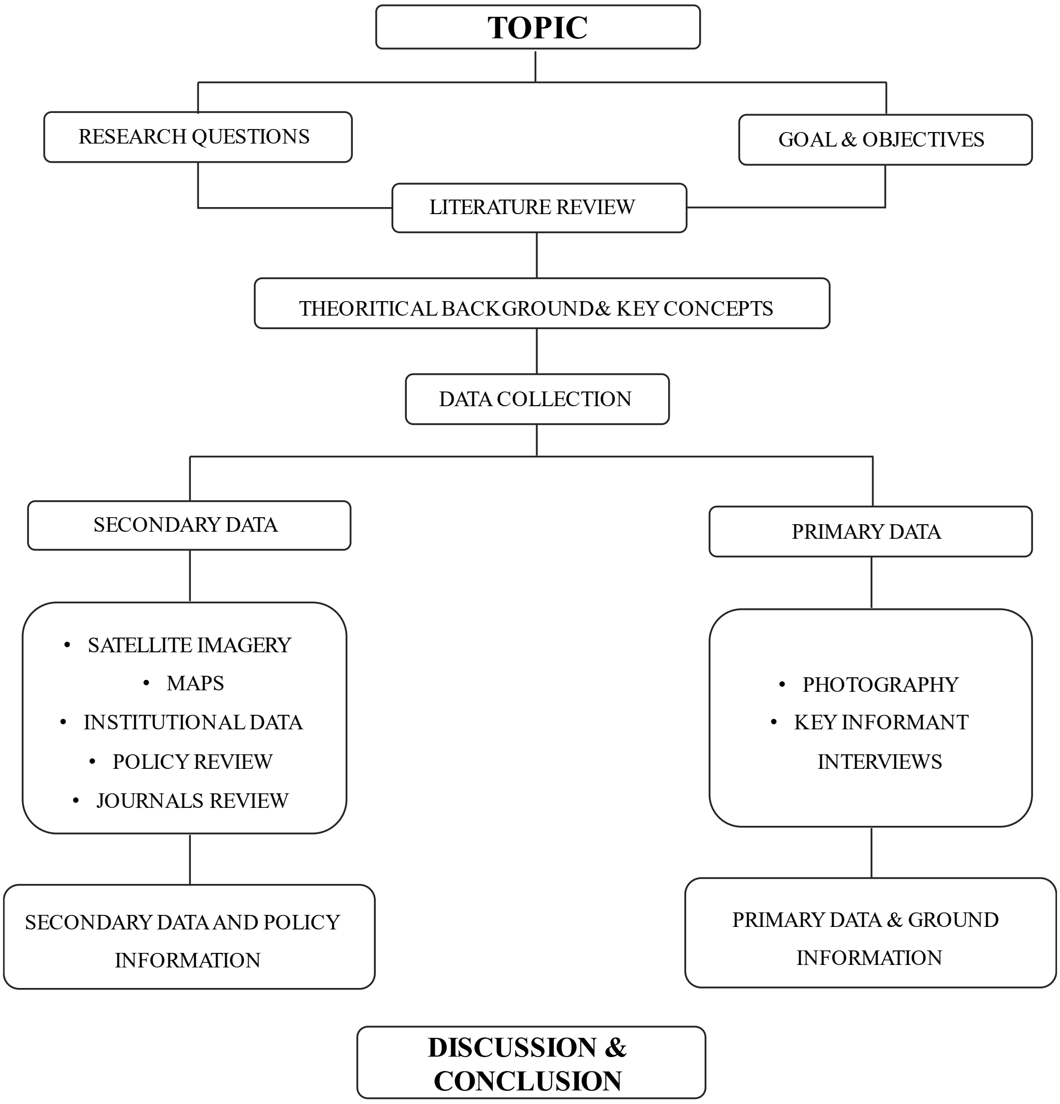


Figure 1.1: Thesis Methodology

1.6 Thesis Structure

This thesis report is organized into main five main chapters. Chapter one forms the introduction highlighting; background information, problem statement, the aim of this thesis, and methodology including the thesis structure. The second chapter discusses the literature background on tropical cities and their challenges. The third chapter discusses the literature on Nature-Based Solutions and also the Sustainable Urban drainage systems in detail. Chapter four discusses the case study of the city of Mombasa. It highlights the main challenges findings and discussion. The final chapter is the conclusion responding to the main research question stated in chapter one (Figure 1.2).

CHAPTER 1 : INTRODUCTION

CHAPTER 2 : TROPICAL COASTAL CITIES, CHALLENGES & CLIMATE CHANGE

CHAPTER 3 : NATURE BASED SOLUTIONS & SUSTAINABLE URBAN DRAINAGE SYSTEMS

CHAPTER 4 : THE CASE STUDY OF MOMBASA CITY & DISCUSSION

CHAPTER 5 : CONCLUSION

Figure 1.2: Thesis Flow

CHAPTER 2

TROPICAL COASTAL CITIES, CLIMATE CHANGE, AND CHALLENGES

This chapter explains tropical zones, tropical cities, and eventually coastal tropical cities along with their characteristics. It also discusses the challenges facing tropical cities including the climate change challenges and their respective adaptation measures.

2.1 World Bioclimatic regions

The world is classified into four bioclimatic regions based on the vegetation typologies located in the different regions. The classification was done by a scientist from Germany by the name Wladimir Koppen in 1900 (Kottek et al., 2006). This was then plotted into a map by Rudolf Geiger in 1954 and 1961. The four vegetation zones are Tropical, Subtropical, Temperate, and Polar zones (Figure 2.1). The Koppen-Geiger climate classification is the most prominent in climatology (Kotttek et al. 2006).

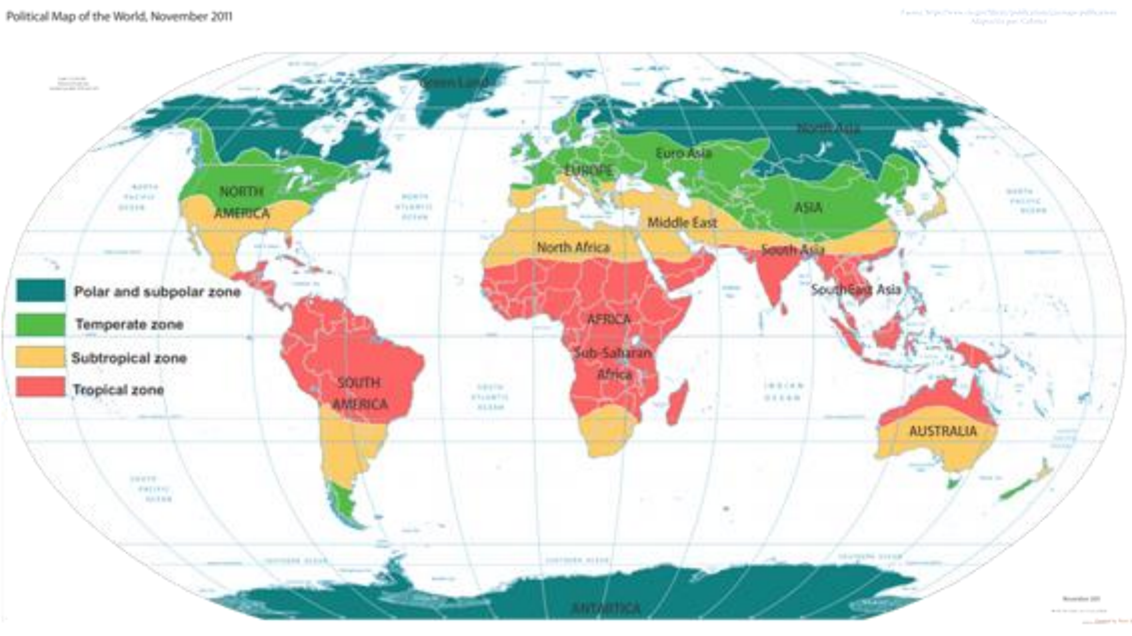


Figure 2.1: World Climatic Zones

(Source: Adopted from Meteoblue, 2021)

The different regions are characterized by distinct climatic and geographic conditions which further affect the urban dynamic and the opportunities and challenges associate. (Steiner Thomas, 2011).

2.1.1 Polar and Subpolar zone

The polar and Subpolar region lies between 60 degrees and the poles (North and South Poles). It includes both Artic/Sub artic and Antarctic/Sub-Antarctic areas. These regions receive significantly less warmth from the sun and the length of days vary significantly, thus rendering the places to be cold almost throughout the year. For the polar regions, three-quarters of the total area is coved by ice forming polar deserts extending widely in the polar region of the Southern Hemisphere. In the Northern hemisphere, it includes Greenland and Artic Islands. This region is the most exposed and most vulnerable to global climate changes.

2.1.2 Temperate zone

This region covers the areas falling between 40 – 60 degrees latitudes. Sun insolation in these areas is quite less and the average temperatures are generally cooler than those of the sub-tropical regions. The length of days and nights vary significantly in these regions throughout the year. This region received regular precipitation throughout the year and less frequent extreme temperatures. It includes parts of North America, Europe and Some parts of Asia, South-Eastern Australia, and a significant part of New Zealand.

2.1.3 Sub-tropic zone

The subtropic zone lies between latitudes 0 – 40 degrees. These regions tend to receive high solar insolation during summer and the sun is almost vertical. The areas located within usually receive less precipitation and the majority of the world's deserts are located within these regions such as Mojave in California, Sonoran in Mexico, Chihuahua in Northern America, Sahara in North Africa, and the Great Victoria Deserts in Western Australia. The temperatures in these areas reduce remarkably in winters and can be cool and moist.

2.1.4 Tropical zone

The region lying between the latitudes 0 – 23.5 degrees is bounded by the tropic of cancer from the north and the tropic of Capricorn to the south. In this region the sun is usually vertical at noon time almost throughout the year, resulting in these areas being very warm. This zone is equally surrounded by the world oceans including the Indian Ocean, Atlantic Ocean, and the Pacific Ocean. The climate is usually warm and humid due to the moist air as a result of evaporation. The continents located within this zone include Southern North America, Northern South America, Most parts of Africa, Central & Southern Asia, and Northern Australia. The region receives solar radiation almost vertically at noontime for nearly the entire year. Due to the temperatures, there is more evapotranspiration, and the air is often moist in these regions thus prone to heavy cloud cover which reduced the impacts of solar radiation on ground temperatures (Meteoblue, 2011).

2.2 The climate in Tropical zones

The tropical climates are classified as type A per the Köppen climate classification. This is because the climate of this zone is the warmest amongst the four zones identified in the section above. The temperatures tend to be warm and generally above 18 °C (Degrees Celsius) throughout the year. The key factors controlling the climate within the tropical region is the Inter-Tropical Convergent Zone (ITCZ) and the influence of land and oceans.

The ITCZ is explained by NASA’s Earth Observatory as the region which encircles the Earth near the equator, creating a zone whereby the trade winds of the world's hemispheres, i.e., Northern and Southern, come into contact. The intense insolation and warm water of the equator heat the air in the ITCZ raising its humidity and making it float as its meets with the Trade-winds it cools releasing moisture in form of rainfall. The geographical position of the ITCZ changes throughout the year thus affecting the rainfall availability in the different parts of the equatorial countries. This results in the change between dry and wet seasons within this zone.

According to the Köppen climate system, the tropical bioclimate is further classified into; Tropical Rainforest also Equatorial (Af), Tropical Monsoon (Am), and Tropical Wet and Dry also Savannah (Aw), (Figure 2.2).

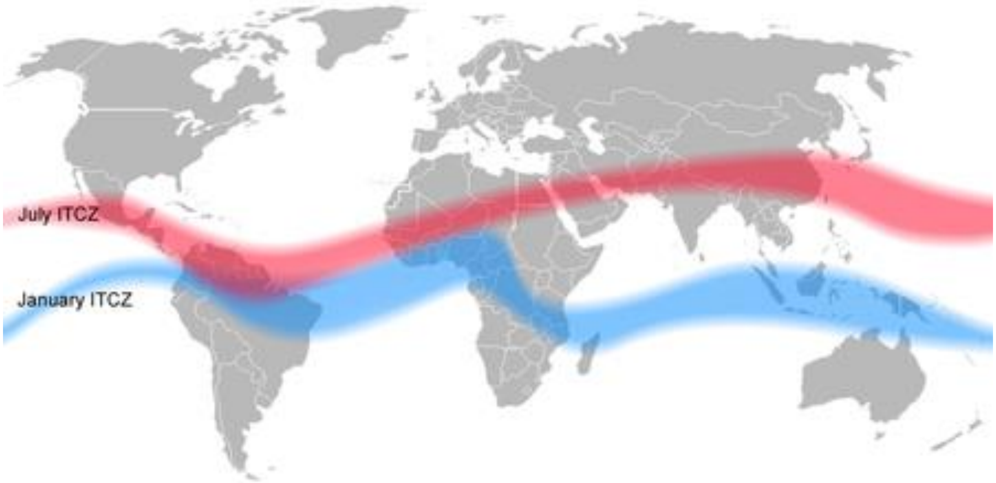
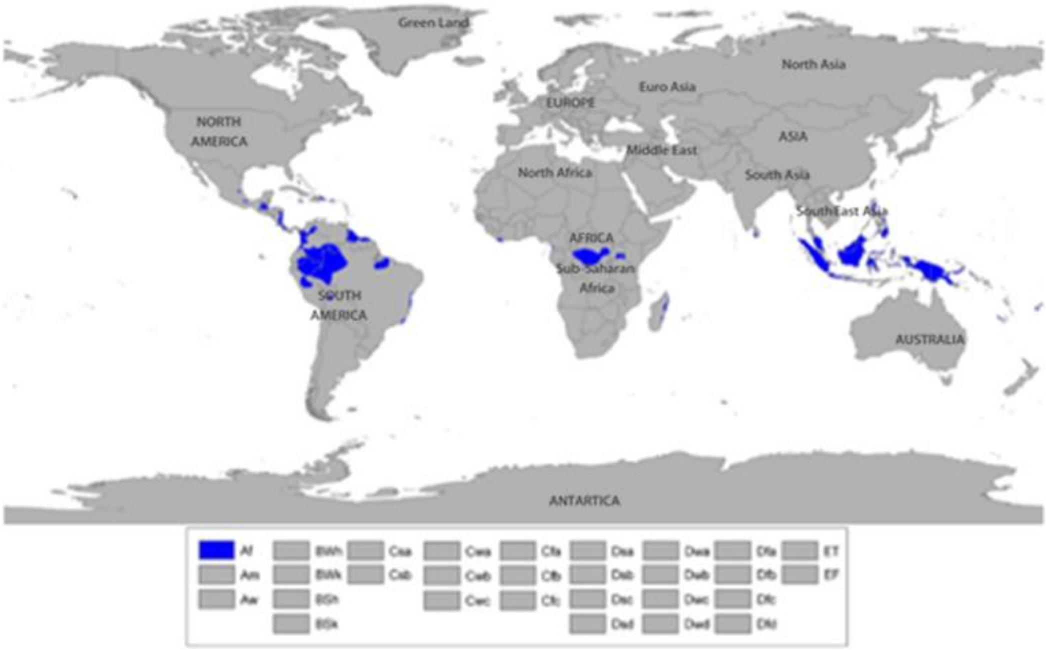


Figure 2.2: Inter-Tropical Convergence Zone (ITCZ)

(Source: weebly.com; http://thebritishgeographer.weebly.com/the-climate-of-tropical-regions.html accessed on 03.04.2021 at 22.52)

2.2.1 Tropical Rainforest (Equatorial)

This zone has warm average temperatures and a significant amount of precipitation throughout the year of approximately 60mm and annual precipitation of over 2000mm. It has a diurnal temperature difference that is higher than the annual temperature scale. The zone correspondingly has a dense vegetation cover and experiences a higher range of transpiration which further contributes to the warm and wet climatic conditions. The global distribution rainforest includes areas in Central and South America including the Bosawas and Amazon rainforest; Western and Central Africa such as Cameroon and Congo, Western India, Southeast Asia such as the Philippines, Indonesia, Malaysia, Papua New Guinea, and Sri Lanka; the Island of New Guinea, Australia, and some parts of Pacific islands such as Hawaii. Global distribution of tropical rain forest zones within the different continents (Map 2.1).

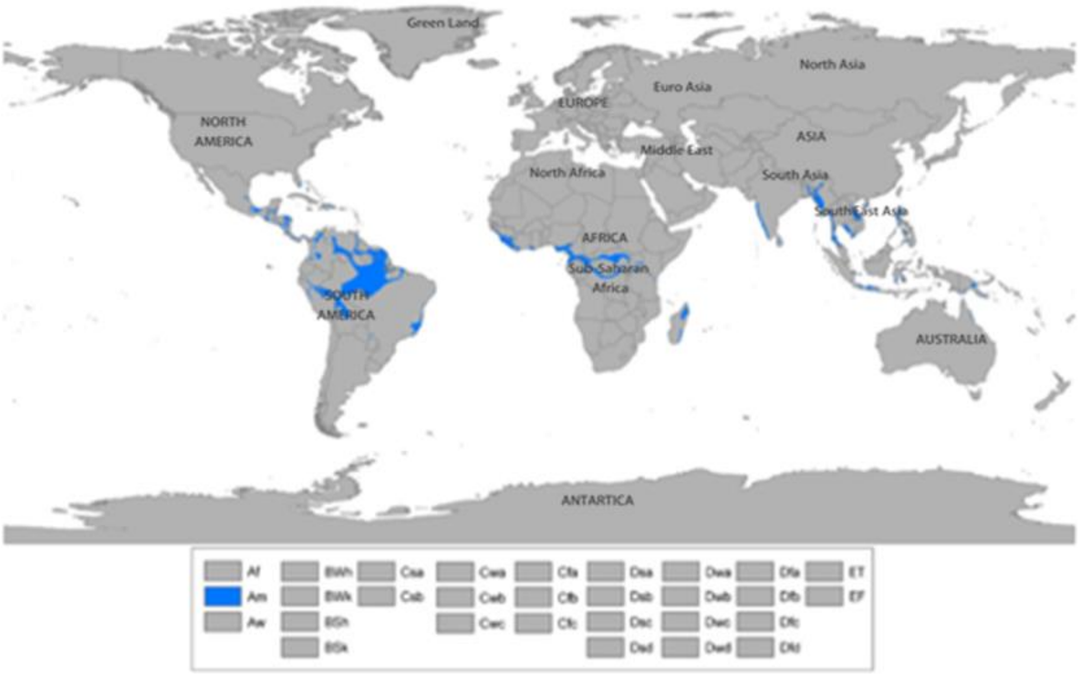


Map 2.1: Tropical Rainforest Climate Distribution

(Source: Weebly; http://thebritishgeographer.weebly.com/the-climate-of-tropical-regions.html)

2.2.2 Tropical Monsoon Climate

The type of climate is scarce within the tropical zone compared to the others. The zone tends to experience average temperatures of more than 18 °C throughout the year. It also experiences both wet and dry seasons depending on the winds and the position of the ITCZ. The rainfall experienced within this zone averages 1000mm annually and equally experiences dry weather conditions during the winter solstice, i.e., when the sun rays are directly overhead at the Tropic of Capricorn. The Geographical areas covered by this climate include Northern South America, Some parts of West and Central Africa, and a small section of South Asia. Tropical monsoon climate across the different continents within the globe (Map 2.2).



Map 2.2: Tropical Monsoon Climate Distribution

(Source: Weebly; http://thebritishgeographer.weebly.com/the-climate-of-tropical-regions.html)

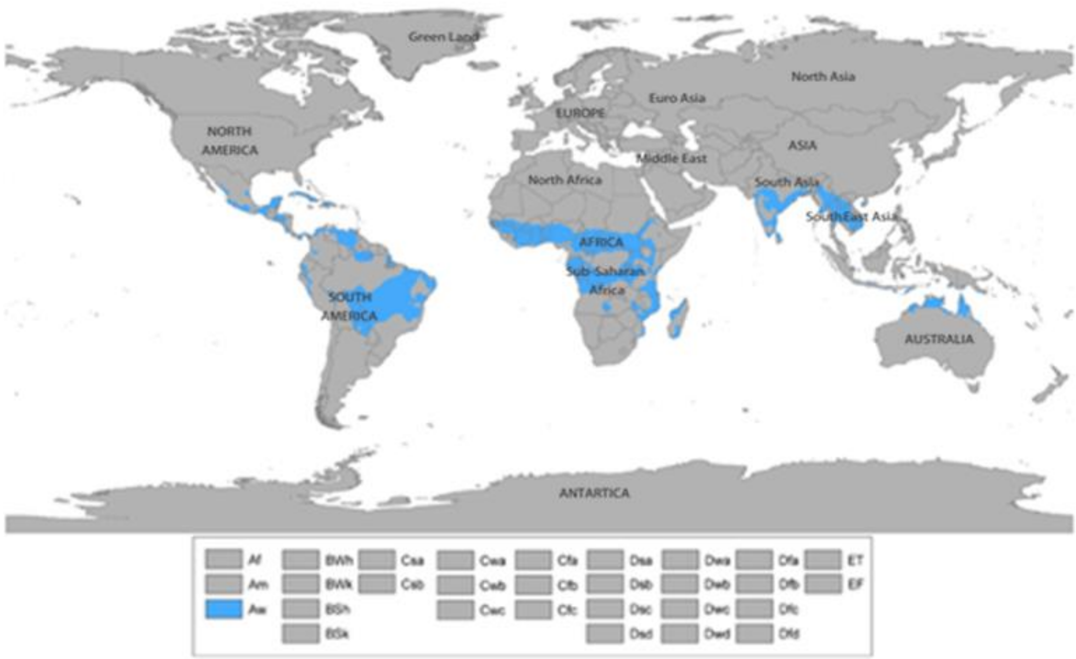
2.2.3 Tropical Dry and Wet Climate (Savannah)

The is zone is equally referred to as Savannah climate, generally receives an annual rainfall of less than 60mm throughout the year. It also receives a lower annual rainfall of 1000mm. They have two main seasons, dry and wet seasons depending on the movement of the ITCZ (Map 2.3).

Jauregui E. (1991) explains the tropical climate to be characterized by both warm temperatures and humidity combine creating a feeling of sultriness i.e., Hot & Humid weather. Whereby the region is characterized by hot temperatures with high content of air humidity. It is differentiated into four sub-bioclimatic zones namely, -

- Inner tropical – consisting of mainly wet and dry with heat prevailing for months before the onset of rainy seasons which are influenced by the ITCZ migrations.
- Tropical highland – these zones are characterized by high altitudes and are characterized by cold winters and mild summers (Sinha, 2010)
- Subtropical dry desert – referring to areas characterized by heat in the summer and cold in winter. It mainly includes the desert areas.

- Low altitude or Coastal – These mainly include the coastal lowlands and the areas are characterized by mainly warm and humid conditions experienced almost throughout the year.



Map 2.3: Tropical Wet and Dry climate (Savanna) Distribution

(Source: Weebly; http://thebritishgeographer.weebly.com/the-climate-of-tropical-regions.htm)

The focus of this thesis would be the low latitude areas within the tropical zone, mainly the 'tropical coastal cities' which are mainly characterized by hot and humid weather conditions.

2.3 Tropical Coastal Cities

Tropical Coastal Cities can be explained as dense human settlements along the coastal regions within the tropical zone. The key attribute of coastal cities is their proximity to the sea, ocean, or large water bodies. Small et al (2003), Dam & Le (2019) define a coastal area as a geographical region within100 km from the shoreline and about 100m of sea level. Correspondingly, coastal cities are explained by McGranahan et al (2007) as "a contiguous area along the coast that is less than 10 meters above sea level." Hence, the common characteristic of the coastal areas as discussed in the definition above is their proximity to sea or ocean and the altitude above the sea level.

2.3.1 Characteristics of Tropical Coastal Cities

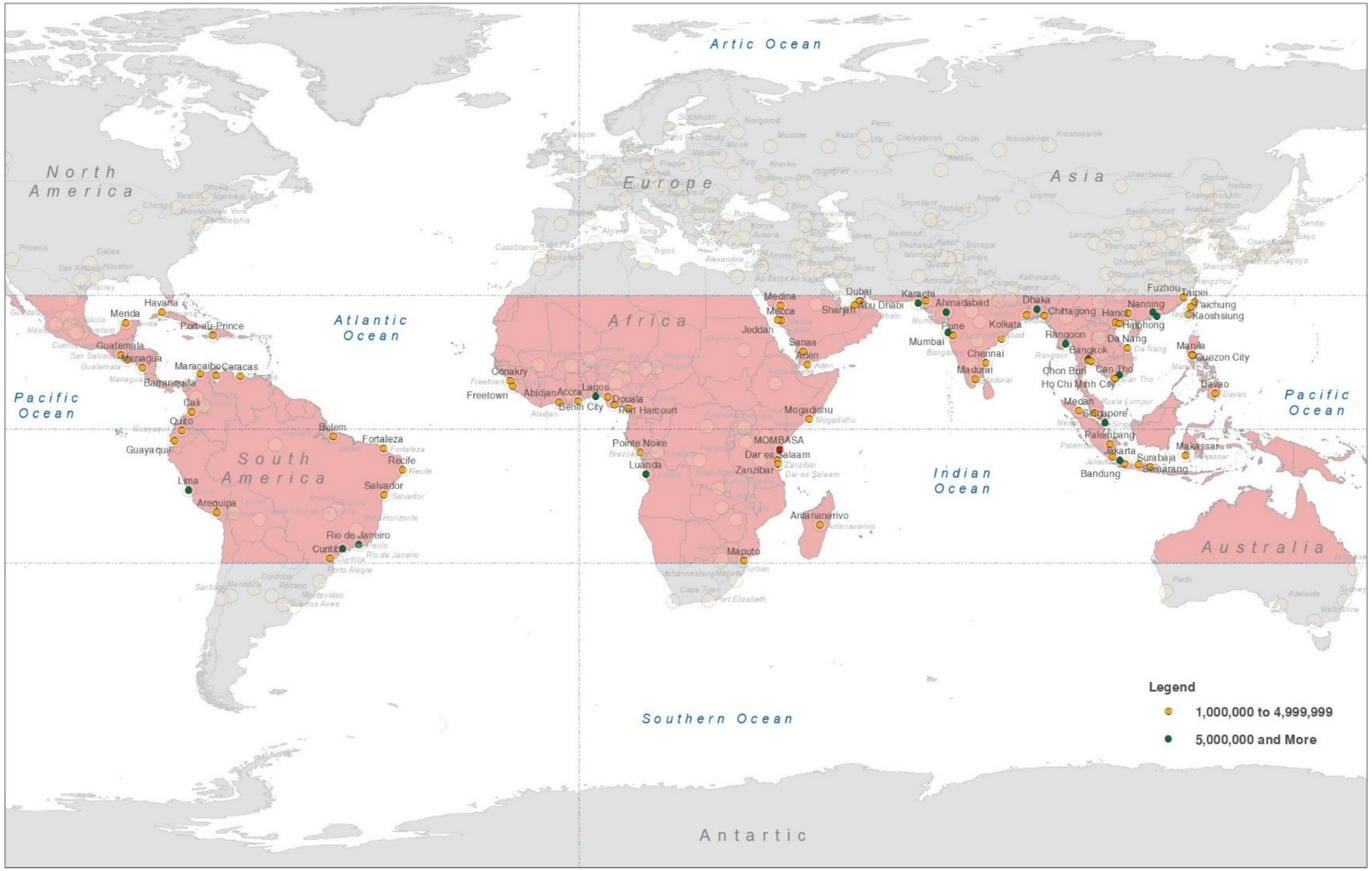
According to Xiang et al., (2020), Surjan & Shaw (2016) coastal areas are characterized by rapid socio-economic development, increasing population growth, shortage of land resources, threats of disasters, and risks. Thus, rendering the coastal areas with adequate financial resources to reclaim land from the oceans.

Tropical coastal cities on the other hand are explained as the coastal cities situated within the tropical zones. These are normally characterized by hot and humid climates, the rapid expansion of population, environmental degradation, air pollution, heat stress, and flash-floods which jeopardize the health and safety of local communities (Oke et al. 1991).

According to Dam & Le (2019), Coastal cities more so in countries still developing are at a greater risk of climate change due to their low adaptive capacities. These cities already experience a variety of challenges both climatic and non-climatic related (Dam & Le, 2019).

2.3.2 Global Tropical Coastal Cities Distribution

Tropical cities are mainly located within Central and South America, Sub-Saharan Africa, East and Southeast Asia, and Some parts of Australia. Most of these cities share similar characteristics including warm climatic conditions, rapid urbanization, levels of economic development, urbanization trends, levels of infrastructure developments, and urban governance issues among others. The global distribution of tropical coastal cities is highlighted, from the different continents of the globe, including Mombasa City in Sub-Saharan Africa, Kenya (Map 2.4).



Map 2.4: Global Tropical Coastal Cities

(Source: Author, 2021)

Below (Table 2.1) is a summary of major tropical coastal cities with a population of more than one million: -

Table 2.1: Global Tropical Coastal Cities

South America	Sub-Saharan Africa	Southeast Asia
▪ Barranquilla	▪ Accra	▪ Bangkok
▪ Cartagena	▪ Cotonou	▪ Bombay
▪ Lima	▪ Dakar	▪ Calcutta
▪ Rio de Janeiro	▪ Dares-salaam	▪ Dacca
▪ Salvador	▪ Lagos	▪ Jakarta
▪ Santiago	▪ Luanda	▪ Karachi
▪ Havana	▪ Maputo	▪ Manila
	▪ Mombasa	▪ Mumbai
		▪ Singapore
		▪ Hanoi
		▪ Ho Chi Minh

2.3.3 Challenges Facing Tropical Coastal Cities

Due to the nature of their geographical location, level of economic development, and similarities in climatic conditions, tropical cities tend to have similar climate and development challenges. Studies related to challenges facing coastal cities can be broadly classified into three broad dimensions namely Global warming-related, Climate Change connected, and Socio-Economic factors attributed (Dam & Le, 2019). A fourth dimension has been included which relates to subsidence. These factors are discussed below as follows.

2.3.3.1 Global warming

It is explained as the long-term heating of the earth's climate system due to natural and human activities resulting in increasing temperature, disturbance of water supply, food security, and health. These challenges are experienced globally but more severe in tropical cities due to rapid population growth and low technological and economic capacities, among others.

2.3.3.2 Climate change effects

Climate Change is defined by Balica et al., 92012), as the continuing change in the typical weather patterns that characterize the local, regional, and global average temperatures, rainfall patterns, and humidity among other weather elements. The phenomenon does not only affect weather patterns but also the environment, biodiversity, and socioeconomic activities. Climate change is manifested through rising sea levels, flooding, erosion, storm surge, and typhoons along with coastal areas. (Balica et al. 2012)

2.3.3.3 Non-climatic factors

The non-climatic factors include all the factors not directly associated with the climate. They include mainly social and economic factors such as rapid population increase, faster rates of urbanization, inadequate infrastructure, weak data systems, poor urban connectivity, inadequate social service provision, Insecurity of land tenure, and low economic development among other factors. These factors further increase the susceptibility of these settlements to climate change and lower the capabilities of disaster risk management.

2.3.3.4 Subsidence

It is explained as the gradual downward settling of the ground's surface mainly associated with the removal of subsurface earth materials (USGS). It is primarily associated with excessive extraction of groundwater to rapid population growth driving up the demand. Subsidence has been evidenced in several coastal cities such as Bangkok, Ho Chi Minh City, and Jakarta among others (Erkens G. et al., 2015). It is attributed to factors including rapid population growth and increasing extraction of groundwater hence exposing cities to flood vulnerability. The figure below illustrates the drivers, causes, and impacts of subsidence.

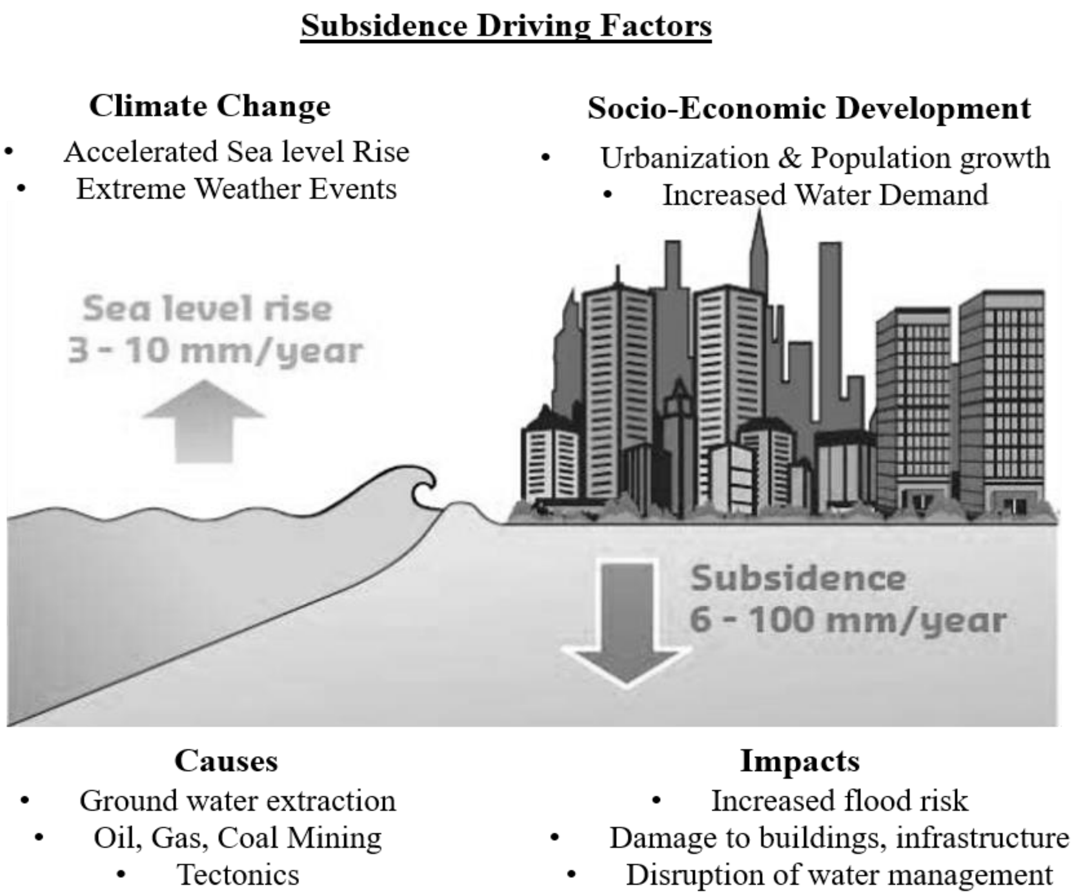


Figure 2.3: Subsidence in Tropical Coastal Cities

(Source: Adopted from Erkens G. et al., 2015)

The general challenges related to tropical Coastal Cities (Table 2.2), can be classified into Socio-Economic, Physical, Environmental, Institutional, and Cultural as identified according to Dam & Le (2019).

Table 2.2: Challenges of Tropical Coastal Cities

Dimension	Description
Socio-Economic	o Rapid urbanization o Urban Migration o Inadequate urban planning o Limited access to basic services o High rates of urban poverty o Inadequate housing and unfavourable housing conditions
Physical	o Inadequate access to water and sanitation services

	○ Inadequate supply of water ○ Inadequate coverage of sewerage system ○ Inadequate capacity of drainage services ○ Inadequate waste management ○ Water shortage ○ Inadequate connectivity ○ Traffic congestion ○ Inadequate public transport ○ Lack of disaster resilient infrastructure
Environmental	○ Environmental degradation is attributed to both human and natural activities. ○ Poor land-use practices ○ Urban air & Noise pollution ○ Lack of child-friendly spaces ○ Unsustainable pressure on critical ecosystems and biodiversity
Institutional, Cultural & Others	○ Insecurity of land tenure ○ Weak regulatory framework and enforcement ○ Political resistance in implementation and enforcement ○ Low technological capacity ○ Inadequate financial resources

(Source: Adopted from Guneralp & Lwasa, 2017; Dam & Le, 2019; UN-Habitat & UNICEF,2020)

2.4 Climate change

2.4.1 Climate change definition

Climate change is among the biggest challenges confronting human society in the 21st century. It has significant pressure on the normal functioning of the ecosystem and also the well-being of communities (Kabisch et al., 2017). It is explained by the United Nations Framework Convention on Climate Change (UNFCC, 2011, p. 1) :

As "*A change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or the variability of its properties for an extended period, typically decades or longer*."

It entails changes in climate for a long time due to natural or human-induced changes. There are several long-term changes anticipated at different levels including continental, regional, and ocean basin scales. Among the changes expected comprise; changes in arctic temperatures and ice, alterations in precipitation patterns and amounts, ocean salinity, changing wind patterns, and extreme weather elements encompassing droughts, heavy rainfall, heatwaves, and increasing strength of tropical cyclones. (UNFCCC, 2011).

According to the United Nations Framework Convention on Climate Change, the general challenges to be experienced as a result of Climate Change (CC) encompass; -

- Increasing levels of atmospheric carbon dioxide concentrations leading to increasing acidification of the oceans
- Reduced snow cover
- Shrinking of sea ice in both Arctic and Antarctic
- Extremely weather such as heatwaves increased rainfall
- Changes in rainfall patterns mainly in high latitudes and possible decreases in subtropical regions
- Human-induced warming and rising sea levels would likely continue for decades to come due to the long timescales related to climate processes and events even when emissions stabilize.

According to Dam and Le (2019), climate change is expected not to be escapable even with the increasing efforts to reduce emissions. This is because, as much as there are efforts to curb emissions, the entire climate reversing process takes time and significant damage has been done. Thus, the risks and impacts associated are quite high.

2.4.2 Climate change in tropical Coastal and low-lying areas

The coastal regions more so in the tropical and Sub-Saharan regions are anticipated to bear a brunt of climate change effects. This is attributed to their low adaptive capacities in terms of economic and technological advancements. The UNFCCC (2011) identifies the following projected impacts on coastal areas and low-lying regions:

- Erosion along the coastal areas and the rising sea level are likely to be the most disturbing challenges in coastal areas. The effects are more pronounced by the increasing population pressure and the urbanization trends in the coastal regions.
- Rising sea levels are like to result in extreme weather events.
- Increased exposure to annual flooding in low-lying areas which are densely populated and have fairly low adaptive capacities. The Challenges are anticipated to be more severe in Delta cities of Asia and Africa and also the small islands (UNFCC, 2011)
- Ocean acidification equally poses a greater risk in the coastal regions due to oceans absorbing Carbon Dioxide (CO_2). This would negatively impact marine life including oysters and coral reefs, among others.

Thus, from the above, coastal urban areas are prone to suffer severe challenges attributed to climate change. This juxtaposed with the existing challenges facing tropical coastal cities results in a catastrophic situation of the cities which calls for immediate interventions.

2.4.3 Climate Change Challenges in Tropical Coastal Cities

The climate-related tropical coastal cities challenges as identified by FEMA 2011, Finkl 2012, Wong et al. 2014, Revi et al 2014, and Dam & Le 2019 include rising sea levels, coastal flooding, increasing storm, coastal erosion, intrusion of saltwater into wetlands and ground water, Tsunamis, urban heat islands, drought, inland flooding, earthquakes, land subsidence, and landslide, among others. These challenges are tabulated below into three dimensions: - General challenges, Coastal areas, and Urban Areas.

2.4.3.1 General challenges

This dimension includes general land-related challenges which could be experienced anywhere regardless of the geographical context. These challenges facing tropical coastal include: - Earthquakes, land subsidence, and landslides (Table 2.3).

Table 2.3: General Tropical Coastal Cities Challenges

Challenge	Causes	Effects
Earthquakes	- Construction in seismic hazard areas, - Surface fault ruptures, - Ground failures.	- Destruction of property & infrastructure - Tsunamis - Soil liquefaction (Soil losing strength & Stiffness)
Land subsidence	- Extraction of water from the ground on a large scale, - Biological oxidation and soil drainage caused by Organic processes, - Compaction of sediments.	- Inundation of land and flooding - Reduction in aquifer capacity to store water - Rupturing of land surface - Drainage systems malfunctioning - Changes in the flow of drainage systems or River canal - The intrusion of seawater into inland areas.
Landslide	- Occurrence of erosion at steep slopes, - Earthquakes, - Increased precipitation and Flooding - Deforestation, and - Poor construction practices.	- Social disruption and even death - Damage or loss of property & infrastructure - Damage of ecosystems and habitats - Economic losses - Impact water quality

(Sources: Dam & Le, 2019; FEMA, 2011; Finkl, 2012; Wong et al., 2014; Revi et al., 2014; USGS, 2020)

2.4.3.2 Coastal areas challenges

This dimension entails challenges experienced along with the coastal areas. These challenges include: - Coastal flooding, sea level rising, storms and cyclones, coastal erosion, saltwater intrusion, and Tsunamis (Table 2.4).

Table 2.4: Coastal Challenges of Tropical Coastal Cities

Challenge	Causes	Effects
Coastal flooding	- Storm surge, - Rising sea and ocean levels, and - Rising of tides	- Destruction of properties & infrastructure - Displacement of people - Destruction of habitats and ecological zones
Sea level rising	- Thermal expansion of water (Due to Increasing temperatures) - Melting of the glacier, and - population increase in coastal low-lying areas	- Flooding of coastal areas - Submerging of coastal lowlands - Salinization of soils - Destruction of properties & Infrastructure
Storm/Cyclone	- Erosion - Increasing flash floods - Storm surges,	- Erosion of Coastal areas - Destruction of ecosystems
Coastal/Riverbank erosion **(Wiping out of coastal land or Riverbanks)**	- Increasing Storm surges, - Rising of sea level, or - The severe flow of river water	- Destruction of ecosystems & biodiversity - Siltation
Saltwater intrusion **(A situation whereby saltwater enters into surface or groundwater)**	- Sea level rise, - Droughts affecting aquifer recharge.	- Salination of freshwater sources - Decrease in freshwater ecosystems biodiversity
Tsunamis	- Earthquakes occurring under the sea.	- Destruction of property and infrastructure

(Series enormous waves of water that are created by the dislocation of a huge water volume)	- Landslides - Occurrence of volcanic eruptions, - Subducting of tectonic plates	- Displacement of people & animals - Destruction of ecosystems & habitats

(Sources: Dam & Le, 2019; FEMA, 2011; Finkl, 2012; Wong et al., 2014; Revi et al., 2014; USGS, 2020)

2.4.3.3 Urban areas Challenges

This dimension of challenges relates to the densely developed areas within the cities. The common challenges in these areas include the urban heat island effect, inland flooding, and drought, among other (Table 2.5).

Table 2.5: Urban areas related Challenges in Tropical Coastal Cities

Challenge	Causes	Effects
Urban heat island **(High temperature in urban areas caused by hard surfaces)**	- Frequent high temperatures	- Warm conditions in the urban areas - Increase demand on energy consumption for cooling
Inland flooding	- Heavy rainfall	- Destruction of property & infrastructure - Economic losses
Drought	- Increasing global temperatures	- Food insecurity - Loss of biodiversity - Morbidity & Mortality

(Sources: Dam & Le, 2019; FEMA, 2011; Finkl, 2012; Wong et al., 2014; Revi et al., 2014; USGS, 2020)

2.5 Climate Adaptation & Mitigation in Tropical Coastal Cities

The adaptation to climate change is explained by the IPCC as modifications of systems both human and natural to address the existing or anticipated climate impetuses and or their respective effects, to reduce harm or take advantage of underlying opportunities (IPCC and McCarthy et al., 2001).

The UNFCCC, (2011) explains that communities can counter the aspect of climate change challenges by managing the rate and intensity of the change. This can be achieved through the reducing emission of Green House Gas (GHG) while adopting creative adaptation measures where necessary.

To adequately comprehend the aspect of climate change adaptation and mitigation, the concepts discussed below are key to understand as identified below. (Bierbaum et al., 2013, Klein and Fussel, 2006, Dam & Le, 2019, and IPCC,2007 & 2012).

- **Disaster Risk** – explained as the possibility of major change in the normal functioning of societies due to the occurrence of disastrous climatic events resulting in vulnerable social conditions.
- **Vulnerability** – is narrated as the interaction of three dimensions namely exposure, sensitivity adaptive capacity.
- **Exposure** – it entails the actual availability of communities, sources of livelihoods, biodiversity and different species, local resources including economic, social, environmental, or cultural resources in areas that are exposed to destruction.
- **Sensitivity** – the extent to which an environment is affected by climate change. It could be directly, indirectly, adversely, or beneficially.
- **Adaptive Capacity** – involves the ability of a system to adjust to disturbances to prevent adverse destruction, take advantage of available opportunities or adjust to the new situation.

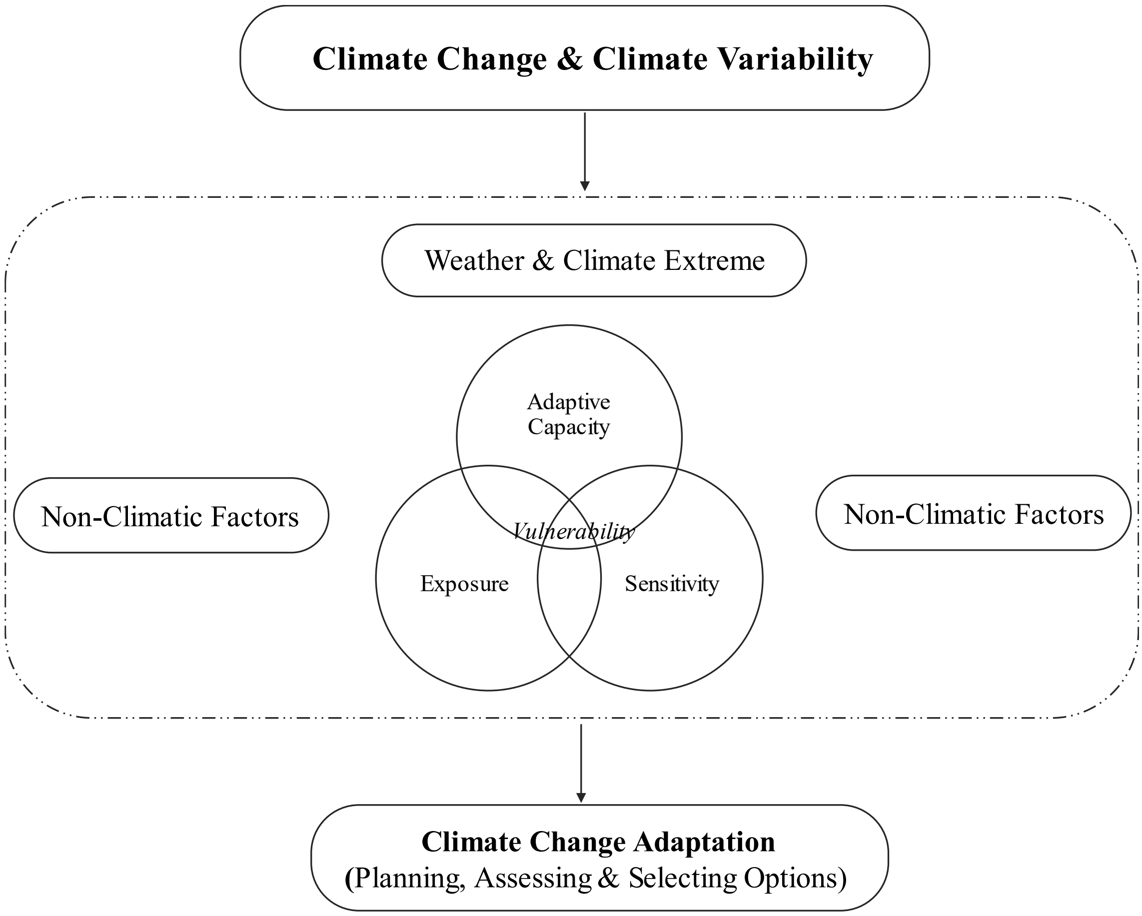


Figure 2.4: Climate Change Adaptation Variables

(Source: Redrawn from Dam & Le, 2019)

The figure above shows the three key concepts: Exposure, Adaptive capacity, and Sensitivity revolving around the Climate Change adaptation framework. The interaction of these factors results in climate change vulnerability in a given area or community. According to the UNFCC report (2011), climate change adaptation is necessary to address the impacts generated due to the warming already being experienced as a result of past emissions.

2.5.1 Climate adaptation Measures

The adaptation measures for coastal cities should include both Structural and social measures. According to Dam and Le (2019), satisfactory adaptation measures need to create a balance between protection and accommodation. Thus, they should be able to accommodate engineering, environmental, informational measures including institutional programs and guidelines, and educational improvement strategies (Figure 2.5), as outlined by Dam & Le (2019).

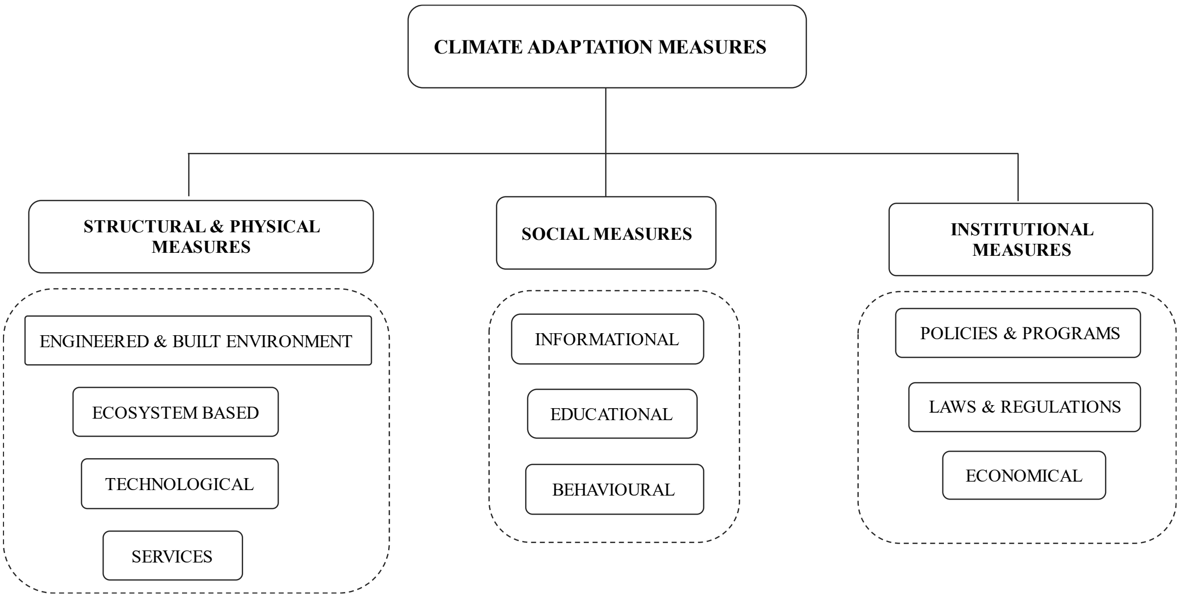


Figure 2.5: Climate Change Adaptation for Coastal Cities
(Source: Adopted from Dam & Le, 2019)

There is a need to incorporate integrative measures in climate change adaptation that incorporate physical, social, and institutional measures to address the existing and the projected challenges.

2.5.2 NBS as a possible Climate Change Adaptation measure

Nature-based solutions (NBS) consist of an extensive range of ecosystem remediation and green infrastructure programs that are focussing on environmental resilience but are also geared towards creating economic and social benefits to communities (Curran & Hamilton, 2020). It has the potential to mitigate and adapt the ecosystem to withstand the pressures brought about by climate change. They can foster urban sustainability transitions while creating multiple-dimension benefits including health and socio-economic development (Kabisch et al., 2017). Among the NBS options to be explored include the provision of urban greenery including parks, street trees to regulate air temperatures and water infiltration within the urban areas. Planting natural habitats in flood-prone areas and coastal belts such as Mangroves and Marshes to mitigate flooding. Soft engineering and Architectural measures such as bioswales, living shoreline barriers green roofs, and walls. The benefits associated with NBS interventions include Stormwater capture & retention, Filtration, Reduced flooding & erosion, Improved air, and water quality, Habitat creation for pollinators & wildlife, Evapotranspiration, Community development, Beautification, Increased property values, Economic benefits, Human health benefits. The diagram below illustrates the different NBS options available that could be instrumental in enhancing the adaptative capabilities of tropical coastal cities.

The idea of Nature-Based solutions is further explored and discussed in the next chapter (chapter three) including other urban sustainability practices.

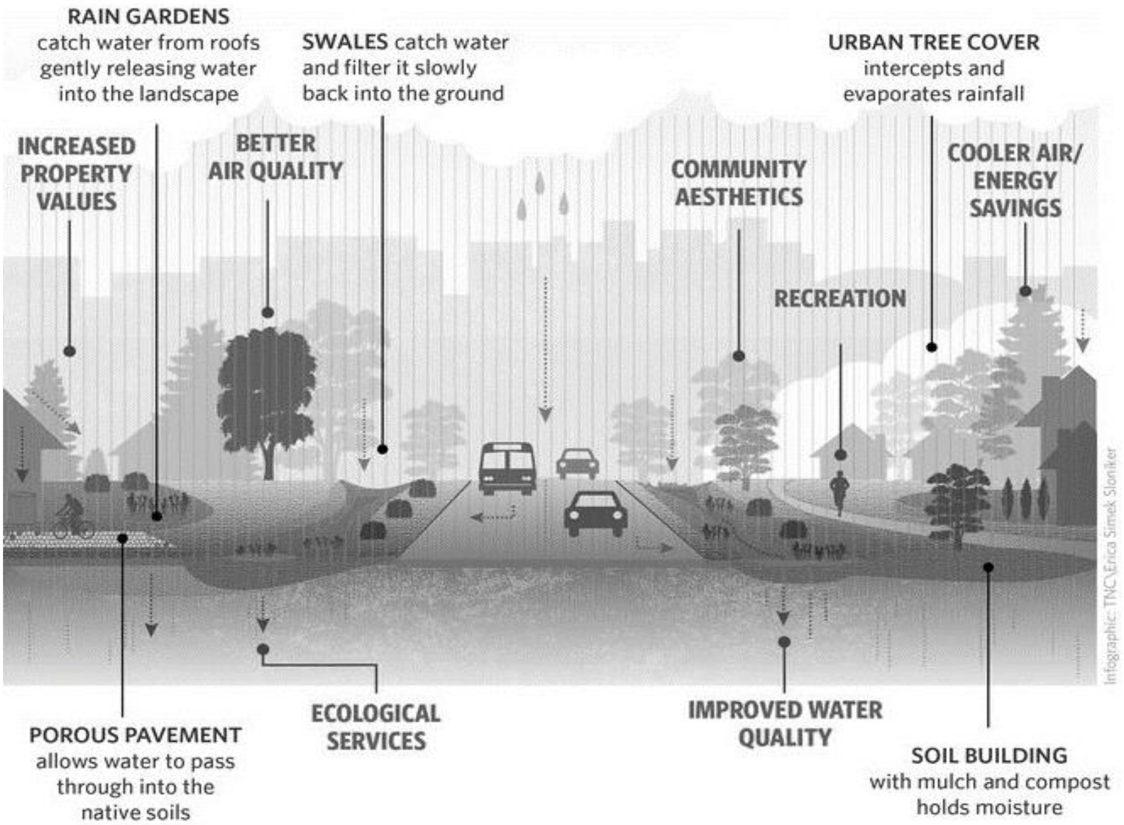


Figure 2.6: Illustration of NBS and their Benefits
(Source: washingtonnature.org)

2.6 Chapter Summary

This chapter discussed tropical cities and climate change. It identified the main world bioclimatic regions which include the tropical zone. It further discussed the sub-bioclimatic zones under the tropical zones which narrowed down to the tropical wet and dry savannah which also introduced tropical coastal cities. It continued by discussing the characteristics of tropical cities, their distribution, and their challenges. The concept of climate change and related challenges are introduced and narrowed down to the specific challenges facing tropical coastal cities which were discussed into three dimensions; general, coastal areas, and urban areas specific. The chapter concludes with possible measures for adapting to climate change and actions that can be adopted to mitigate the phenomenon. Mitigation measures and introduces Nature-Based Solutions as possible ecological-friendly interventions that could be adopted to make tropical coastal cities more climate-resilient (Figure 2.7).

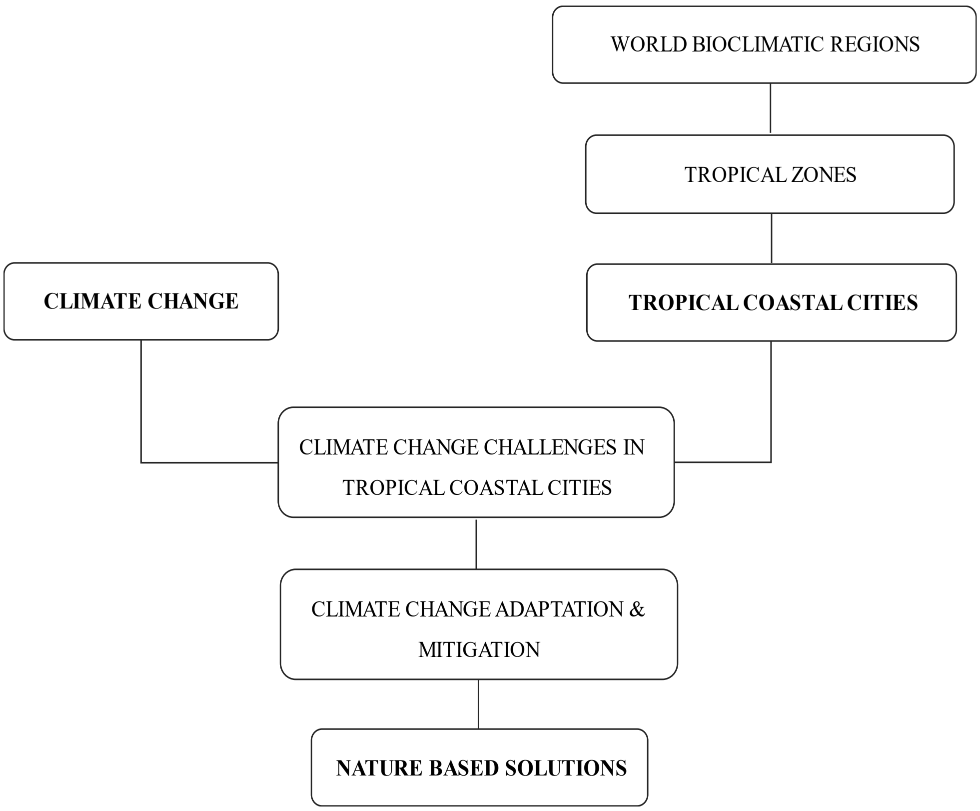


Figure 2.7: Chapter Two Summary

CHAPTER 3

NATURE BASED SOLUTIONS & SUSTAINABLE URBAN DRAINAGE SYSTEMS (SUDS)

This chapter discusses Nature-Based Solutions (NBS), Green Infrastructure (GI), and other Sustainable Urban Drainage Systems (SUDs). It introduces the concept of NBS, other similar ecological concepts, benefits, strategies, opportunities, challenges, best practices, and also the criticism of the various NBS interventions. It also explains SUDs by explaining the key concepts entailed, the different types of SUDs systems, design requirements, and applicability in the different contexts. It concludes with a summary of NBS systems which is discussed in three sections: Coastal flooding and Erosion, Riverine Flooding, and Urban Storm water Management.

3.1 Nature-Based Solutions

Nature-based solutions are considered as a more refined ecosystem-based approach towards ecosystem and resource management. This is because it builds on the previous approaches (Eggermont et al., 2015). It is a refinement of strategies such as Green Infrastructure, Ecosystem-Based Adaptation, Ecosystem-based Disaster Risk reduction, and also Natural Water Retention Measures (Faivre et al., 2017).

The European Commission (2016) explain NBS as: -

"*Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social, and economic benefits and help build resilience. They bring more diverse nature, natural features, and processes into cities, landscapes and seascapes, through locally adapted resource-efficient and systemic interventions*".

Cohen-Schacham et al 2016 equally explain NBS as a concept that is aimed at initiating nature supportive strategies as part of climate mitigation and adaptation measures. According to the International Union for Conservation of Nature (IUCN), NBSs are described as solutions closely linked to nature and with the ability to mediate challenges facing the globe including climate change, water and food insecurity, and also socio-economic and development challenges.

From the foregoing definitions, NBS can be explained as nature-based projects that offer to incorporate or mimic nature in addressing the contemporary urban challenges that range from climate change to its accompanying challenges, socio-economic problems, and environmental crises. Thus, they offer multiple benefits to the environment and also to society. They are preferred to other ecosystem approaches due to their strength in adopting an integrative approach and offer simultaneous solutions in addressing urban challenges.

3.1.1 Characteristics of Nature-Based Solutions

The international union for conservation of nature (IUNC) explains that an intervention is considered part of a nature-based solution if it has the following characteristics.

- Solving a key global challenge by incorporating nature – the intervention should be addressing world challenges including global warming, climate change, shortage of water, urban heat island, and flooding in urban areas.
- Enhances biodiversity and ensures proper management of the environment – NBS(s) are expected to promote biodiversity by promoting flora and fauna within the urban ecosystems. They should equally protect the environment by increasing vegetation cover, prevent soil erosion, and also catchment areas.
- Cost-effective compared to other strategies – the solutions are expected to be fairly affordable compared to the traditional systems for them to be fully implemented.
- Easily comprehensible – nature-based interventions should be simple to understand by all stakeholders including the community, implementing agencies, and policy makers.
- Measurable, Verifiable, and able to be emulated – the interventions are expected to be measurable to see their effectiveness in addressing the particular challenges. They should equally be easily emulated so that they can be easily replicated elsewhere.
- Respect and strengthen communities' values and access to natural resources – the measures should include the local communities to ensure public participation and community ownership while also promote equitable access to natural resources.

- Include both private and public funding options – the measures should source funding from different sources including public and private sources to ensure success.

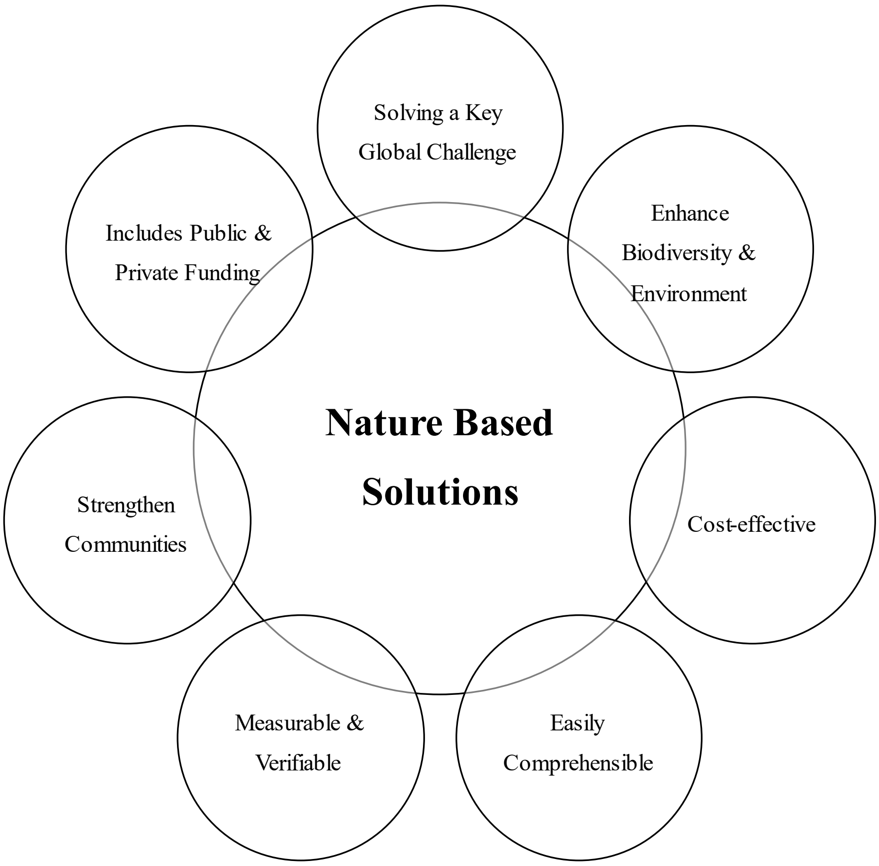


Figure 3.1: Characteristics of Nature-Based Solutions

(Source: IUNC, 2012)

3.1.2 Goals and Benefits of Nature-Based Solutions

Nature-based solutions should be oriented towards solving societal challenges while consequently realizing gains to both the environment, economy, and community. The European Commission identifies four important goals of Nature-Based systems. These include:

- Foster sustainable urbanization – should enable economic development while correspondingly improving the quality of the environment. They should improve the aesthetic value of cities and also enhance the quality of life.

- Restore ecosystems – NBS should be able to enhance the ecosystem and enable them to function to its full capacity while benefitting society.
- Foster climate adaptation and mitigation – the interventions should provide amicable responses to more resilient climate responses.
- Improve risk management – the solutions should improve risk management in a manner that yields more benefit than traditional methods and have the capabilities of offering myriad benefits.

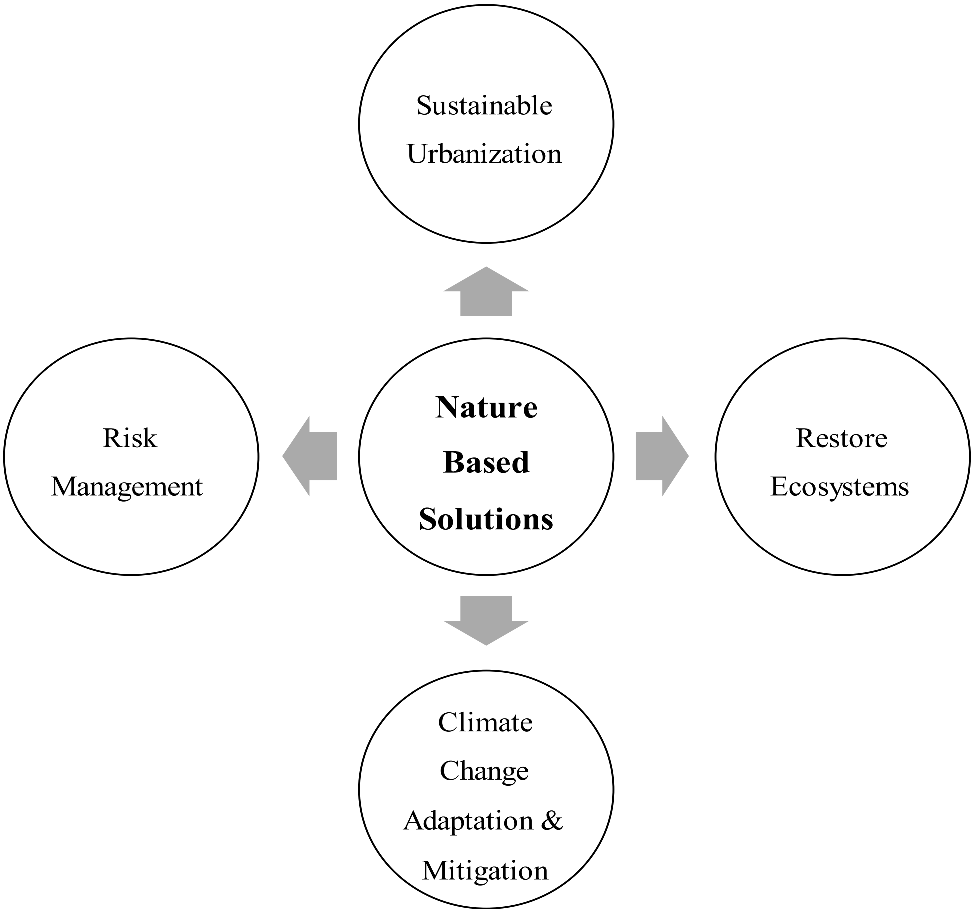


Figure 3.2: Goals of NBS

(Source: EU, Directorate-General for Research & Innovation, 2015.)

Faivre et al. (2017) explain Nature-Based Solutions to include a myriad of benefits comprising ‘increment in the quality of life and well-being, regeneration of urban areas, enhancement of resilience in coastal areas, multifunctional watershed management, restoration of the ecosystem, fosters sustainability in resource usage, and also increases carbon sequestration (Figure 3.3).

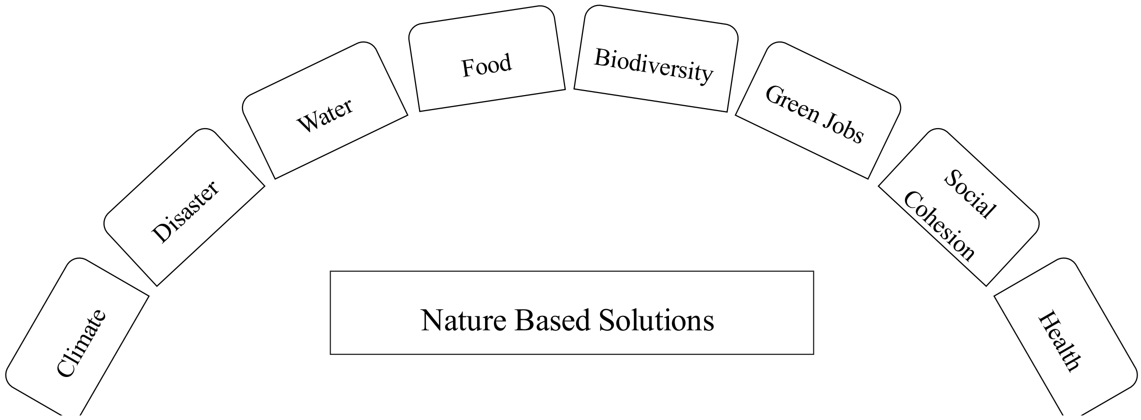


Figure 3.3: Benefits of Nature-Based Solutions
(Source: Faivre N. et al, 2017)

The Nature-Based solutions are aligned with the United Nations, Sustainable Development Goal 11 which talks on “Sustainable Cities and Communities’ (Figure 3.4). According to Faivre et al., 2017 the different NBS interventions are linked to the specific targets of SDG 11 whereby Pocket parks and street trees are linked to ‘a safe, accessible, inclusive, and green and public spaces’, Green roofs and community gardens lead to the ‘Reduction of adverse impacts on air quality’, Natural water retention and Sustainable Urban drainage control flooding leading to a reduction water-related risks and disasters impacting economic activities and infrastructure’; Bio sequestration and Afforestation benefits the environment through ‘Urban planning for to enhance adaptation to climate change and provide mitigation measures’, Green corridors provide a ‘Link between urban peri-urban and rural areas and finally Natural Coastal protection and Flood plain restoration leads ‘urban planning and policies for disaster resilience’.

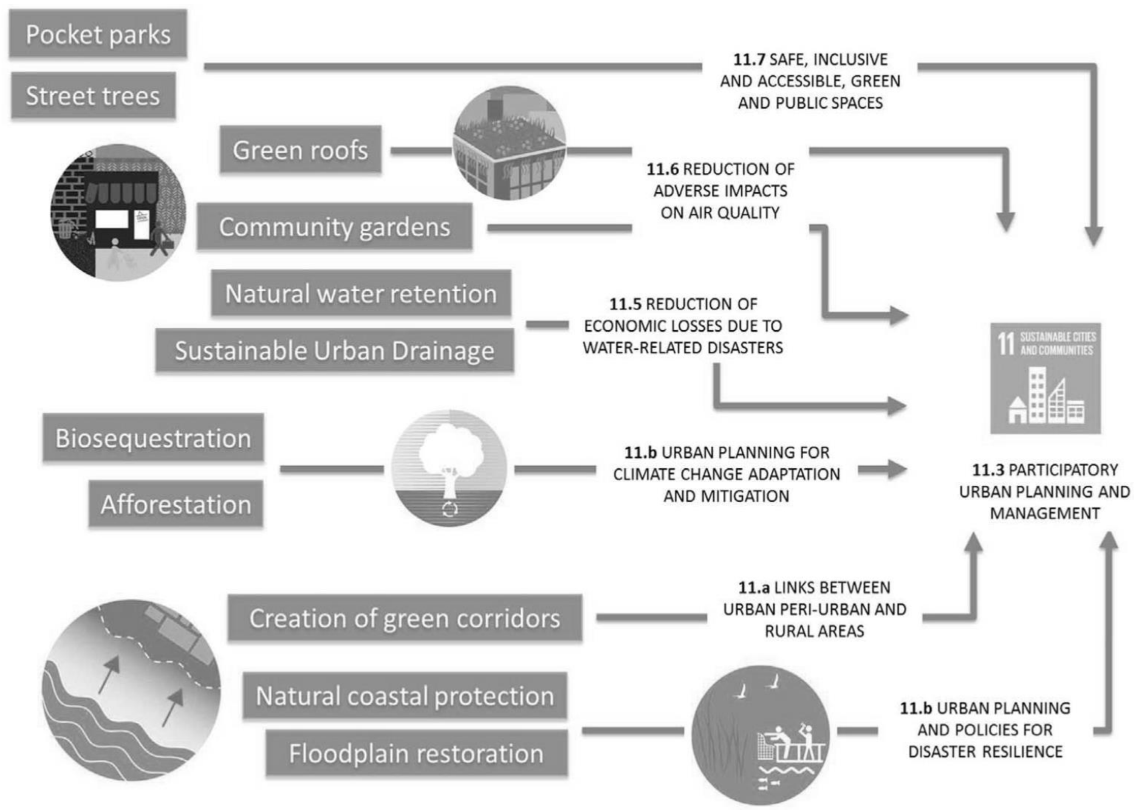


Figure 3.4: Alignment of NBS to SDGs

(Source: N. Faivre et al., 2017)

3.1.3 Concepts related to Nature-Based Solution

NBS is closely related with other ecological concepts which focus on ecosystem management to promote environmental sustainability, social good, and ensure well-being and good quality of life in cities. Nesshöver C. et al (2017) discusses six concepts closely linked with the Nature-Based Solutions which include "Green/Blue Infrastructure (GI/BI), Ecological Engineering (EE), Ecosystem Services Approach/Framework (ES), Catchment Systems Engineering (CSE), Ecosystem Approach (EA), Ecosystem-Based Adaptation/Mitigation (EBA), and Natural Capital (NC)"

3.1.3.1 Ecological Engineering (EE)

The concept of ecological engineering is explained by Mitsch and Jorgensen, (1989) as "the design of sustainable ecosystems that integrate human society with its natural environment for the benefit". It can also be explained by Rey et al., 2015 as "actions using and/or acting for nature". Thus, ecological engineering can be explained as an ecosystem-based approach that brings closer the society to nature as a way of enhancing co-existence between the two. It is equally linked to the concept of ecological restoration. Catchment Systems Engineering on the other hand is explained as an "interventionist approach to altering the catchment scale runoff regime and nutrient dynamics through the manipulation of hydrological flow pathways to manage water quality and quantity sustainably". The goal of this strategy is to create systems that imitate or acclimate how natural ecosystems function to realize their objectives.

3.1.3.2 Green and Blue Infrastructure (GI & BI)

The European Commission 2013 explains green infrastructure as "a strategically planned and managed, spatially interconnected network of multifunctional natural, semi-natural and man-made green and blue features including agricultural land, green corridors, urban parks, forest reserves, wetlands, rivers, coastal sand other aquatic ecosystems." Examples of green infrastructure comprise protected green areas, eco-ducts and tunnels to provide for wildlife passages, parks, and green roofs (Nesshöver et al., 2017). Blue Infrastructure consists of natural areas such as coast shorelines, rivers and lakes, creeks, and wetlands. They also include designed elements comprising ponds, constructed wetlands, artificial channels, water reservoirs, retention basins, and urban wastewater networks (EU, 2013, ECNC, 2013). The primary objective of the GI and BI is to provide a wide range of gains including ecological, economic, and social while enabling people to understand how nature benefits society.

3.1.3.3 Ecosystem Approach (EA)

The ecosystem approach intervention involves a participatory approach towards resource management. It is explained by the United Nations Environmental Programme as a strategy "based on the application of appropriated scientific methodologies focused on levels of biological organization which encompass the essential processes, functions, and interactions among organisms and their environment." This approach perceives humans including social and cultural multiplicity as a key part of the ecosystem. The strategy is guided by the following principles as outline by Nesshöver et al. 2017: -

i. The objectives of resource management should be tied to society.
ii. They should factor in the real and prospected effects of activities on ecosystems.
iii. They should preserve the ecosystem composition and support ecosystem services.

iv. Ecosystems have to be operated within their capacities.
v. Ought to be done at suitable scales.
vi. It should be able to accommodate change.

The core aim of the ecosystem system approach is to protect resources and ensure that they are used sustainably and equitably (UNEP, 2000).

3.1.3.4 Ecosystem-Based Adaptation (EBA)

The concept is also referred to as ecosystem-based mitigation. It is a type of intervention that focuses on policies and strategies that factor in the importance of the ecosystem in reducing climate change vulnerability of communities in terms of incorporating different sectors and at various scales (Nesshöver et al., 2017). Thus, it brings together the policy makers, communities, private sector, NGOs, and governments in addressing issues such as changes in land uses, climate change, and ecosystem management to increase the social and economic resilience of communities (Vignola et al.,2009). The EBA strategies are intended to lessen the exposure of societies to climate change thus enhancing resilience.

3.1.3.5 Ecosystem Services Approach (ES)

The ecosystem approach tends to identify the extent to which natural systems can be useful to humans. It is also known as the Ecosystem services framework. It bridges ecosystem structures and processes operations including their results that benefit people directly or indirectly (Turner and Daily, 2008). The ecosystem provided both provisioning services comprising food, water, energy, building materials; Cultural services encompassing recreational opportunities, education, tourism, and a sense of place; Policy and regulatory measures including flood and erosion protection, climate change effects; Supporting activities such as the formation of soil and cycle of nutrient (Alacamo et al., 2003).

Provisioning Services	Cultural Services	Regulatory Services	Supporting services
• Food, • Water, • Energy, • Building materials	• Recreational Opportunities • Tourism • Education • Sense of place	• Protection against flood & erosion • Climate change	• Soil formation • Nutrient cycling

Figure 3.5: Ecosystem Services

The ecosystem services approach is aimed at elaborating how nature benefits society and inform the socio-political process on how to improve the governance and management of ecosystems.

3.1.3.6 Natural capital (NC)

The concept is explained by Nesshöver et al., 2017 as the total endowment of both living and non-living components of the ecosystem that bring benefits to human beings either in a direct way or indirect. However, the definition of this concept varies in respect to the subject matter and extent (Wackernagel and Rees, 1997). It could include earth's land and water, geological and biophysical components, processes from natural systems, renewable and non-renewable resources, or even information stored in natural systems. Natural capital can be viewed as the collection of assets whereas ecosystem services the movements of benefits resulting from these assets (Daily et al., 2011). The NC enables valuation of natural systems hence enhancing proper management just like any other capital such as human capital, social, financial, and manufactured capitals (Natural Capital Initiative, 2016). The relationship between natural capital and how it underpins the ultimate goal of realizing nature-inspired actions (Figure 3.6).

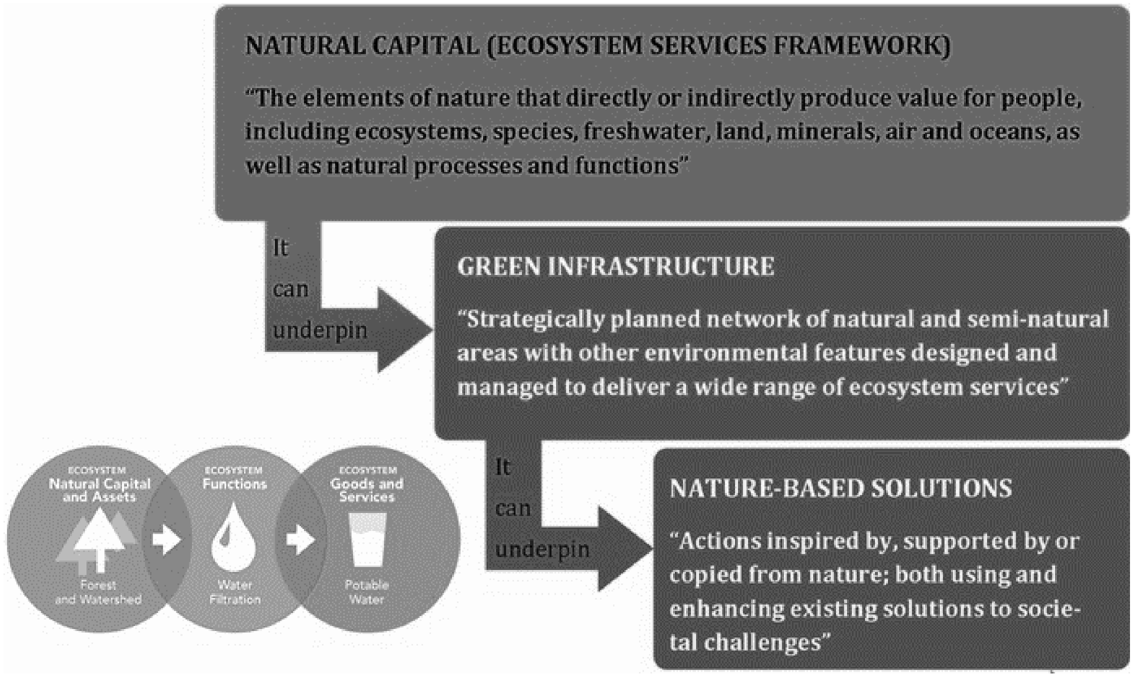


Figure 3.6: Natural Capital Illustration
(Source: Baro, 2016)

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3.1.4 Relationship of Other Ecosystem Approaches to NBS

NBS solutions have been considered as a refinement of the ecological approaches towards ecosystem and resource management as discussed above. The potential relationship between NBS and other ecological-based concepts (Table 3.1).

Table 3.1: Relationship of Other Ecological Approaches to NBS

Concept / Approach	Goal	Relationship with NBS
Ecological Engineering & Catchment Systems Engineering	To Create systems that imitate and, or adapts to the natural way of how an ecosystem functions at a catchment scale	Both focus on addressing societal challenges using by mimicking nature
Green & Blue Infrastructure	To render benefits at multiple levels including ecological, social, and economic benefits while enabling people to understand how nature benefits society	It is a version of NBS

Ecosystem Approach	To provide for the usage and protection of resources in a manner that is equitable and sustainable conservation and sustainable use of resources in an equitable manner	NBS borrows the sustainability principle.
Ecosystem-based Adaptation	To diminish society exposure to climate change hence enhancing resilience	They form part of NBS in ensuring climate adaptation
Ecosystems services approach	To elaborate how nature benefits the society and inform socio-political process and governance and management of ecosystem and resources	They inform NBS design and appraisal
Natural Capital	To enable the valuation of natural systems hence enhance proper management	They strengthen the viability of NBS against other traditional interventions

3.2 Sustainable Urban Drainage Systems (SUDs)

The concept of SUDs is explained as a sequence of storm water management measures intended to drain surface runoff sustainably to ease the capacities of the existing drainage systems within the urban context (Butler & Davies, 2011). These systems tend to imitate the natural drainage by incorporating measures that enable the collection, storage, and cleaning of surface water runoff before it goes back to the environment. SUDs have been gaining prominence as a complimentary adaptation in storm water management (Fryd et al. 2012) this can be attributed to their relatively low implementation cost and also the opportunity to co-create with the local community.

3.2.1 Themes and Dimensions of SUDs

Sustainable Urban Drainage Systems involve various stakeholders and professions. Fryd et al (2012) introduce a framework that combines time, space, and human values towards approaching SUDs. The framework borrows from a variety of models including that of Mitchell (1979) on resource analysis, Agarwal et al (2002) on land-use changes model, and Tjallingii (1996) on development framework for the planning of ecocities. These models are interlinked and explained into three core themes and dimensions, namely: Biophysical processes, Spatial strategies, and Adaptive strategies. They are further expounded below.

3.2.1.1 Biophysical processes

The biophysical processes comprise both quantitative and qualitative aspects. The processes are dependent on the local climate of a site. Among the factors constituting biophysical processes include precipitation, runoff, evaporation, local soil type, and conditions, and the receiving water bodies including rivers, seas, and ponds, among others.

3.2.1.2 Spatial strategies

Spatial strategies entail the actual physical orientation, layout, and design of the cities and urban areas. The aspects included here are SUDs design and alterations of the physical environment of the urban setting. It involves a mix of technological and ecological frameworks to manage the urban drainage system.

3.2.1.3 Adaptive strategies

The adaptive strategies relate to the decision-making and factors influencing the entire process which includes uncertainty, time, technological transitions, and the decision field. These strategies enable SUDs to be resilient and to adapt to changing conditions.

3.2.2 SUDs Axes

According to Fryd (2012), the three strategies discussed above are connected by three key axes which are: Human values, Time, and Space. Human values in this sense are explained as a sequence of ecological and technological worldviews (Ahern, 2007), which determine the thought process of the stakeholders involved in the decision-making process (Voros, 2003). Space is explained as a linear continuum that ranges from site to regional context (Woods Ballard et al., 2007). Lastly, time is explained in two perspectives, firstly, as a series of steps ranging from a few seconds to decades (Zevenbergen et al., 2008), concerning the coping mechanism with climatic events and also the return periods of this such as flooding and heavy precipitation, among others.

The second dimension of time is the chronological aspect referring to past, present, and future activities or goals.

The three main axes in SUDs; Human values relating to ecocentric focusing on ecological approaches and technocentric relating to technological developments, Space which relates to the site at the local or regional context. The time axis can range from seconds to decades and relates to the return periods of the different climatic events or the horizon or the horizon of the targets and goals. The three axes are interlinked by the three strategies as discussed above. Spatial Strategies consist of human values and space, while the actors in this strategy include planners and designers. It involves physical intervention on space through planning and design. The Biophysical strategy consists of time and space and involves mainly engineers. This strategy involves modelling and understanding site conditions. The last strategy is the Adaptive strategy which involves Human values and time. The actors in this category entail managers, experts, and authorities and involve decision-making and implementation of preventive and mitigative measures. The connection of the different dimensions to the entire framework of sustainable urban drainage systems (Figure 3.7).

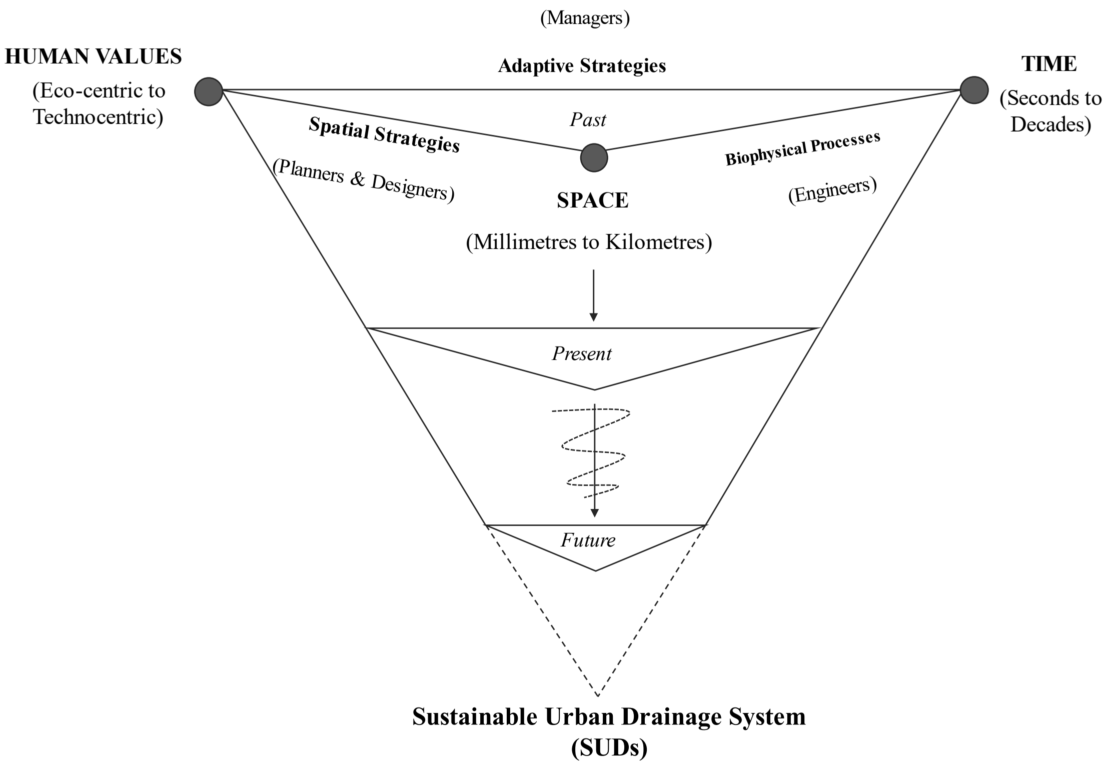


Figure 3.7: Framework for the SUDs

(Source: Redrawn from Fryd et al. 2012)

3.2.3 Sustainable Drainage Concepts

The concepts and terminologies describing the activities and principles relating to urban drainage are diverse and could confuse if not well-conceived (Fletcher et al., 2015). Among the concepts used to describe SUDs include Stormwater Best Management Practices (BMP), Green Infrastructure (GI), Low Impact Development (LID), Source control, Integrated Urban Water Management (IUWM), and Water Sensitive Urban Design (WSUD). These concepts relate to intervention measures that enable retaining, slow infiltration, ample time for evaporation, transpiration, and draining of surface water within an urban context (Fryd et al. 2012). This section focuses on the above concepts, their origin, and how they are applied in the urban realm.

3.2.3.1 Low Impact Development (LID)

This concept is popular in New Zealand and North America. In some cases, it is also known as Low Impact Urban Design & Development (LIUDD). It has been in use since the 1980s in Environmental Sensitive Area (ESA) planning. It is aimed at minimizing the cost of surface water management through factoring aspects of ecological design and incorporating nature in the design process (Fletcher et al., 2015). LID is commonly linked to stormwater at a local scale as opposed to large extent such as a catchment area. Examples of LID systems include green measures like green roofs; Stormwater Bioretention Systems, and Bioswales, among others. They are usually located on-site or near the source.

3.2.3.2 Water Sensitive Urban Design (WSUD)

The concept of WSUD is traced back to Australia and it has continued gaining momentum in countries such as the United Kingdom and also New Zealand (Ashley et al., 2013). It advocates for the inclusion of all the drainage basins in urban areas including streams within the urban design framework and involves a multidisciplinary approach. According to the Whelans et al. (1994), the objective of WSUD include to: -

- Create a balance in water circulation by fostering groundwater recharge, flood management, and runoff.
- Improve on water quality including protection of riparian vegetation and minimizing pollutants getting to surface and groundwater.

- Promote water conservation by harvesting stormwater, recycling wastewater, and reducing irrigation requirements.
- Provide recreational, aesthetics, and environmental opportunities

WSUD tends to view urban water management in its entirety from supply sewer and stormwater management. The figure below summarizes the benefits that can be realized from Water Sensitive Urban Design. They include mitigation of climate change risks like flooding and droughts, improve water quality, conserves water, controls soil erosion and sedimentation, reduce urban heat island effect, increases carbon sequestration through the provision of additional greenery, restores biodiversity, enhances the well-being of communities, and provides a quality environment. Other benefits include stimulation of local economies by the creation of new jobs, improvement of recreational and tourism activities, increment in land values and revenue collection, fosters the use of energy and resources sustainably located within an urban area and lastly, it assists in urban renewal and refurbishment of abandoned spaces.

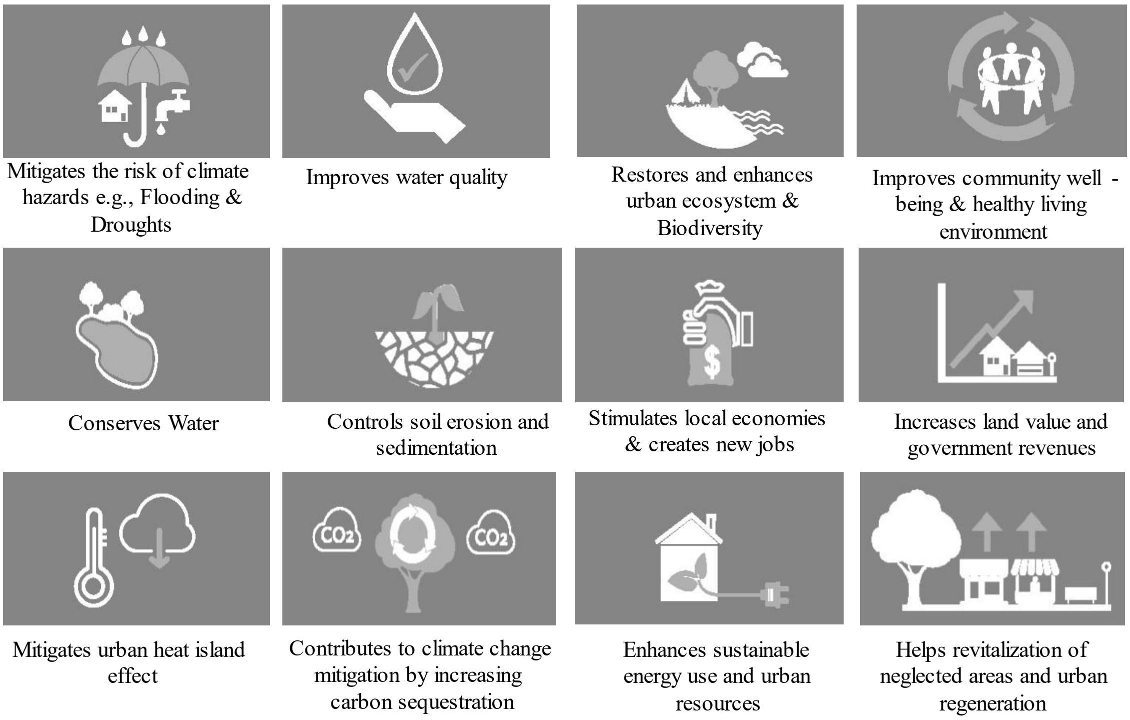


Figure 3.8: Rewards of Water Sensitive Urban Design

(Source: Nature-Based Solutions for Cities in Vietnam Report, 2019)

Among the water sensitive urban design options available include:

1. Sediment Basin

Location:

- Downstream prior to a wetland or water way.

Function:

- Captures fine particles and sediment
- Helps in slowing peak stormwater flowing

2. Retarding or Detention basin

Location:

- Situated inside or at the edge of the site

Function:

- Slows flow of peak stormwater
- Provides green recreational spaces outside flooding season

3. Vegetative Swales

Location:

- Situated towards the edge of streets in small sites

Function:

- Holds fine particles and nutrients
- Reduces Peak stormwater flows

4. Wetland

Location:

- Positioned towards the edge of a site or in a sunken natural area.

Function:

- Captures phosphorus, nitrogen, and fine fragments
- Slows flow of peak stormwater

- Provides recreational opportunities, green spaces and increases property worth

5. Rainwater tank

Location:

- Located on individual buildings site

Function:

- Accumulates storm water runoff from the roof
- Enables storage of water storage for non-potable uses
- Reduces Peak stormwater flows

6. Litter trap – exposed

Location:

- Positioned towards the edge of a street.

Function:

- Holds particles, waste & contaminants
- Enables easy monitoring of pollution types and quantities

7. Litter trap - hidden

Location:

- Towards the edge of street or lot

8. Infiltration system

Location:

- Positioned at the same level with the street

Function:

- Holds contaminants and waste
- Hides the pollution
- Reduces Peak stormwater flows

Function:

- Holds contaminants and wastes
- Slows flow of peak stormwater

9. Grassed Swale drain

Location:

- Located at the end of the street or lot

Function:

- Takes nutrients from the runoff
- Slows flow of peak stormwater runoff

10. Rain garden

Location:

- Positioned as the same level with the street

Function:

- Captures nutrients and grass pollutants
- Slows the flow of peak stormwater

3.2.3.3 Integrate Urban Water Management (IUWM)

The notion of IUWM is more comprehensive since it wholistically views the water cycle from the broader perspective of the catchment basin. It relates to the comprehensive handling of water in all its circulation phases within a given catchment basin (Biswas, 1981). Thus, IUWM encompasses the supply of water, underground water aquifers, handling of greywater, and also rainwater management (Fletcher et al., 2007). The principles that guide IUWM at outlined by Mitchell (2006) include:

- Considerations of the water cycle in its entirety and treat them holistically including naturally existing areas and man-made, on-surface and under-surface.

- Factoring in all the requirements for water encompassing ecological and human.
- Consideration of the site context understanding conditions of the environment, social dynamics, cultural significances, and economic characteristics.
- Fostering sustainability in the short, medium, and long terms.

3.2.3.4 Sustainable Drainage Systems (SuDS)

This concept was started in the UK in the 1990s (Fletcher, 2015) to enhance the quality of water in the destination water bodies. They consist of a blend of systems that sustainably allow management of stormwater mimicking the natural system. According to Fletcher T.D et al., (Urban water journal, 2015, pg. 529),

"*SUDs are configured as a sequence of stormwater practices and technologies that work together to form a management train*."

Thus, they entail a series of practices and activities that provide for efficient management of runoff.

3.2.3.5 Best Management Practices (BMPs)

BMPs can be traced back to North America mainly the US and Canada (Fletcher, 2015). The concept entails activities that comprise both structural and non-structural measures to prevent pollution. According to Environmental Protection Agency (2011), BMPs can include,

"*Schedules of activities, prohibitions of practises, maintenance procedures, treatment requirements, operating procedures and practices to control site runoff, spillage or leaks, sludge or waste disposal or even drainage from raw material storage*."

Thus, BMPS could range from techniques, processes, activities, or systems that could mitigate surface water pollution. These solutions could be applied in isolation or along with other measures.

3.2.3.6 Stormwater control measures (SCMs)

The SCMs concept is popular in the US, and it came in place as a way to make the BMP concept more objective and specific (Fletcher, 2015). This concept equally entails structural and non-structural control measures for sustainable urban drainage.

3.2.3.7 Alternative Techniques (AT)

This concept has French roots and is also known as compensatory techniques because the interventions were anticipated to offset the impacts of urbanization (Fletcher, 2015). They were formulated as an alternative to traditional drainage systems to offer more natural solutions to urban drainage. They are seen as means to address drainage and pollution issues while ensuring a high-quality life for the communities in cities. According to Fletcher (2015), the key objectives of the AT included to:

- Reduce the surface runoff volume and peak flows.
- To mitigate the exposure of flooding in cities.
- To protect the receiving water bodies and environments

Among the measures incorporated as alternative techniques included detention, attenuation, infiltration, source control of stormwater (Azzout et al., 1994). The key criticism of these techniques is that they are more concerned with human benefits as opposed to realizing ecological and landscape amenity benefits.

3.2.3.8 Source Control (SC)

The concept of source control originated from the need to advocate for managing stormwater on-site as opposed to the traditional system of providing large detention basins constructed downstream. (Fletcher, 2015). It is considered efficient in managing the stormwater impact on receiving water bodies. Like the SCMs it involves both structural and non-structural strategies. The non-structural can include measures to prevent pollution like the proper design of the site and also a good choice of construction materials.

3.2.3.9 Green Infrastructure (GI)

According to Walmsley (1995), the GI concept was started in the US in the 1990s. Its origins can be traced to landscape ecology. The concept primarily advocates for the creation of a network of green spaces. According to Norman Foster et al. (2011), It is explained as;

"*A Network of decentralized storms water management practices, such as green roofs, trees, rain gardens, and permeable pavement, that can capture and infiltrate rain* *where it falls, thus reducing stormwater runoff and improving the health of surrounding waterways*."

The US Department of Environmental Protection Agency highlights the benefits of GI to include efficient management of stormwater, flood mitigation, air quality management, enhancing urban amenity, improving human health (Tzoulas et al., 2007).

Wider adoption of Green infrastructure can enable a more coordinated approach towards stormwater management and reduce pressure on receiving channels.

3.3 Typologies of Nature-Based Solutions Interventions

According to Faivre N et al., (2017), Nature-Based Solutions present an avenue for innovation within the urban realm and are appealing to authorities and professionals due to their cost-effectiveness in promoting a green economy that is equally competitive.

Some of the nature-based interventions for ten different dimensions within cities are discussed in this section. They are discussed under three zones of vulnerability namely; - Coastal areas, Urban areas, and Wetlands & Creeks.

Dimension 1: Air Quality Regulation	
NBS Goal: Extract chemicals, particulates, air contaminants and emissions	
Zones	**Possible NBS Intervention**
Coastal zone	- Plant and maintain Mangrove
Urban areas	- Protect urban green spaces - Plant trees alongside roads
Wetland / Creeks	- Plant trees - Restore wetlands vegetation

Dimension 2: Climate Change Regulation	
NBS Goal: Control Green House Gases Emissions & Biodiversity	
Zones	**Possible NBS Intervention**
Coastal zone	- Protecting intertidal muds, salt marshes, planting mangroves,

	- Restoring vegetated dunes and seagrass beds. - Controlling aquaculture activities and construction development in intertidal areas. - Restoring microtopography and creeks.
Urban areas	- Protect urban green spaces
Wetlands & Riparian areas	- Protect and increase riparian vegetation

Dimension 3: Water Flow Regulation	
NBS Goal: Alter the quantity and flowing speed of stormwater runoff and flood occurrence while recharging aquifers	
Zones	**Possible NBS Intervention**
Coastal zone	- Re-connecting river systems to coastal wetlands. - Construct river control structures able to accommodate seasonal floods
Urban areas	- Construction of green walls & rooftops garden to slow down stormwater - Plant rain gardens: bioswales and planted sunken areas to absorb stormwater. - Construction of ponds to accommodate excessive runoff and slow water movement. - Storing water underground.

Dimension 4: Regulating erosion	
NBS Goal: Reduce erosion of soil and sediments	
Zones	**Possible NBS Intervention**
Coastal zone	- Protection of intertidal muds and saltmarshes - Planting mangroves and restoring seagrass beds and vegetated dunes. - Protecting forests along the coast and vegetating beach ridges.

	- Ensure proper maintenance of wetlands along the coast. - Protect and restoring sand-dunes. - Controlling the extraction of groundwater to enhance water flow and limit subsidence. - Reduce the usage of chemicals in farmlands and ensure proper handling of agricultural waste. - Proper management of solid and liquid waste. - Abstain from construction activities near coastal shores in wet seasons to prevent sediments washing and erosion into water bodies.
Urban areas	- Using Phytoremediation and Phyto stabilization to manage contamination - Replace hardscapes with soft capes and permeable materials in construction.
Wetlands & Creeks	- Increase plantation of mangroves along creeks - Maintain and restore wetlands

Dimension 5: Cleansing water and treating greywater	
NBS Goal: To improve on the functioning of the environment in removing impurities from water.	
Zones	**Possible NBS Intervention**
Coastal zones	- Restore and protection of mangroves and salt marshes. - Control liquid waste management and limit water contamination. - Restoration of reefs to control nitrates, sediments, and related pollutants.
Urban areas	- Creating detention areas to accommodate and filter water while releasing it slowly - Proper management and handling of liquid waste from industries - Enhance biological remediation in waste management. - Employ phytoremediation to treat contamination

Wetlands & Creeks	- Utilization of bioremediation processes to manage pollution - Proper solid and liquid waste management.

Dimension 6: Disease Regulation	
NBS Goal: Enhance the ecosystem capacity to regulate diseases	
Zones	**Possible NBS Intervention**
Urban areas	- Proper handling of effluent - Bioremediation and biodegradation of waste beforehand - Increasing green space in urban areas to promote biodiversity and insect species that feed vectors - Create more green spaces in urban areas to encourage biodiversity and the establishment of vector feeding species. - Wide application of softscapes and permeable spaces to prevent stagnant water that would attract diseases. - Biological remediation such as increasing planting of trees and providing bird shelters to regulate insect populations such as mosquitoes.

Dimension 7: Regulating pollination	
NBS Goal: Improve biodiversity mediated pollination	
Zones	**Possible NBS Intervention**
Urban areas	- Encourage planting of appropriate resource plants and caterpillar food plants in gardens and municipal areas. - Retain areas of rough ground or old built structures for nesting habitat.

Dimension 8: Reducing Disasters and Risks	
NBS Goal: Restore & Enhance ecosystems ability to reduce natural hazards	
Zones	**Possible NBS Intervention**
Coastal zones	- Planting, restoring, and protecting mangroves and salt marshes - Safeguarding intertidal mudflats and seagrass beds - Restoring and construct vegetated dunes - Sensitize communities closer to coastal areas on mangrove plantation - Establish and maintain riparian reserves and implement barriers like dunes, beaches, and gravel ridges - Control beach erosion by replenishing eroded areas. - Increasing afforestation along the coastal shoreline to prevent tsunami and storm surges.
Urban Areas	- Implementation of SUDs - Increase soft capes and permeable surfaces in cities. - Afforestation in urban green spaces - Provision of green parks and more areas that are natural. - Construction of rooftop gardens and green walls in buildings - Construction - Increase use of balancing ponds and underground storage systems. - Safeguarding riparian reserves of streams and rivers within the cities. - Increasing community awareness of softscapes, greenery, risks associated with flooding, and the need for protection
Wetlands & Creeks	- Controlling the extraction of groundwater to reduce the risk of land subsidence - Restoration of protection of mangroves - Maintaining and revegetation riparian reserves

Dimension 9: Soundscape management	
NBS Goal: Reducing the impact of noise in the community	
Zones	**Possible NBS Intervention**
Urban areas	- Creating buffers between roads and residential areas by planting trees and increasing vegetation. - Smart use of water fountains in public spaces to diffuse unwanted noise - Planting of trees and creation of birds' shelters to attract songbirds

Dimension 10: Management of Health	
NBS Goal: Improving the psychological and physical wellbeing of urban communities	
Zones	**Possible NBS Intervention**
Urban areas	- Make green spaces attractive and accessible to all. - Establishing green corridors to schools, workplaces, and homes. - Promoting biodiversity and different vegetation and bird species.

(Source: European Commission, EU Research, and Innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities, 2015)

3.4 Global NBS Best Practices

NBS has had the most prominence in Europe and some parts of the United States such as Philadelphia. The section highlights some of the case studies NBS interventions relating to Coastal areas erosion & flooding, Urban areas flooding and stormwater management, and lastly, Creeks and Wetlands flooding & Erosion.

3.4.1 Coastal flooding and Erosion

Coastal flooding is a common challenge experienced along coastal cities and is anticipated to be more significant due to the changing climate effects. It is caused by either storm which results in significant impacts or tidal cycles which occur more frequently but have low impact flooding in low-lying areas. Coastal erosion on the other hand is experienced as a result of collapsing or loss of land along coastal areas due to floods or regular waves. Among the NBS solutions of coastal erosion include: - Oyster Reef, Beaches Dunes and Reef restoration, Waterfront parks, Voluntary buyouts in vulnerable areas, Mangrove belts, Seagrasses, Coral reefs, Coastal Marshes, Open space preservation for the vulnerable areas.

<u>Case 1: Coastal Erosion & Flooding Management – Southeast Florida</u>

The project is located in Southeast Florida and addresses issues related to coastal erosion, flooding, and tidal flooding. The strategies adopted included restoration of dune and sandy beaches, wetlands along the coast, coral reefs, population of the mangroves, offshore restoration, and also procurement of open spaces.

The paybacks derived from the project included both social, environmental, and institutional. Among the benefits included availability of recreational areas, lowered crime rates, increased community understanding, and education, reducing flooding and erosion risks, and lastly restoring the ecosystem in its entirety.

Restoration of vegetated dunes

Coral restoration

Plate 3.1: Coastal Restoration in Southeast Florida

(Source: nrcsolutions.org)

Case 2: Beaches and Dunes restoration - South seaside park, New Jersey

The project is located in New Jersey in a seafront residential area with a population of 1,579. It involved the restoration of coastal features, beaches, and Dunes. The dunes that existed ingeniously were destroyed to pave way for a clearer view of the ocean and easy access to the adjacent community.

The benefits derived from the project included a reduction in flood damage and losses. The project equally has minimal maintenance cost and most labours were provided by volunteers. However, the natural protection provided by beaches and dune requires substantive space compared to traditional infrastructures like seawalls.

Riparian reserve

Vegetated dunes restoration

Plate 3.2: Beach Restoration in South seaside New Jersey

(Source: nrcsolutions.org)

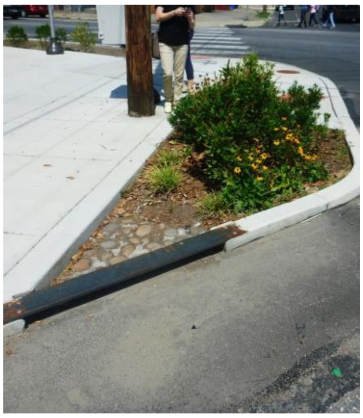
3.4.2 Urban Storm Water Flooding

In the context of urban context storm, water flooding is a result of heavy rainfall that overwhelms the local drainage and stormwater management infrastructure resulting in streets and buildings flooding. Among the remedies for urban stormwater flooding include Planting of Urban trees, Rain gardens, Green Streets, Bioswale, Floodwater detention, Green roofs, and Green parking lots.

Case study 1: Storm Water management & Cleaning Water – Green City, Philadelphia, Pennsylvania

The project entailed polluted surface creeks and streams in the city of Philadelphia which were converted into sewers in the late 19^{th} century. They presented a challenge of polluted runoff along with increased runoff from paved and hard surfaces resulting in an increased amount of runoff and prevalence of flooding.

The strategies implemented included the creation of green streets, installation of stormwater planters, permeable pavements, and also bump-outs to accommodate rainwater among others.



Stormwater bumpout

Stormwater tree precedent

Stormwater planter:

Plate 3.3: Storm Water Management Infrastructure

(Source: City of Philadelphia, Green Streets Design Manual, 2015)

Plate 3.4: City Neighbourhood Street

(Source: City of Philadelphia, Green Streets Design Manual, 2015)

Plate 3.5: Urban Arterial Street

(Source: City of Philadelphia, Green Streets Design Manual, 2015)

Plate 3.6: Low-density residential Street

(Source: City of Philadelphia, Green Streets Design Manual, 2015)

3.4.3 Riverine flooding & Erosion

Riverine flooding is a result of excess water entering a river of a stream hence making it overflow its banks and spreading out into the surrounding low-lying areas. Erosion is a natural river process however might exacerbate during a river flooding event. The strategies to mitigate river flooding and erosion include: - implementation of Flood Bypasses to redirect water, Flood Plains to slow and restore water, River Front Parks, Voluntary Buyouts, and Open Space Preservation in vulnerable areas.

Case study 1: Boulder creek floodplain restoration

The project entailed flood mitigation in the city of Boulder, Colorado, due to the devastating flash floods experienced and its vulnerability to stormwater flooding. The intervention involved the restoration of the boulder creek and safeguard it from construction and development to minimize the likelihood of flooding and associated impacts. This resulted in the creation of the Boulder Creek Restoration Master plan which intended to improve resilience along the 38.6km (24miles) creek at an estimated cost of $69.5 million.

Before After

Plate 3.7: Boulder Creek Restoration

(Source: www.aloterraservices.com)

The interventions included both local (at the Creek level) and City-wide intervention. It encompassed the installation of vegetative swales, greening the streets, planting of trees within the urban area, protection, and restoration of urban forests, restoring of flood plains, replanning & re-zoning of areas, and also the creation of floodwater detention areas. The benefits derived from the project included general flood protection, wildlife habitat restoration, and the creation of new open spaces.

<u>Case Study 2: Reducing flood reduction using LID concepts – Norfolk, Virginia.</u>

Chester Heights Neighbourhood in the city of Virginia has experienced a raising in sea level of more than 14 inches. This has resulted in the area experiencing regular flooding rendering the existing drainage ineffective. Correspondingly the community riverfront has been eroding as a result of wave action. Professionals, community, and academia worked together to conduct an adaptation design process for the shoreline community.

The project involved the preparation of a Storm Water Management Model (SWMM) that was based on the peak stormwater flow. A distributed stormwater handling approach was opted involving; disconnection of downspouts, installation of Cistern Systems, rain gardens, vegetative swales, and porous & permeable pavers connecting with cisterns under the streets. Installing a living shoreline was also opted to prevent shoreline erosion while maintaining a natural feel.

Plate 3.8: Chesterfield Heights Neighbourhood in Virginia
(Source: nrcsolutions.org)

3.5 Tropical Coastal Cities Experience of NBS

This section draws NBS practices in Tropical Coastal Cities in line with the principles of Sustainable Urban Drainage Systems.

3.5.1 Case Study 1: Ho Chi Minh City, Vietnam

<u>Flood risk Mitigation Risk and Providing Socio-cultural benefits</u>

The project involved the rehabilitation of a cultural park named Go Vap in Ho Chi Minh City. The intervention sought to establish a park equally serving as a floodplain that will be able to accommodate excess runoff during extreme storm events. It also created a recreational park for the community to provide recreational and social interaction opportunities.

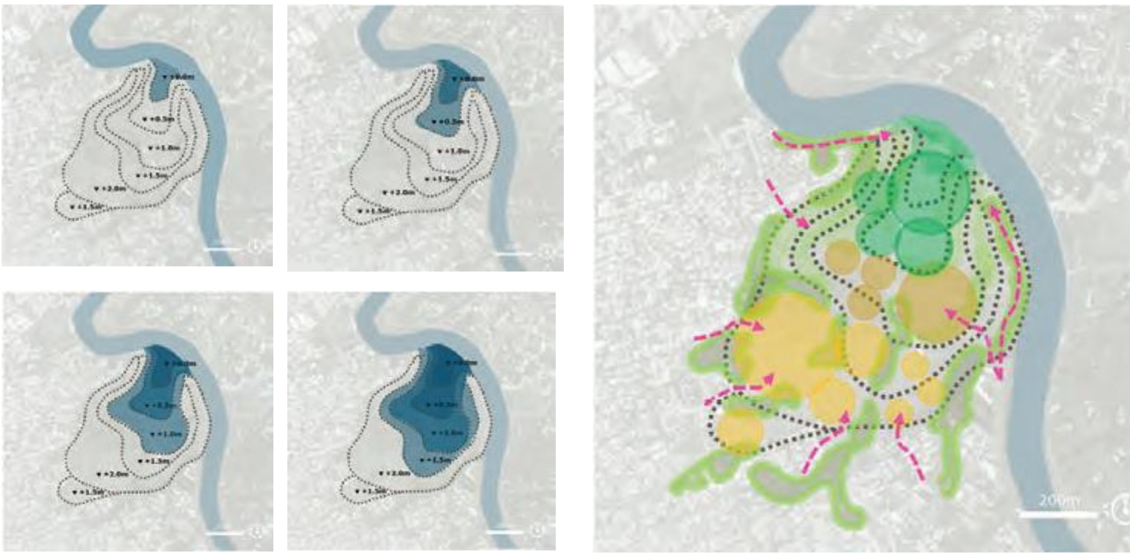


Plate 3.9: Flood Analysis

(Source: Nature-Based Solutions for Cities in Vietnam Report, 2019)

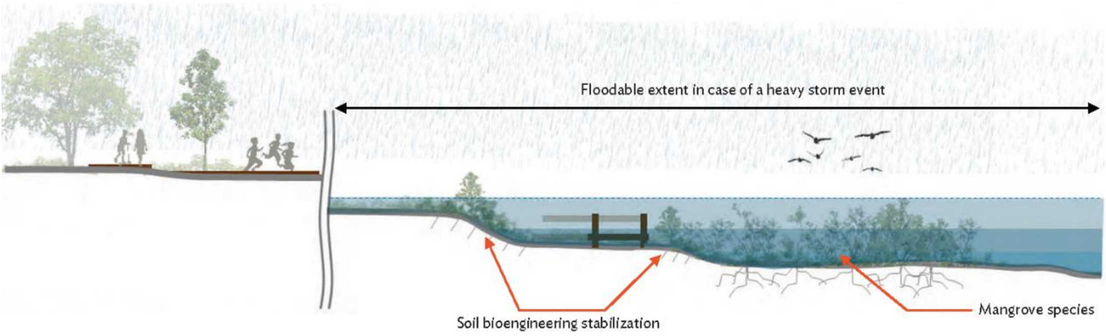


Plate 3.10: High Storm Event Go, Vap Cultural Park,

(Source: Nature-Based Solutions for Cities in Vietnam Report, 2019)

<u>Benefits</u>

The rehabilitation involved the incorporation of community activities such as sports, children playing, markets, fitness, walking & Cycling Relaxing, and enjoying nature which increased the quality of life and social benefits. This case is an ideal case study of NBS solutions providing both mitigation measures and socio-cultural functions.

3.5.2 Case study 2: Pasig River, Philippines

<u>Flood management & Rehabilitation of Pasig River, Philippines</u>

The project entailed restoration clean-up, slope stabilization, water, and flood management of Pasig River. The river divides the city of Manila, the Philippines capital, into two halves and connects Laguna de Bay to Manila Bay. It extends for almost 27 km and has a total drainage basin of 4,678 square kilometres.

The NBS interventions adopted included the installation of bioswales, terracing of riverbanks, installation of nets to capture solid waste management, protection and stabilization of the riverbank through the installation of vegetated revetment, and combination of rocks and native vegetation.

Plate 3.11: Pasig River Restoration and Rehabilitation
(Sources: Rappler. static.rappler.com)

Plate 3.12: Floating Billboard Made of Vetiver to Clean Polluted Wastewater

(Source: A report on NBS Case studies from the Greater Mekong sub-region, 2016)

Benefits

The rehabilitation efforts also focussed on restoring the tributary of the Pasig, which was accommodating a market, thus generating a tremendous amount of waste that polluted the river. Materials recovery facilities were installed to collect Solid waste.

Among the benefits derived from the project consisted of the mitigation of solid and liquid pollution, an increment in greenery and vegetation cover, biodiversity, reduction of illnesses and vector insects, and reduction in obnoxious odours.

3.6 Criticism of NBS

As much as the NBS brings together pillars of sustainability in that it incorporates social, environmental, and economic dimensions in an integrated manner, there are still questions regarding the solutions and the concept in general. Nesshöver C. et al (2017) discusses the following key questions regarding Nature-based Solutions:

- What are the varieties of the problems that can be addressed using the NBS interventions, and whether the problems are temporary or unrelenting?

This question involves the kind of problems that NBS can address and whether the interventions entail climate-based challenges or could also resolve other urban challenges resulting from rapid urbanization. Thus, it should be clear that NBS(s) need to intervene in solving problems related to social, economic, and the environment. However, the subject of the kinds of challenges as to whether they are transitory or permanent is still grey.

- What is the integrity level of naturalness, since most NBS projects have some degree of alteration of nature?

NBS(s) are being applauded as nature-friendly interventions, however, they still involve alteration of nature, and this varies from one intervention to the next. Thus, begging the question to what extent should nature-based interventions alter nature for them to qualify as environmentally friendly solutions.

- Is it possible to consider all the advantages and disadvantages of an intervention and whether the benefits and costs can be considered in a more detailed manner?

It is difficult to weigh the entire advantages and disadvantages of solutions and also the question of the best method of assessing the benefits resulting from the implementation of a particular nature-based intervention. Having a particular set of criteria or objectives to achieve could create an ideal basis for evaluating a particular NBS intervention.

- How do the solutions handle complex urban challenges since some ingrained problems with many set-offs that are hard to be divided into simple solutions?

NBS interventions assume a simple solution would fix a particular problem, however, some challenges are complex and have multiple dimensions. Thus, the solution towards these problems should also adopt a multidimensional approach and not a simple fix.

- What degree are non-structural and social innovations deemed important if most interventions depend on the technocratic type of innovations?

Nature-based solutions primarily involve physical interventions or technical innovations. However, some challenges need more than physical interventions or do not necessitate physical intervention but rather a particular way of thinking or social behaviour whereby individuals need to change their perception and behaviours to enable solving a given problem. An example could be waste management, whereby physical interventions are inadequate but rather change in the community’s perception and behaviours are necessary.

- How do the solutions guarantee the inclusion of all critical stakeholders involved?

NBS without stakeholder involvement would likely be unsuccessful. Hence the need to involve the affected stakeholders to foster community ownership and enhance the success of the project. This would equally enhance the acquisition of indigenous information that would equally boost the success of the intervention.

3.7 Chapter Summary

This chapter discussed NBS and SUDs including the related concepts in detail. It started by introducing the two concepts, their goals, dimensions, and other related concepts. Correspondingly, the chapter further discusses global best practices of NBS in terms of Coastal flooding and erosion, Urban stormwater flooding, and Riverine flooding and Erosion. It gives examples of NBS experience of tropical coastal cities in middle and low economic development countries Philippines and Vietnam. The chapter concludes by providing a criticism of the NBS and the way forward (Figure 3.9).

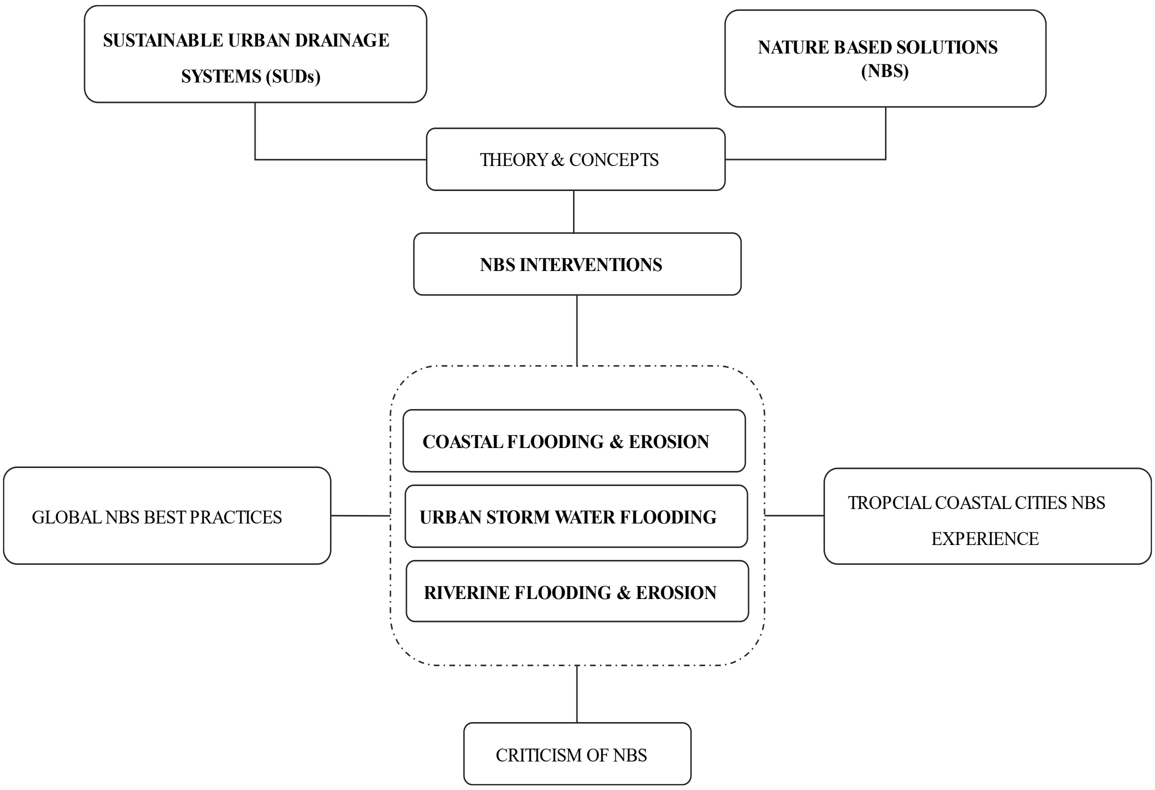


Figure 3.9: Chapter Three Summary

CHAPTER 4

THE CASE OF MOMBASA CITY

This chapter discusses Mombasa City in detail and its vulnerability to climate change. It starts by reviewing the basic background information including geographical information, social, economic, and physiographic, and environmental characteristics. It also identifies the major climate-related challenges and discusses measures and strategies which have been put in place to mitigate the negative effects. Correspondingly the chapter discusses study findings and results from the analysis of secondary materials and primary data collected and further evaluates and models the appropriate nature-based solution systems for the coastal city.

4.1 Background Information

4.1.1 Geographical Location

Mombasa City is located in the south-eastern part of Kenya along the Indian ocean. It is the country's second-largest city after the capital, Nairobi, and oldest.

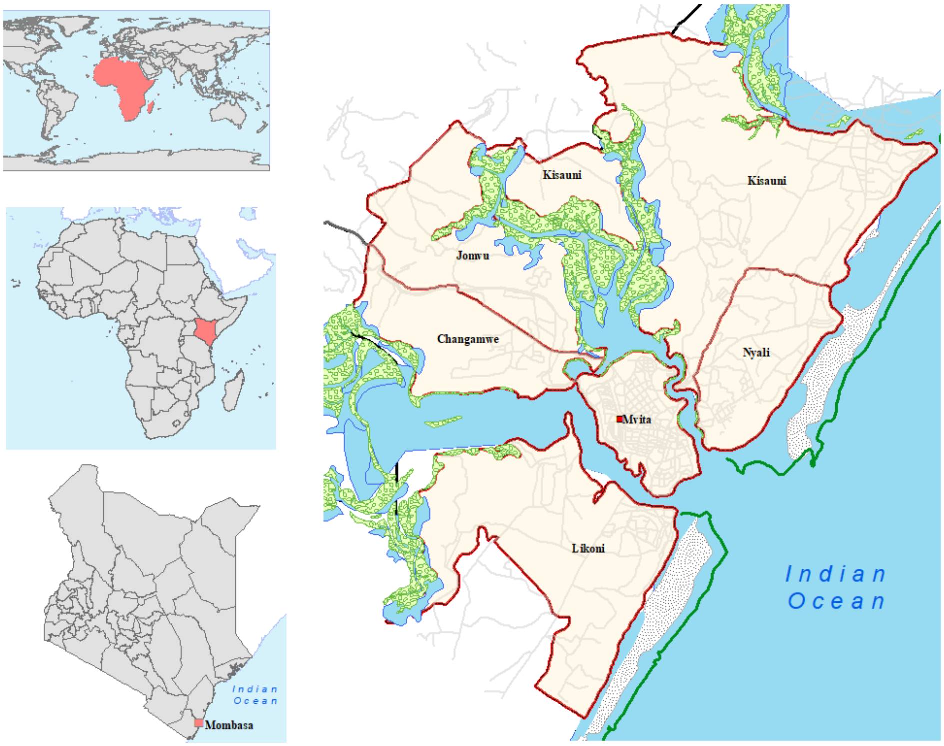


Figure 4.1: Location Context Mombasa

(Source: Author, 2021)

The city county is found approximately 4.1^0 S $39.7\ ^0$ E. It covers a total geographical area of $287.94km^2$ comprising $222.82\ km^2$ of landmass and $65.12\ km^2$ of water mass. The average elevation of 50 meters from the sea level. Map 4.1 above illustrates the locational context of Mombasa City within international, regional, and local contexts.

4.1.2 Historical Background

The history of Mombasa dates back earlier before the 6^{th} century originally inhabited by African Bantus who were involved in farming, fishing, and local trading. The first visitors to the City were the Jordanians in the 6^{th} century, then the Persians in the 9^{th} century, and Arabs in the 10^{th} century. These groups contributed significantly to the cities diverse culture, architecture, and traditions. During this period, it emerged as an important trading route across the Indian ocean and an important commercial centre along the Indian Ocean coastline. The trade involved gold, spices, and ivory. It was later visited by the Portuguese in 1498, who then took control over the town for the period 1593 to 1730. Due to its strategic location as an important trade route, it was fought over several times by the Arabs, Persians, and Portuguese thus assuming a name as the island of war[1]. The timeline of the historical development of Mombasa City (Figure 4.2).

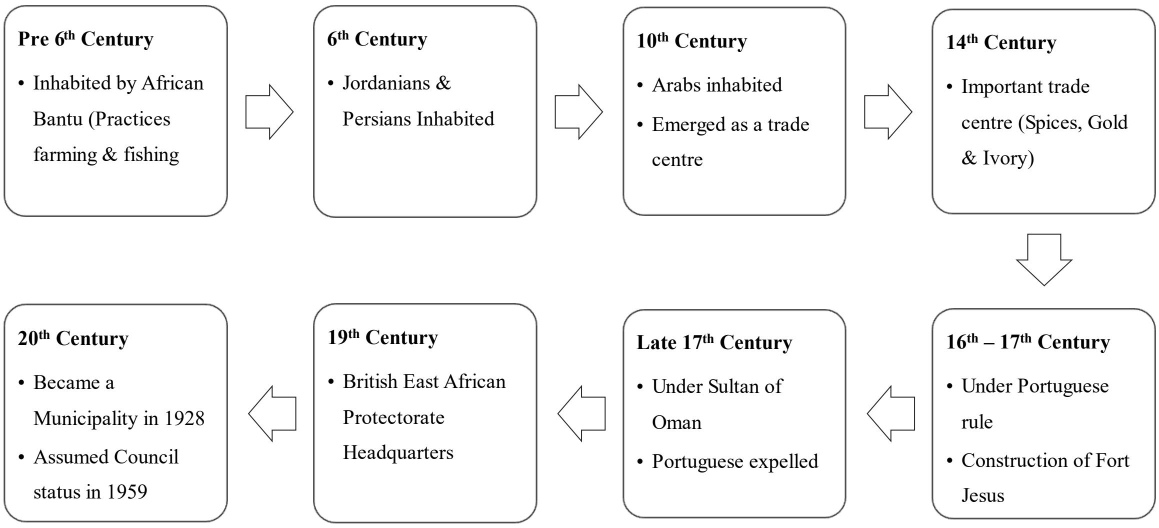


Figure 4.2: Historical Timeline of Mombasa City
(Source: Author, 2021)

[1] https://www.britannica.com/place/Mombasa

The city started being administered by the British in 1895 and became East Africa's protectorate capital up to 1907. It gained a municipality status in 1928 and got the status of a council in 1959.

Mombasa city has a strong influence on middle east architecture and historic urban fabric (Plate 4.1).

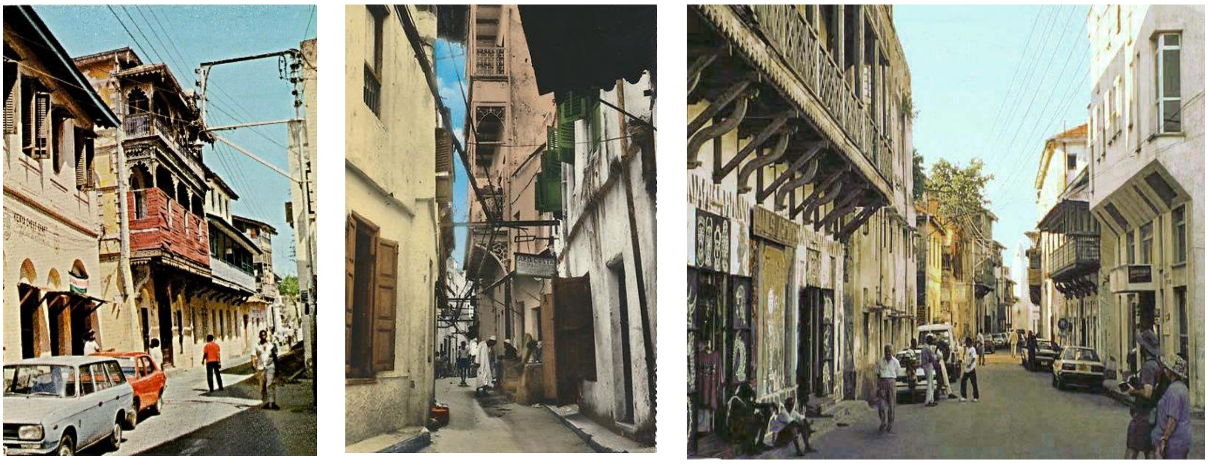
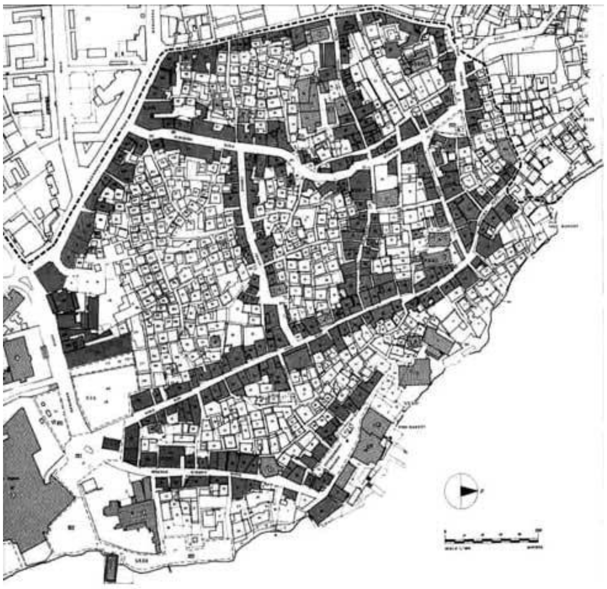


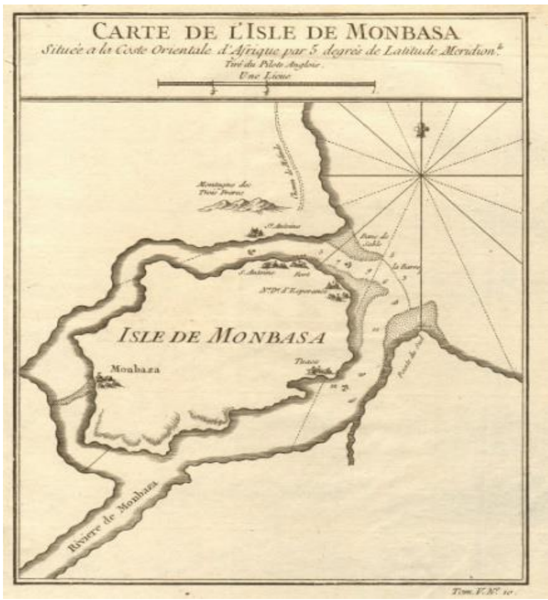
Plate 4.1: Old Images of Mombasa City

(Source: Hart, 2007)



Map 4.1: Mombasa Old town conservation

(Source: Hart, 2007)



Map 4.2: Mombasa 1748 Map by Nicolas Bellin

(Source: antiquemapsandprints.com)

4.1.3 Socio-economic Characteristics

4.1.3.1 Population

The population of Mombasa city stood at 1,208,333 as of 2019 according to the Kenya National Bureau of Statistics (KNBS) population census of 2019. It has a population growth rate of 3.29% lower than the Country's average of 4.0% but higher than the world urban population growth rate of 1.89%. It correspondingly has a total of 378,422 households and an average household size of 3.2 slightly lower than the country average of 3.9 (Kenya Population and Housing Census: Volume 1, 2019).

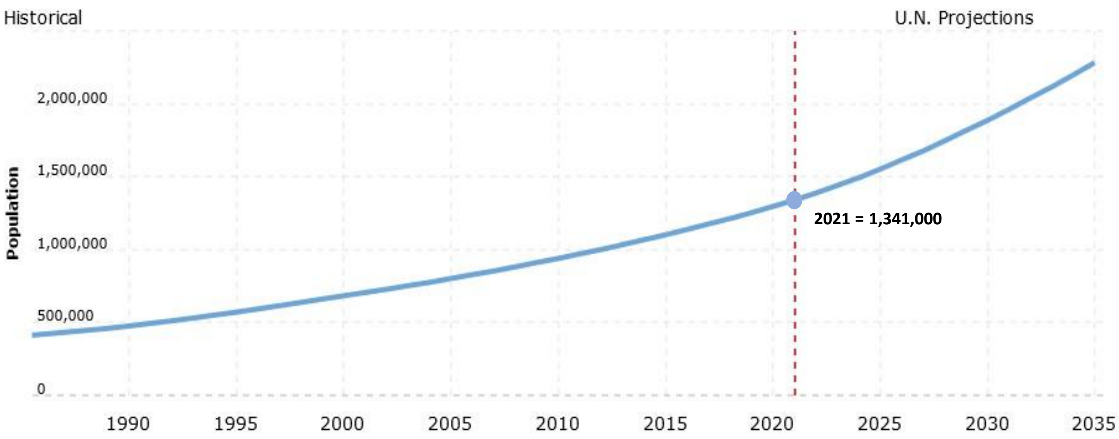


Figure 4.3: Current and Projected Population of Mombasa City

(Source: Macro trends.net, Data from UN World Population Prospects, 2021; https://www.macrotrends.net/cities/21708/mombasa/population)

The graph above shows the historical and projected population growth of the city. From the graph, the population is seen to be increasing and projected to reach 2.3 Million by 2035. Mombasa being the administrative and commercial hub of Kenya's coastal region, the city attracts population from the entire coastal area of the country and its hinterland thus experiencing rapid population growth.

4.1.3.2 Economic Activities

The city is the hosts the largest port in East Africa with two harbours namely Kilindini and Old Port. The ports have a significant position in shaping the economy of the City and the entire region at large. It supplies commercial imports and exports to the neighbouring landlocked countries with the larger East African region such as Congo, Burundi, South Sudan, Rwanda, and some regions in Tanzania. (Awuor et al., 2008). The

City contributes to approximately 4.7 % of Kenya's GDP (World Bank, 2017) with an estimated GDP of $ 4.98 billion compared to the country's 2021 estimate of $106.04 billion.[2]

Other economic activities include small-scale agriculture in the city outskirts, fishing, conventional sectors such as cargo logistics related to port import and export businesses, manufacturing consisting of cement and salt processing. Mombasa is equally a tourist city with marine-based ecological attractions, sandy beaches, tropical weather, historical and cultural monuments (Plates 4.2, 4.3, 4.4, 4.5, 4.6 & 4.7).

Plate 4.2: Fishing Activities in Mombasa

Plate 4.3: Logistics & Shipping Business

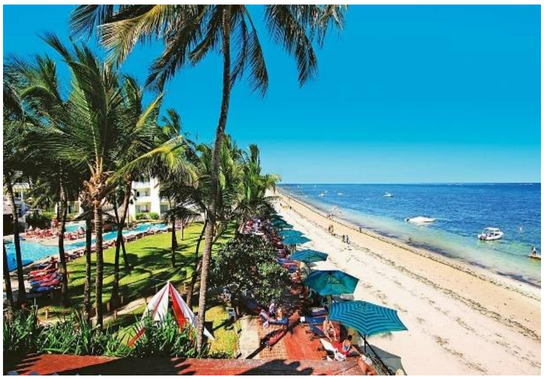


Plate 4.4: Tourism

Plate 4.5: Manufacturing

[2] https://www.statista.com/statistics/451111/gross-domestic-product-gdp-in-kenya/

Plate 4.6: Business & Trading

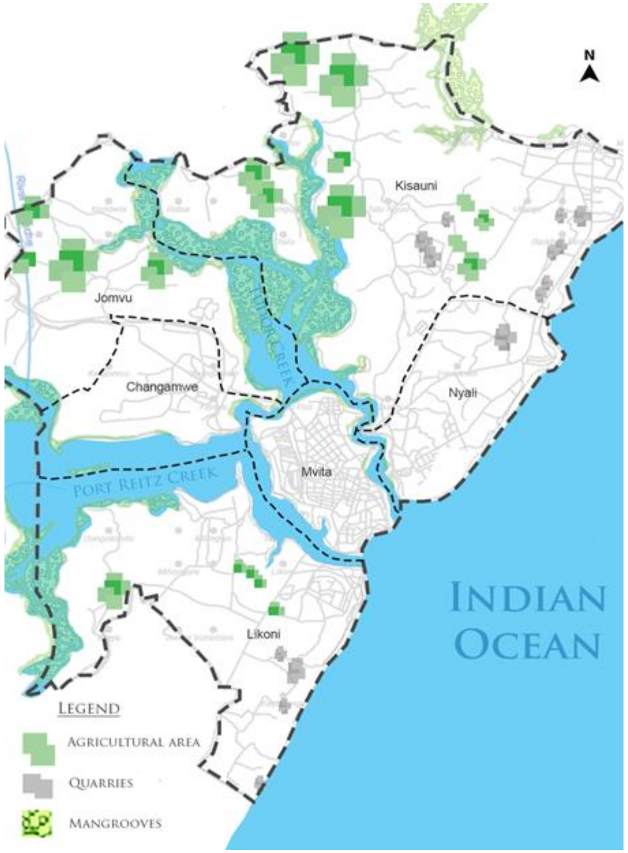
Plate 4.7: Small Scale Agriculture

4.1.3.3 Spatial distribution of economic activities within the City

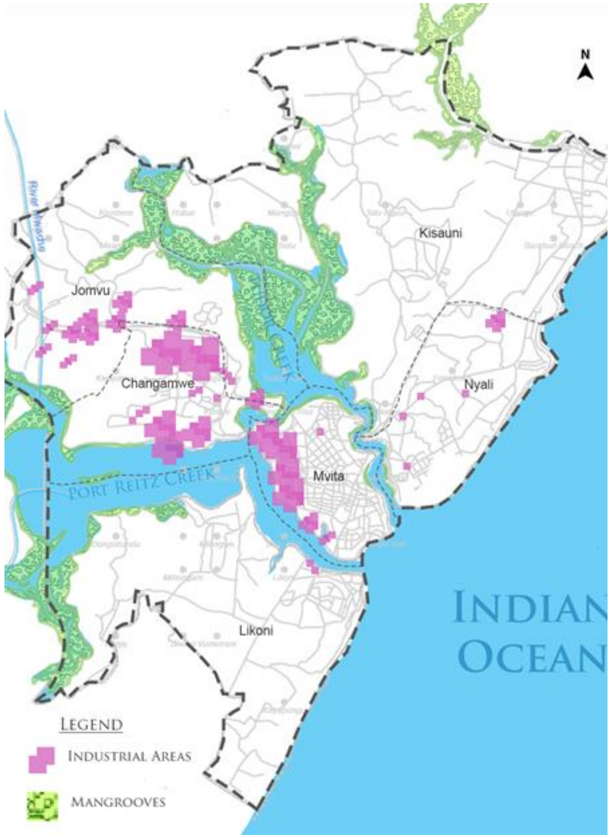
The economic activities discussed above are classified into three major classifications as primary, secondary, and tertiary economic activities. The primary economic activities consist of agricultural practices and fishing industries. The agricultural activities are undertaken in the hinterlands of the mainland whereas the fishing is conducted along the coast (Map 4.4). Secondary activities on the other hand include the manufacturing, industrial, and warehousing activities mainly done within the port area sides of the island and the western main-land parts neighbouring the port (Map 4.5). The tertiary activities comprise the banking services, transport and logistics, tourism, and hospitality industries located in the island and north and southern mainland (Map 4.6).

4.1.3.4 Residential areas and Distribution

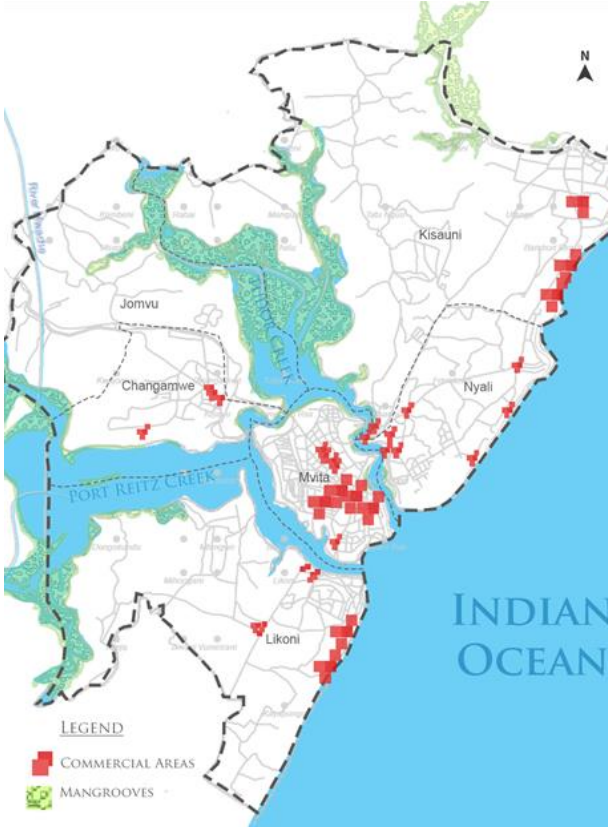
As per the Kenya Population and Housing Census 2019, majority of the households are within Mainland North (Kisauni & Nyali) accounting for 42% of the city population, 158,150 Households. It is then followed by mainland West (Changamwe & Jomvu) which constitutes 26%. The least zone in terms of household is the island zone (Mvita) constituting only 10% which corresponds to 38,995. However, in terms of population density, the island zone has the highest of 10,706 whereas Mainland South (Likoni) has the lowest of 4920 (Map 4.7). Consequentially, due to rapid urbanization, informal settlements are very common and spread out mainly in Mainland North, West and South (Map 4.8).



Map 4.3: Distribution of Agricultural Activities

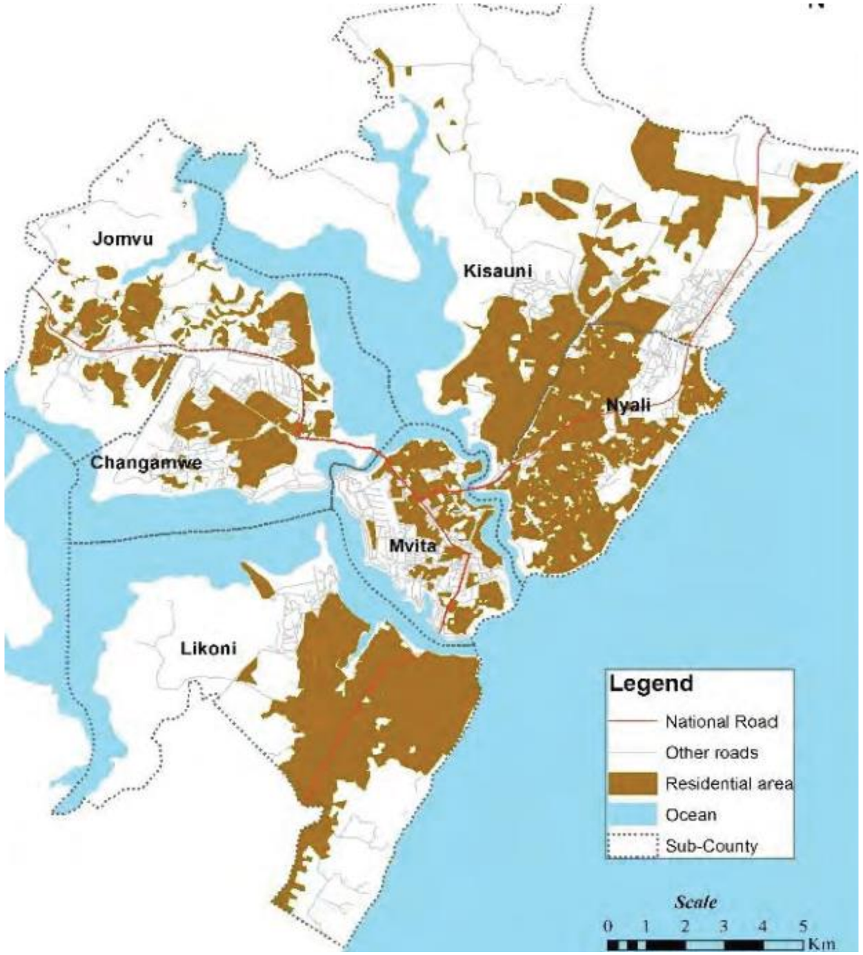


Map 4.4: Distribution of Industrial Activities



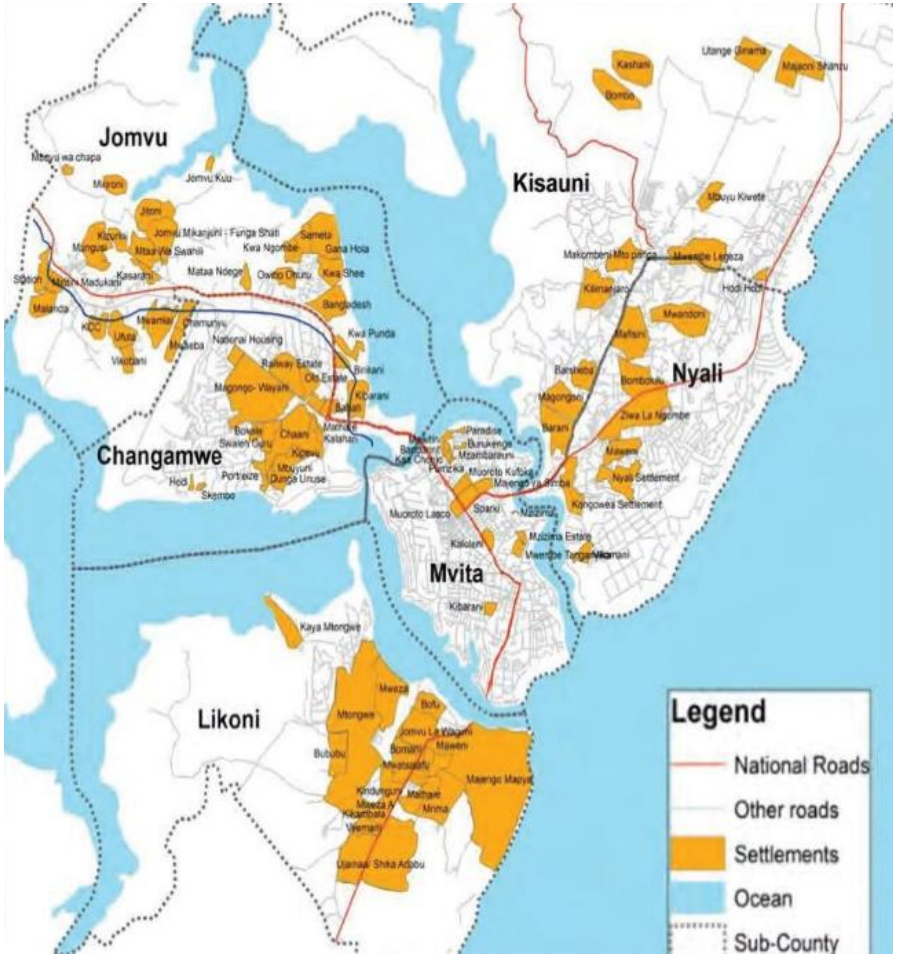
Map 4.5: Distribution of Commercial Activities

Source: Author, 2021



Map 4.6: Residential Areas Distribution in Mombasa

(Source: JICA, 2015)



Map 4.7: Informal Settlements Distribution

(Source: ISUDP Mombasa Draft Report, 2018)

4.1.4 Physiographic Characteristics

4.1.4.1 Topography

Mombasa city has an elevation ranging from sea level on its eastern side up to approximately 100m in the top-most western mainland. The physiographic of Mombasa is categorized into 3 regions; Coastal Plain starting from the sea level to nearly 45m, Eroded terrain dissected by hills, and the Indian Ocean Shoreline. The key topographic features within the city include the Indian Ocean, Creeks and Tidal flats, Sandy beaches, Fringing coral reefs, Cliffs, Island, Ports & Harbours. A significant percentage of the county lies below 20 metres from the sea level (Table 4.1).

Table 4.1: Mombasa City County Elevation

Elevation (m)	< 0.00	< 2.00	< 3.64	< 4.50	< 10.0	< 20.0	Total
Urban Area (Km^2)	4.09	5.01	5.60	6.09	7.02	12.27	26.65
Other (Km^2)	14.81	22.12	26.57	28.97	39.35	56.71	227.11

(Source: Kabede et al., 2009)

From table 4.1, we can see a significant portion of the City county, 17.3 % of Mombasa is below 10m resulting in a greater part of the city being vulnerable to flooding in an event of coastal flooding. It is estimated that a storm surge caused by a sea rise of 43cm (by 2100) would affect a significant of the 14.012 million people (2100 estimates by Hoornweg D & Kevin Pope, 2000) with economic assets and infrastructure worth more than US$17 billion will be at stake. 75% of this exposure is concentrated within the island zone (Kabede et al., 2009), as depicted by the graph of land are a percentage against ground elevation in metres (Figure 4.4).

4.1.4.2 Geology Soil and Minerals

The geological foundation of the city contains mainly sedimentary rocks ranging from Jurassic to quaternary. These include shale, sandstone, limestone, and fringing reefs. The northern parts of the city (Kisauni) consist of alluvial plains, whereas the western regions (Changamwe) consist of Jurassic plain. The areas along the sea consist of coral reefs mainly used to harvest limestone necessary for cement manufacturing and also stones for construction. The soil on the other hand is mainly clay loam in some parts, sand, and beach sands. The main mining activity is limestone which is used in the manufacturing of cement.

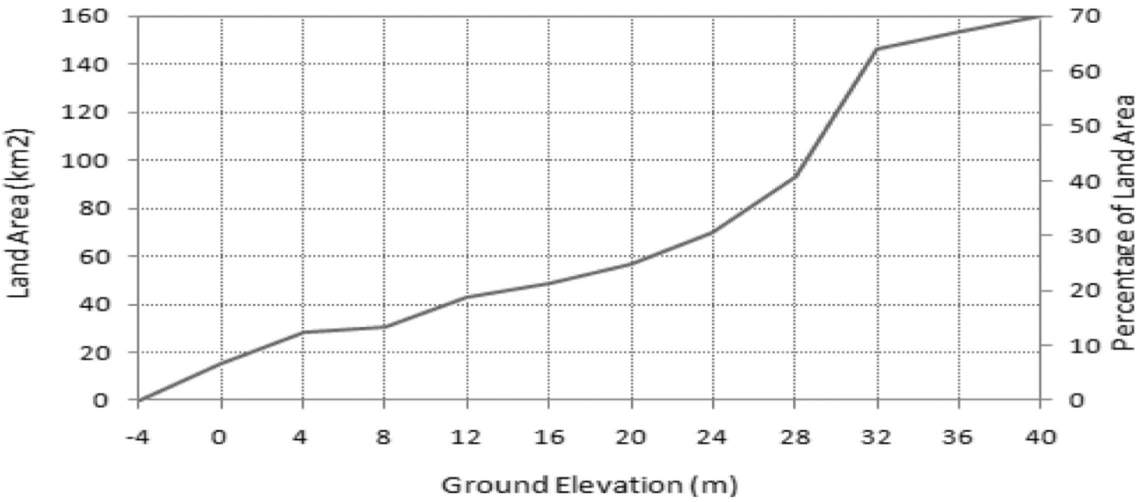


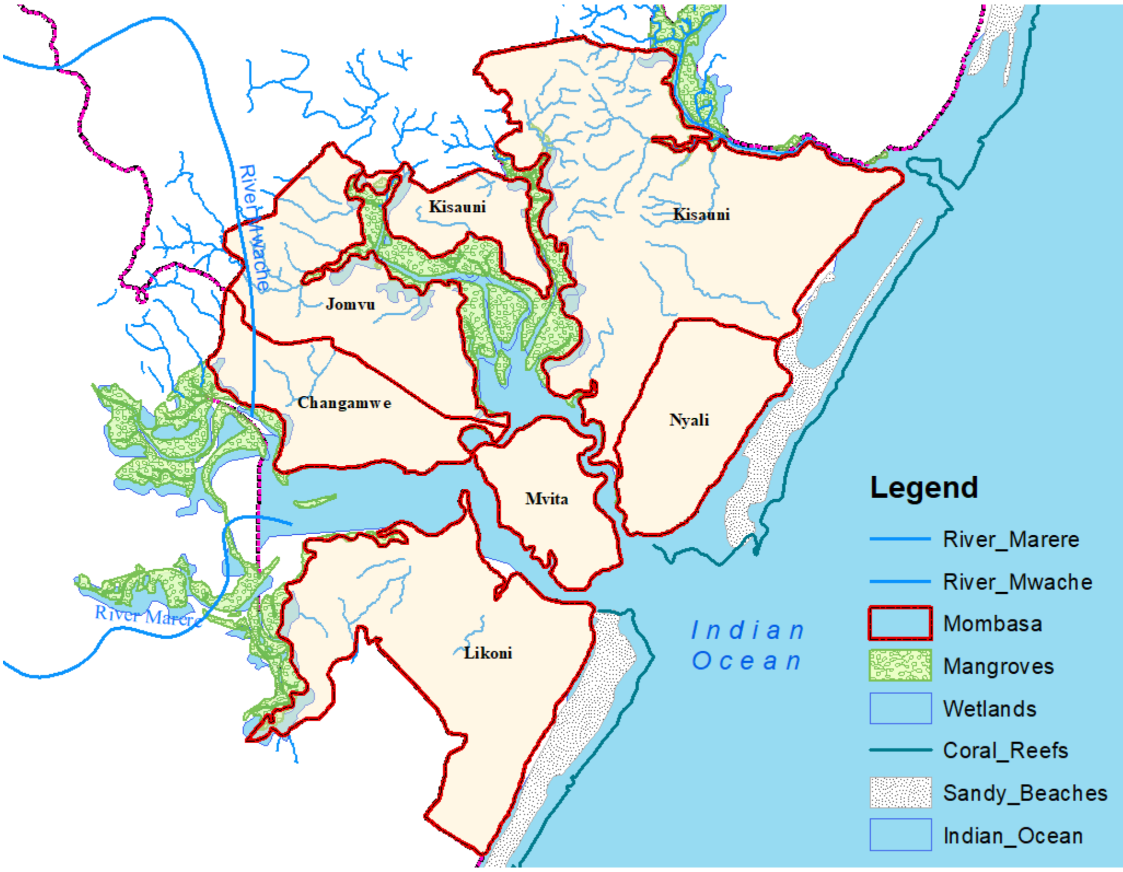
Figure 4.4: Elevation Profile of Mombasa

(Source: Source: Kabede et al., 2009)

4.1.4.3 Hydrology

Mombasa City elevation falls between sea level and approximately 45 meters high from the sea level. The main water body within the city is the Indian ocean which stretches about 30 Km. It has two major creeks namely Portreitz in its southern inlet and Tudor Creek in its Northern inlet. The city has an estuary system consisting of about 47.5 km^2 of wetland areas with an estimated area of 19.5 km^2 of mangrove forest. (World Resources Institute). The mangrove forest acts as an intertidal ecosystem of the overall coastal ecosystem. Two rivers are draining into the Tudor Creek namely, Kombeni and Tsalu. The Portreitz Creek on the other hand receives water from 3 seasonal rivers within the city which are Mambome, Chasimba, and Mwachi (Kamua, 2002).

Concerning freshwater sources, the Mombasa city gets freshwater for domestic consumption from Mzima and Marere springs, and Tiwi-Likoni and Baricho boreholes. These are supplemented by private boreholes sunk by residents. The springs and main boreholes all come from neighbouring counties including; Kwale, Taita taveta, and Kilifi counties (Map 4.9). According to the world bank, 2016, the daily demand for domestic water within the city exceeds 100,000 m^3, whereas the supply falls short of this by more than 50%.



Map 4.8: Hydrology system of Mombasa City

(Source: Author, 2021)

4.1.5 Climate

The city of Mombasa has a tropical climate, owing to its location within the tropical zone. The climate of the city is classified as Aw according to the Köppen-Geiger system, also known as ‘Tropical wet and dry or ‘Savannah Climate’. It has two climate seasons, an extended dry season where the precipitation is less than 60 mm and a short-wet season of precipitation less than 1000mm. Mombasa City has a warm humid tropical climate whereby the wind and precipitation within the city are affected by distribution patterns of the monsoon winds. The different subsets of climate are further discussed below as follows;

4.1.5.1 Rainfall

The average rainfall is approximately 887 mm per annum with the wettest month being May with 235.5mm whereas the driest month being February with 14.0 mm. According to the Kenya meteorological data between 1971 to 2010 the highest annual precipitation recorded was 2244.0 mm whereas the least was 544.0 mm (Ayugi et al. 2016). Mombasa city is prone to floods in an event of heavy precipitation due to poor drainage, uncontrolled urban settlements, and waste management.

4.1.5.2 Temperatures

On the other hand, the average temperature of the city stands at 26.27 ºC whereas the highest being 33.7 ºC in March and the lowest being 19.3 ºC in July and August (Figure 4.5). Climate change is anticipated to intensify the temperatures of the city. This will in turn increase the urban heat island effects hence increase demand for energy in cooling and creates an uncomfortable outdoor environment.

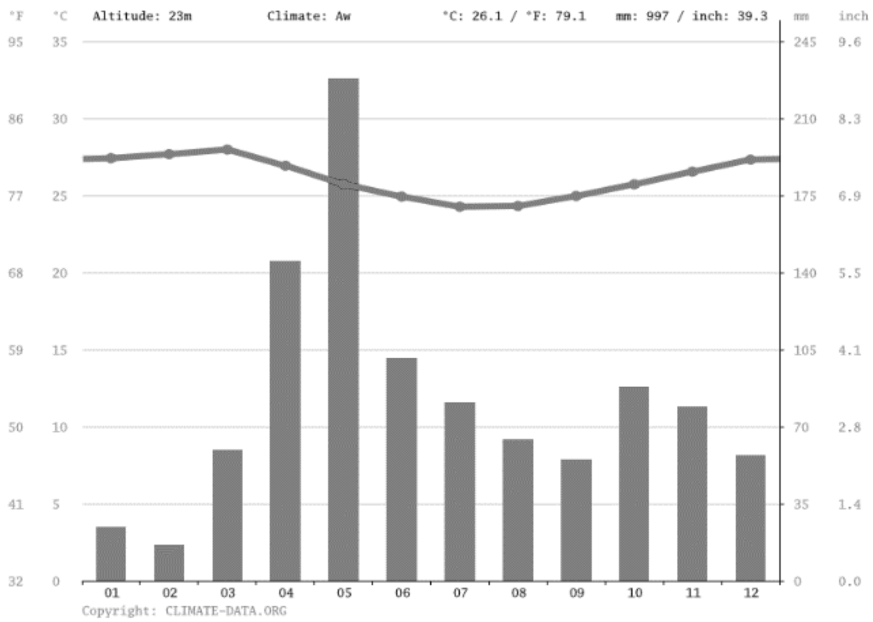


Figure 4.5: Rainfall & Temperature Graphs of Mombasa
(Source: Climatedata.org)

4.1.5.3 Relative Humidity

Mombasa city has a high relative humidity owing to its position close to the Indian Ocean. The average relative humidity is 74% with the highest humidity occurring in July with 86% whereas the least humid month being February with 59%. The high humidity levels of Mombasa City exacerbate the urban island effect of the city during hot weather.

4.1.5.4 Wind

The average wind speed of Mombasa is 3.75m/s. Most of the winds are experienced in May and June whereas the least wind is experienced in November (Figure 4.6). The wind patterns within the city are heavily influenced by the monsoon wind patterns which in turn affect the humidity of the city by carrying water vapour from the ocean to the city thus increasing the relative humidity.

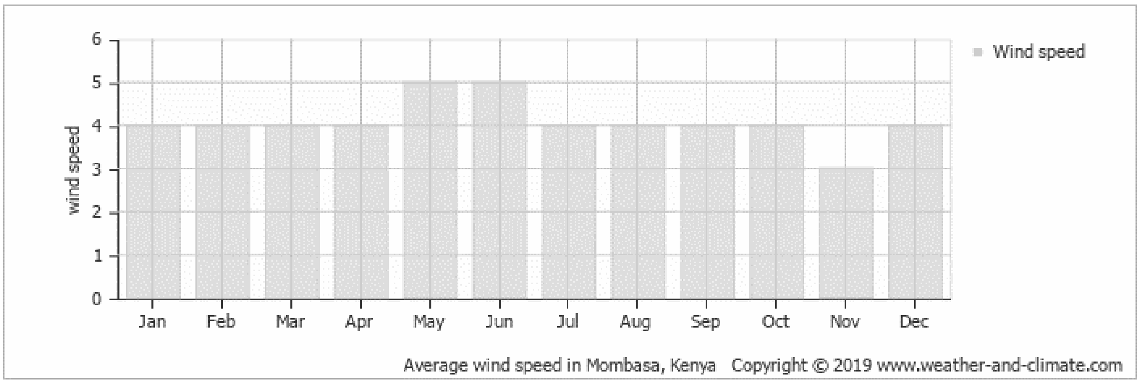


Figure 4.6: Average Windspeed in Mombasa

(Source: Weather & Climate, 2019)

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
Mean Temp. (°C)	27.6	28.1	28.3	27.6	26.2	24.8	24	24	24.7	25.7	26.9	27.4	**26.27**
High Temp. (°C)	33.2	33.7	33.7	32.5	30.9	29.4	28.7	28.8	29.7	30.5	31.6	32.8	**31.29**
Low Temp. (°C)	22.0	22.5	22.9	22.7	21.6	20.1	19.3	19.3	19.7	20.9	22.1	22	**21.26**
Mean Prec. Monthly (mm)	33.9	14.0	55.6	154.3	235.5	88.3	71.8	68.2	67.2	103.4	104.7	75.8	**89.39**
Mean Daily R. Hum. Max (%)	76.0	76.0	78.0	82.0	85.0	84.0	86.0	85.0	82.0	81.0	80.0	78.0	**81.08**
Mean Daily R. Hum Min (%)	62.0	59.0	61.0	66.0	70.0	67.0	67.0	66.0	65.0	66.0	68.0	65.0	**65.17**
Rainy Days	3	3	11	19	18	16	17	16	13	14	15	12	**13.1**
Average Sun hours (Hours)	8.2	8.1	8.2	7.5	7.4	8.1	8.4	8.2	8.1	7.7	7.9	8.6	**8.0**

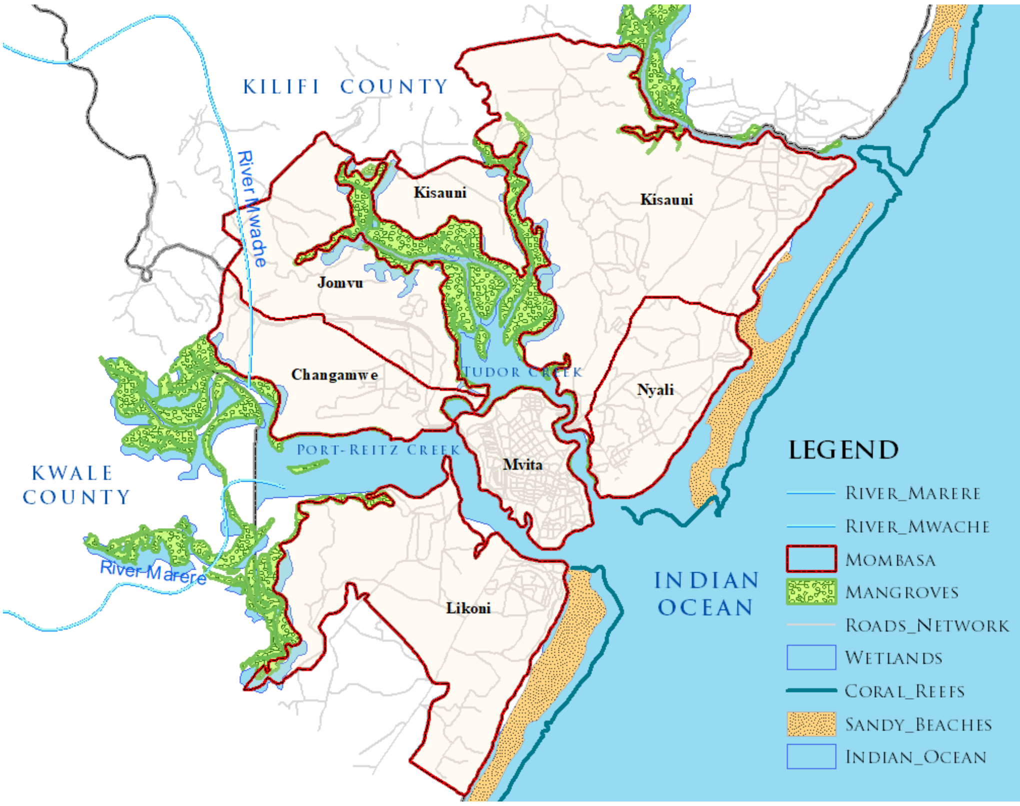
Figure 4.7: A summary of Climate Conditions in Mombasa City

(Source: Data from World Meteorological Organization & Climate-data.org, 2021)

4.1.6 Environment

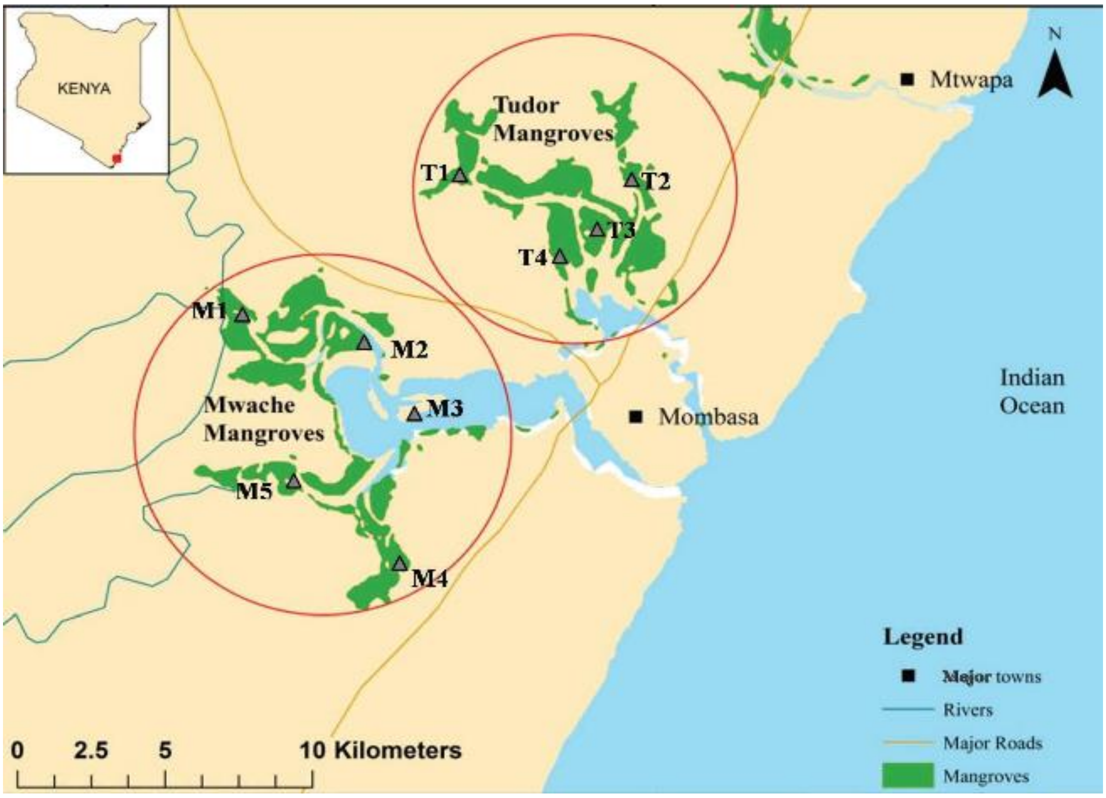
4.1.6.1 Environmental Sensitive Areas of Mombasa County

The environmentally sensitive areas of the county include mainly the Marine areas, Wildlife reserves, cultural heritage areas, historical areas, and recreational areas such as parks, beaches, and green areas (Map 4.10).



Map 4.9: Mombasa City Major Ecological Areas
(Source: Author, 2021)

They also include mangroves, coastal marshes, and riparian areas and several other ecological elements including coral reefs, sandy beaches, mangroves, and wetlands and rivers (Map 4.11).

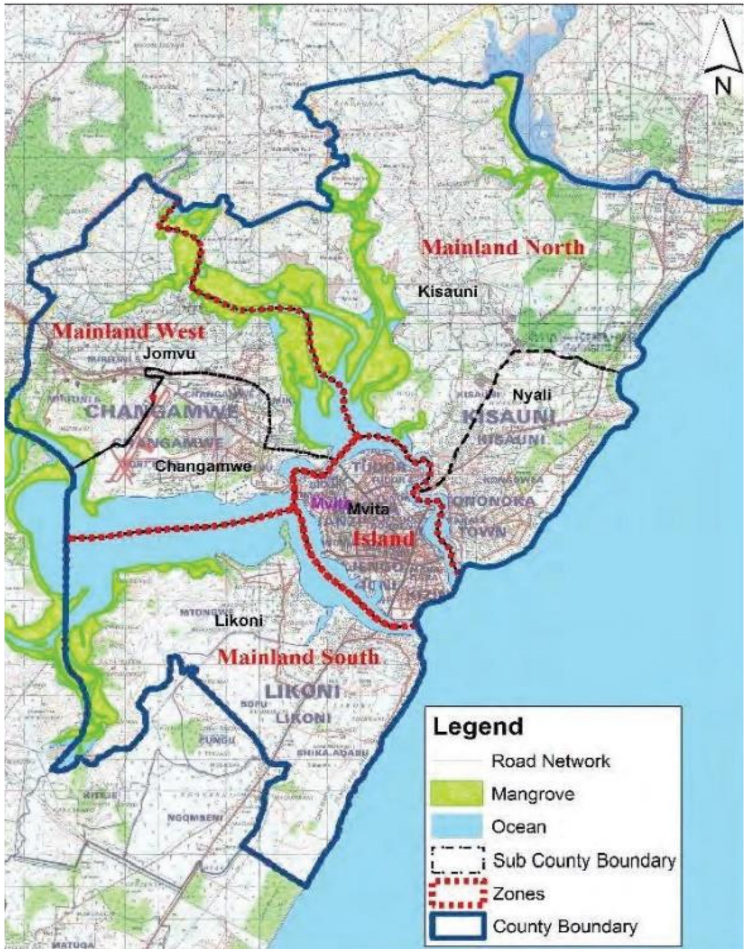


Map 4.10: Distribution of Mangroves within Mombasa City
(Source: Bosire J., 2014)

Plate 4.8: Mangroves within forests in Mombasa
(www.ecosystemrestorationcamps.org)

Mombasa city is equally endowed with prominent historic places, museums, and cultural areas such as Fort Jesus and Mombasa Old town among others. The majority of these historical assets are located within the Island and Mainland North zone (Map 4.12).

Map 4.11: Historic, Nature & Cultural Areas



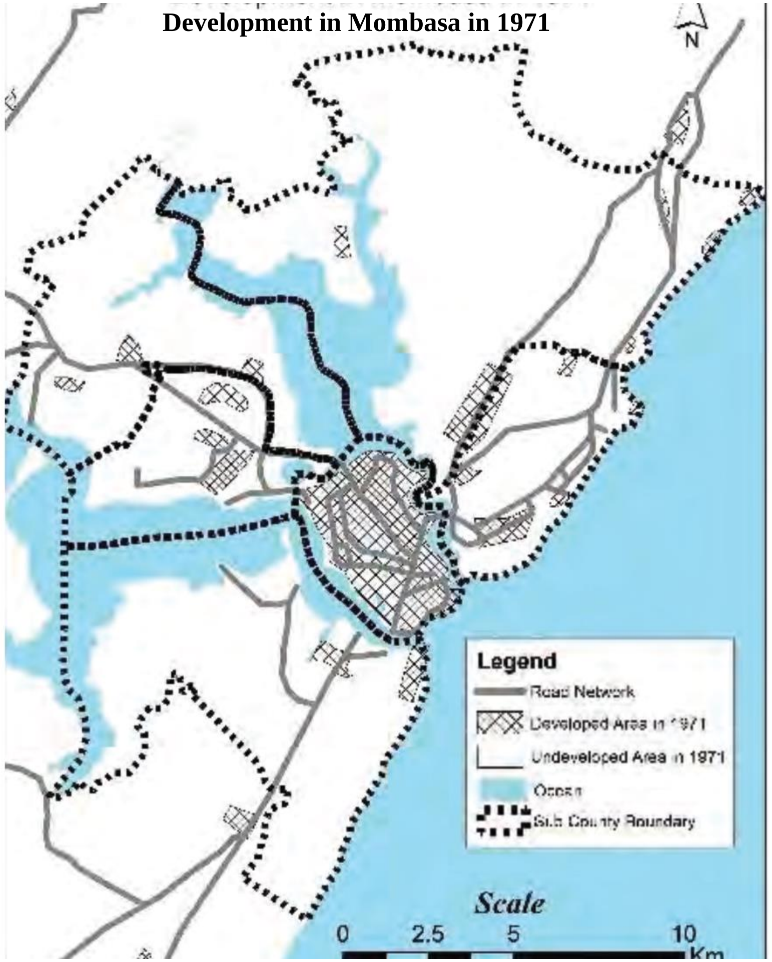
Map 4.12: Coastal, Marshes, and Riparian Areas

(Source: Mombasa Masterplan JICA Expert team, 2015)

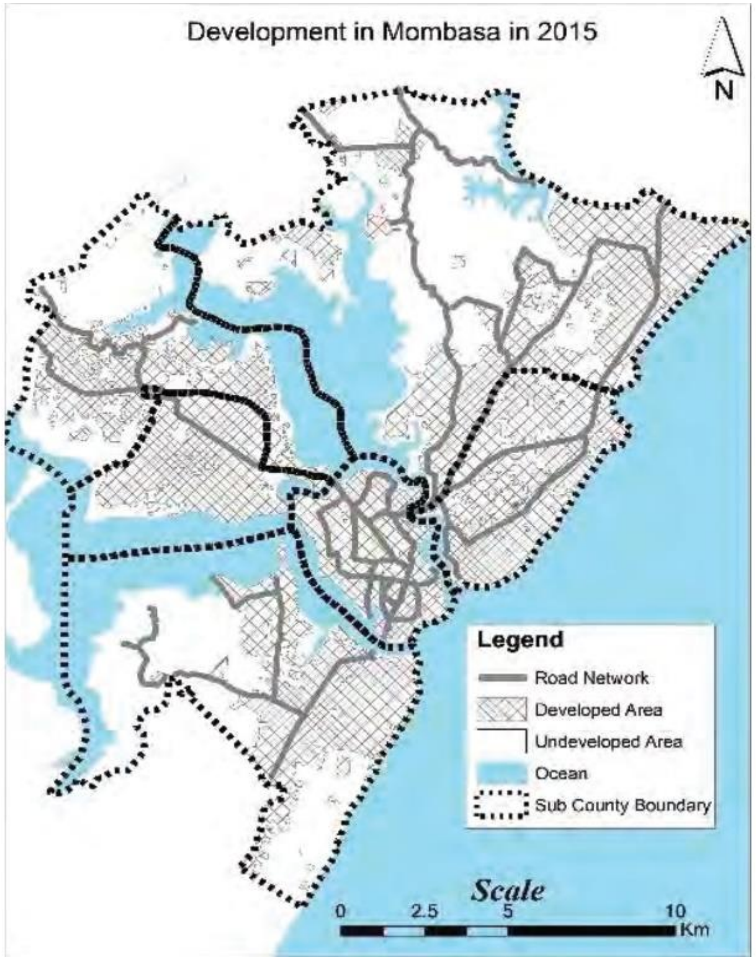
4.1.7 Urbanization trend

Mombasa city was originally inhabited by African Bantu, however, there have been several visitors to the city since the 6th century such as the Jordanians and Persians and then Arabs in the 10th century. The city developed as a trading route and commercial centre and later it became the British headquarters of the East African Company during the railway construction in 1887. The population of the city was 20,000 in 1896 when the construction of the Mombasa – Kisumu railway began where the population was concentrated on the island. The development of infrastructures such as bridges and ferry services resulted in a population rise to 247,073 by 1969. The establishment of industries such as oil refineries, cement factories, and tourism-related industries catalysed rural-urban migration and spurred population growth within the city raising it to 461,753 by 1989. Urbanization continued taking shape resulting in population growth and currently standing at 1,208,333 as of 2019 (KNBS Kenya Population and Housing Census, 2019).

The city prepared its first strategic development plan, where the development was mainly concentrated within the island zone and some pockets in mainland West and North (Map 4.14). However, the development plan was not adequately implemented. The second comprehensive plan is the Mombasa Comprehensive Master Plan prepared in 2015, by rapid development had widely sprawled with little planning intervention (Map 4.15) resulting in several urban challenges including inadequate infrastructure, services and housing and waste management among others. Between the period 1971 and 2015 developed has sprawled towards all the directions of the city, with residential settlements significantly sprawling towards the north around Kisauni and Bamburi and south of the island primarily Likoni.



Map 4.13: Urbanized area of Mombasa City by 1971



Map 4.14: Urbanized area in Mombasa by 2015

(Source: Mombasa Masterplan JICA Expert team, 2015)

4.1.8 Administration & Governance

Mombasa City is under the administration of the county government of Mombasa, a local government within the Kenyan devolved government system. The devolved government framework created 47 local governments in the entire country with two city counties one of them being the capital city Nairobi and the other being Mombasa, the second-largest city.

The county is administered by the county government, headed by a governor, and assisted by a deputy. The county administration is divided further into two, the first being assembly tasked with county legislation and the second being executive. The former is responsible for enacting county laws and is headed by the speaker. The latter on the other hand is concerned with policy formulation and implementation. It is further divided into departments that are tasked with the operations of the different sectors within the city (Figure 4.8).

Mombasa is both a city and a County and is classified into four zones which are Main Island, Mainland North, Mainland West, and Mainland South zones. The four zones constitute 6 sub-counties namely Changamwe Jomvu, Kisauni, Nyali, Likoni, and Mvita (Table 4.2). The lowest administrative unit is the ward represented by a Member of County Assembly (MCA). The city has a total of 30 wards which can also be considered the smallest population census unit.

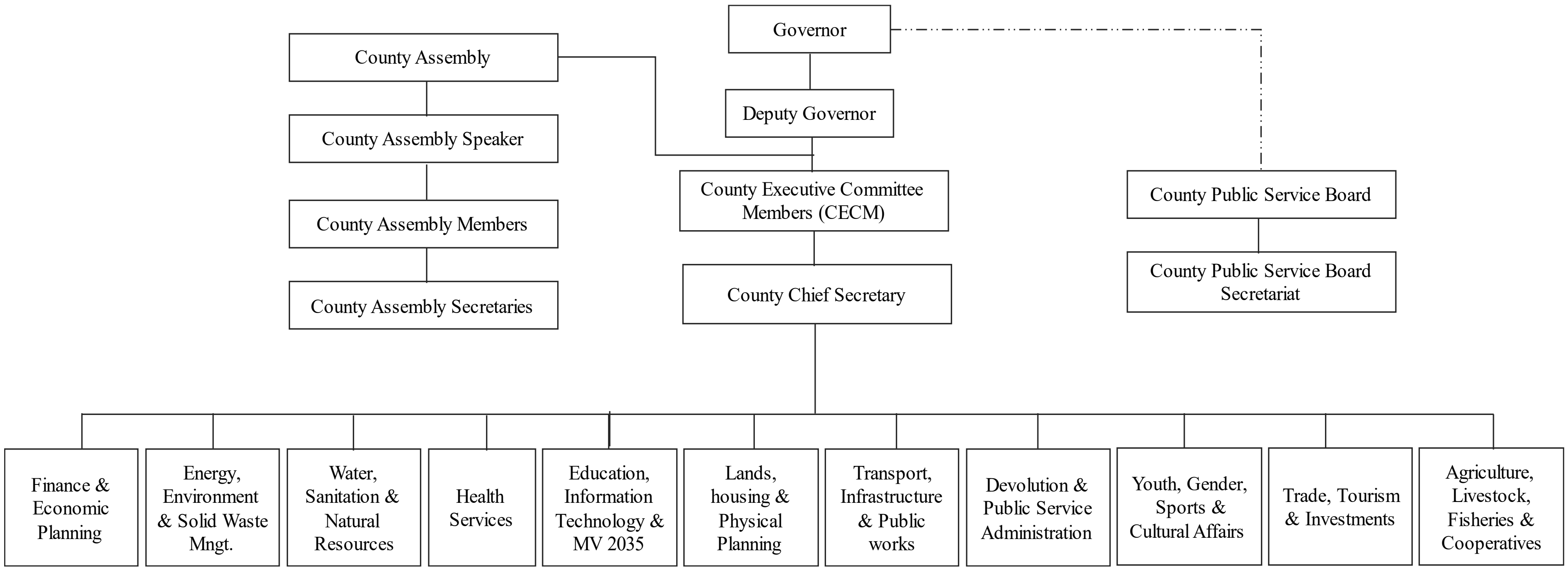


Figure 4.8: Governance Structure of Mombasa City County

(Source: Mombasa County Integrated Development Plan 2018-2022)

Table 4.2: Mombasa Zones

Zone	Subcounty	Ward		Population (2019 Census)	Area (km^2)
Island	Mvita	- Mji wa Kale / Makadara, - Tudor, - Tononoka,	- Shimanzi, - Ganjoni, - Majengo	154,171	14.40
Mainland North	Kisauni	- Mjambere, - Junda, - Bamburi, - Mwakirunge,	- Mtopanga, - Magogoni, - Shanzu	291,930	83.19
	Nyali	- Frere Town, - Ziwa La Ng'ombe,	- Kongowea, - Kadzandani - Mkomani,	216,577	22.79
Mainland West	Changamwe	- Port Reitz, - Kipevu, - Airport,	- Miritini, - Chaani	131,882	18.11
	Jomvu	- Jomvu Kuu, - Magongo,	- Mikindani	163,415	35.02
Mainland South	Likoni	- Mtongwe, - Shika Adabu,	- Likoni, - Timbwani - Bofu,	250,358	50.88

(Source: Author, 2021)

4.1.8.1 Island zone

It consists of the Mvita sub-county which is the most populated zone of the City. It also functions commercial and administrative centre of the metropolis. Other land uses included within this zone include Residential, Industrial, Port & Administrative functions.

4.1.8.2 Mainland North zone

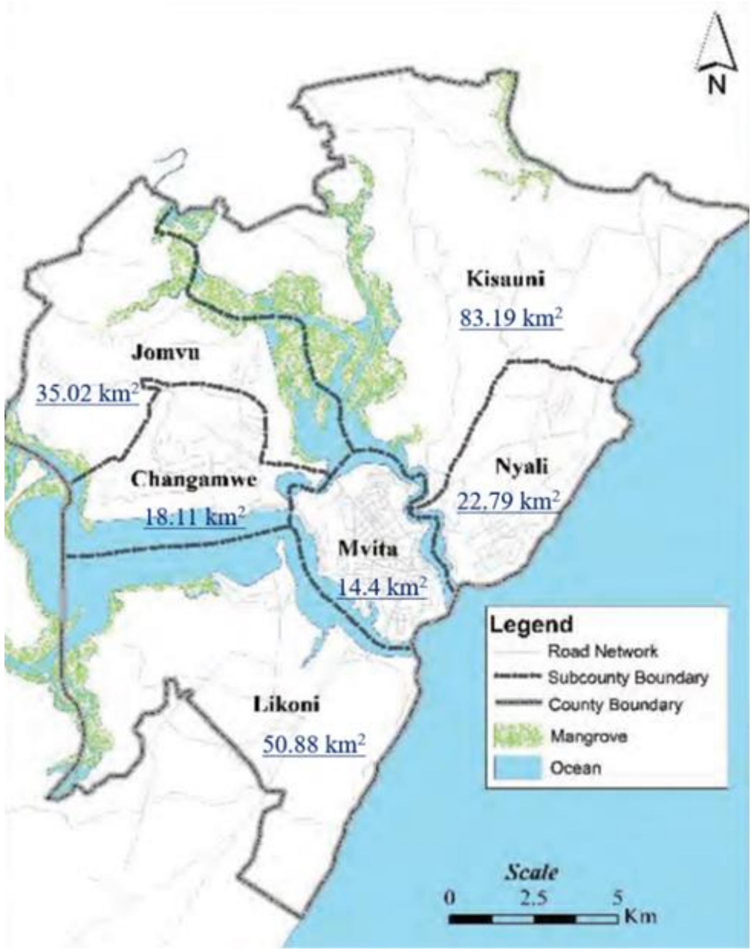
The mainland north zone consists of two sub-counties which are Nyali and Kisauni. The former is a low-density neighbourhood consisting of mainly high-income residential areas, whereas the latter is a high-density neighbourhood consisting of low-income residential areas. It houses the majority of the hotels within the city located along the Indian ocean shore.

4.1.8.3 Mainland West zone

This zone includes two sub-counties namely Jomvu and Changamwe. It primarily functions as the industrial, logistic, and transport zone of the city. It houses the port, airport, container freight stations. There are correspondingly several transport corridors in the zone newly constructed. These include the Southern-Bypass also known as Dongo Kundu bypass consisting of a dual carriageway stretching 8.96 km that connects Mombasa Mainland west (from Miritini) to Mainland South (Mwache) without having to go through the main Island as is currently the situation. Mombasa Northern Bypass connecting Mainland North (from Mtwapa) to Mainland West (Miritini) via Bamburi link road. Finally, the Standard Gauge Railway (SGR) that connects Mombasa city to Nairobi and Naivasha.

4.1.8.4 Mainland South zone

The mainland south has only one sub-county, Likoni which is primarily a low-income residential zone and constituting mainly immigrants from the different parts of the coastal region and Kenya.



Map 4.15: Mombasa Zones and Respective Administrative Boundaries

(JICA Expert Team, 2015)

4.2 Case study methodology

The case study research employed institutional data reviews and key informant interviews mainly through snowball sampling. This was necessary to obtain the relevant key informants who are more familiar with the city and understand the urban development and climate change dynamics of the city. Snowball is among the convenient sampling methods whereby a researcher identifies the first subject who then leads the researcher to other subjects until the desired sample is reached. This concept is discussed by Mahin et al., (2017) as being useful when a researcher faces some hindrances in accessing the desired subjects with the needed characteristics. Thus, in the context of this study, the method was useful in obtaining key informants who have an in-depth understanding of Mombasa city and are familiar with the ecological solutions either through their professional practice or studies undertaken.

A total number of 12 key informants were identified using snowball sampling however, 7 key informants were available for the interview conducted between 18th to 29th of May, 2021. They were done via online media, mainly through skype and WhatsApp calls, and averaged 40 minutes. The interviewees were professionals from a broad spectrum including NGOs, Community organizations, private consultancies, and the Mombasa county government (Table 4.3).

Table 4.3: Snowball Key Informant Interviewees

Name	Profession	Gender	Organization	Type
Interviewer #1	Urban Planner	Female	Mombasa County	Public
Interviewer #2	Urban Planner	Female	Mombasa County	Public
Interviewer #3	Marine Ecologists	Male	Cordio E.Africa	Private
Interviewer #4	Water Engineer	Female	Green water	Private
Interviewer #5	Environmentalist	Male	Provident	CBO
Interviewer #6	Environmentalist	Female	Freelance	NGO
Interviewer #7	Environmentalist	Male	Consultant	NGO

The network of the key informant interviewees started from #KF1 to #KF7 (Figure 4.9). Some key informants were referred to twice like interviewee #4 who was referred to by both key informants #KF2 and #KF3.

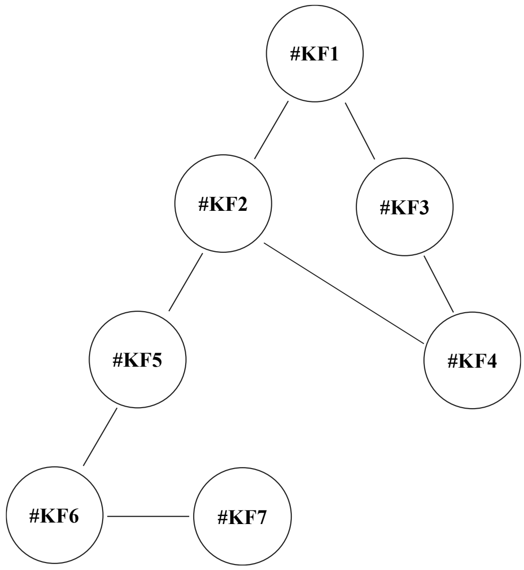


Figure 4.9: Snowball Network of Key Informants

The interviews intended to understand the general challenges of Mombasa city and interventions that have been put in place to help in addressing or reduce the challenges. It then narrowed down to climate-specific challenges facing the city in three broad areas identified in this study; these included Coastal, Urban and Wetlands, and creeks. The questions equally inquired on the measures already taken to address the climate change impacts already being experienced in the different parts of the city. Lastly, the interviewed sought key ecological interventions that can be employed to make the city more climate-resilient. The responses from the interviews were crucial in understanding the challenges of the city discussed ahead and also some of the nature-based solutions proposed in the next chapters.

4.3 Challenges facing Mombasa City

Mombasa City has faced several challenges over its urbanization history. In this report, the challenges are classified into two main categories which include traditional and contemporary challenges (Table 4.4).

4.3.1 Traditional challenges

These include the challenges that have existed over the cities urbanization history. Awuor et al., (2008), highlight the disasters that have stricken Mombasa city in its documented history to include El-Nino, frequent floods, tsunamis, Drought, and Hunger (Figure 4.10). These events have had severe impacts in terms of property destruction, loss of lives, increased incidences of water-borne diseases, starvation, and malnutrition (Awuor, 2008).

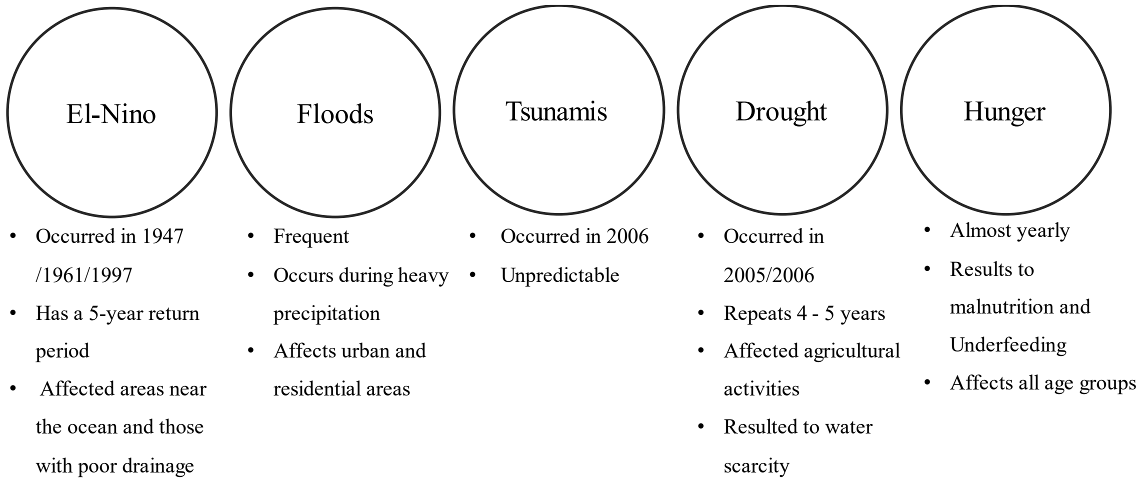


Figure 4.10: Timeline of Climate-related Disasters within Mombasa City

(Source: Adapted from Awuor C. et al., 2008.)

4.3.2 Contemporary challenges

The contemporary challenges refer to the most recent challenges attributed to rapid urbanization and climate change. The former includes the urban heat island effect, insufficient housing, mushrooming informal settlements, inadequate infrastructure, and services, poor waste management, environmental pollution, encroachment on riparian, urban inequality reserves among others (Rakodi et al., 2000). The climate-related challenges include increasing urban flooding, coastal erosion, bleaching and death of coral reefs, increasing water scarcity, reduction in biodiversity and Mangrove species, increasing temperatures, food insecurity, saltwater intrusion, and wetland pollution among others. (Maarifa & Tole, 2003; Kabede et al., 2012; Njoroge, 2014; Ngare et al., 2020).

,

Table 4.4: Traditional & Contemporary Challenges of Mombasa City

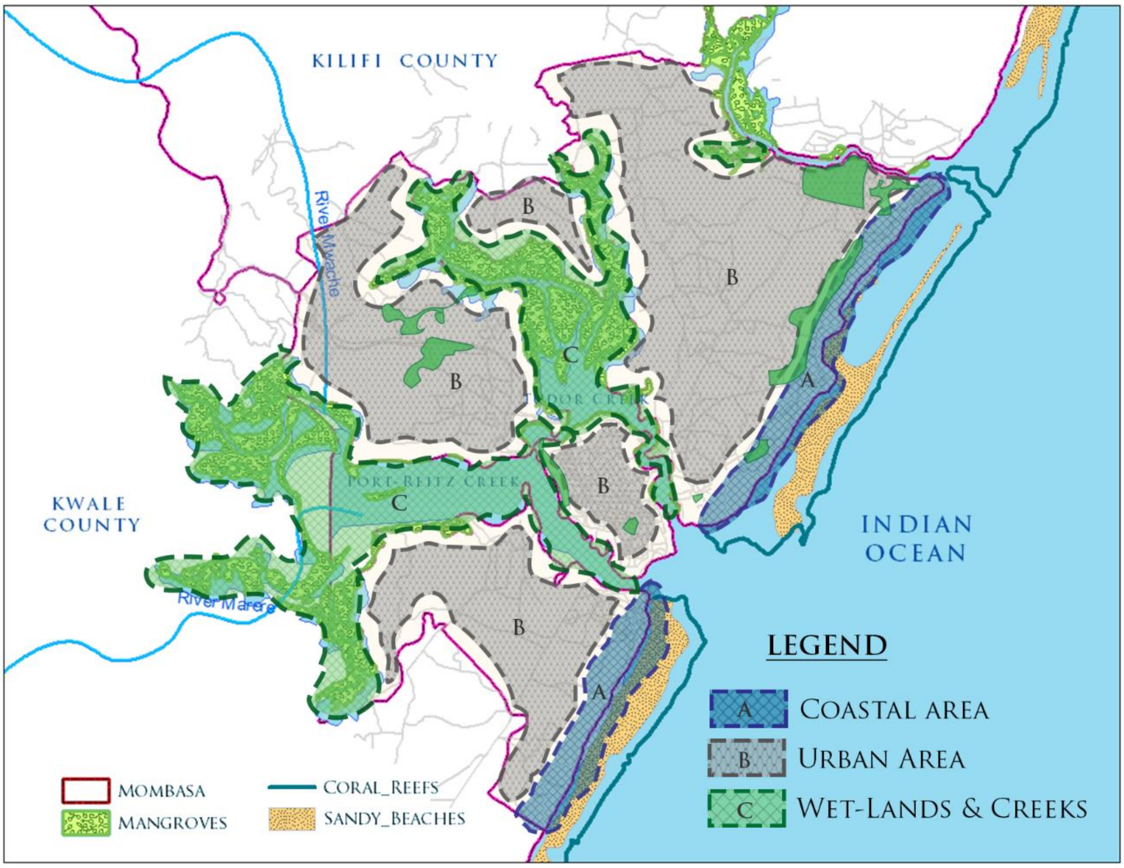
Traditional Challenges	
Weather-related	▪ El-Nino ▪ Drought ▪ Flooding ▪ Tsunami ▪ Food Insecurity
Contemporary Challenges	
Urbanization related	▪ Urban heat island effect ▪ Inadequate Housing ▪ Informal settlements ▪ Urban sprawl ▪ Inadequate Infrastructure and service provisions ▪ Poor waste management ▪ Environmental Pollution ▪ Encroachment on riparian reserves
Climate Change related	▪ Urban flooding ▪ Coastal erosion ▪ Loss of biodiversity: Mangrove & Coral Reefs ▪ Water scarcity ▪ Drought ▪ Food Insecurity ▪ Increasing temperatures ▪ Extreme weather events

(Source: Author, 2021)

The main focus of this thesis are the climate change-related challenges facing Mombasa city, the nature of the challenges, and the geographical locational context of the vulnerable area.

4.4 Climate-related challenges

This section discusses the climate-related challenges facing Mombasa city in detail by the specific vulnerability zones (Map 4.17). The vulnerability of Mombasa city can be classified into three zones. These include - Coastal area which is mainly the area along the Indian ocean labelled A in the map below. The second category is the Urban area comprising of developed areas. The last category is the wetlands and creeks areas consisting of mangroves, marshes.



Map 4.16: Spatial Distribution of Vulnerability in Mombasa City

(Source: Author, 2021)

Each vulnerability area has its unique climate-related challenges depending on its environmental and geographical context (Figure 4.11).

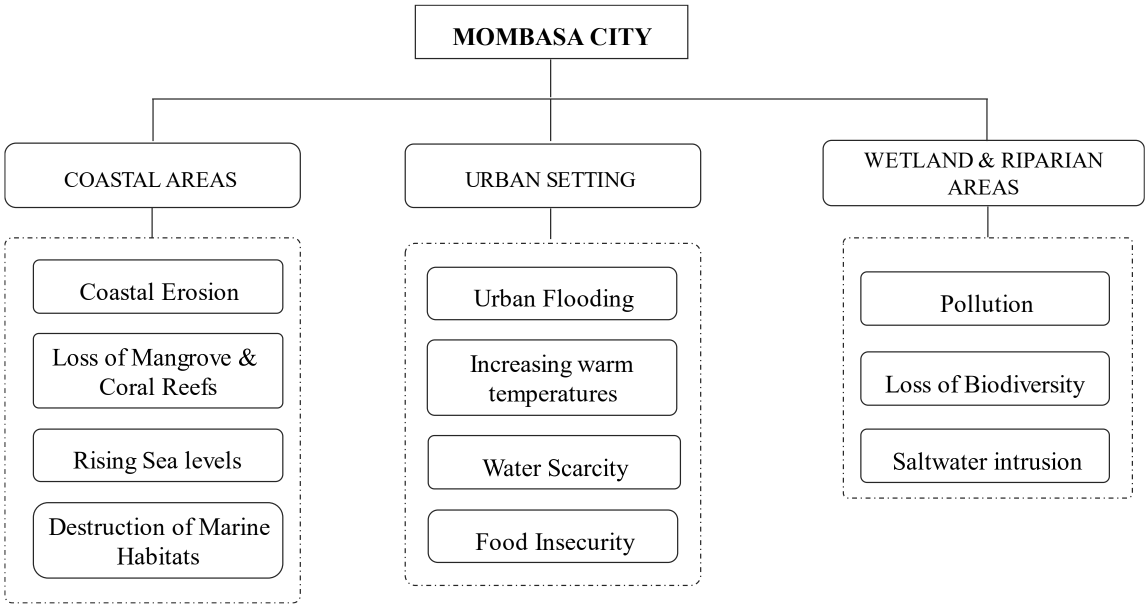


Figure 4.11: Climate-related Challenges in Mombasa City
(Source: Author, 2021)

4.4.1 Coastal Area Challenges

Mombasa city enjoys approximately 30 km of coast shoreline along the Indian ocean (Google Maps, 2021). This, consequently, exposes the city to several coastal challenges resulting from climate change. These include flooding of low-lying coastal areas and erosion[3], increasing levels of the ocean, Destruction, and reduction of biodiversity, mangroves and coral reefs species, loss of marine habitats among others.

4.4.1.1 Coastal flooding and erosion

The areas of Mombasa city vulnerable to erosion and flooding are mainly the low-lying zones found in Mainland North, around Bamburi, causing environmental degradation, destruction of breeding areas, and also causing economic losses. This zone houses, hotels, residential areas, educational institutions, and commercial activities among others. In the steep shores of the city active erosion is evident with the rate of about 0.15m/month to 0.22m/month of the shoreline (Mwakumanya & Tole, 2003). Among the proposals that can be adopted to curb the issue include laying down measures such as planting mangroves to dissipate the wave energy before it breaks on the shoreline.

[3] Interviewee #3 on coastal challenges facing Mombasa

Plate 4.9: Coastal Erosion along the Shoreline

4.4.1.2 Loss of Biodiversity for Mangroves and Coral reefs

The loss of mangrove species is among the significant challenges experienced in Mombasa[4]. it is mainly attributed to anthropogenic factors and neglect. However, efforts have been enacted through community sensitization to plant and protect mangrove forests along the creeks and the Indian ocean. The species of coral reefs on the other hand have equally been destroyed as a result of rising sea temperatures leading to bleaching and also sedimentation from rivers during severe weather incidences.

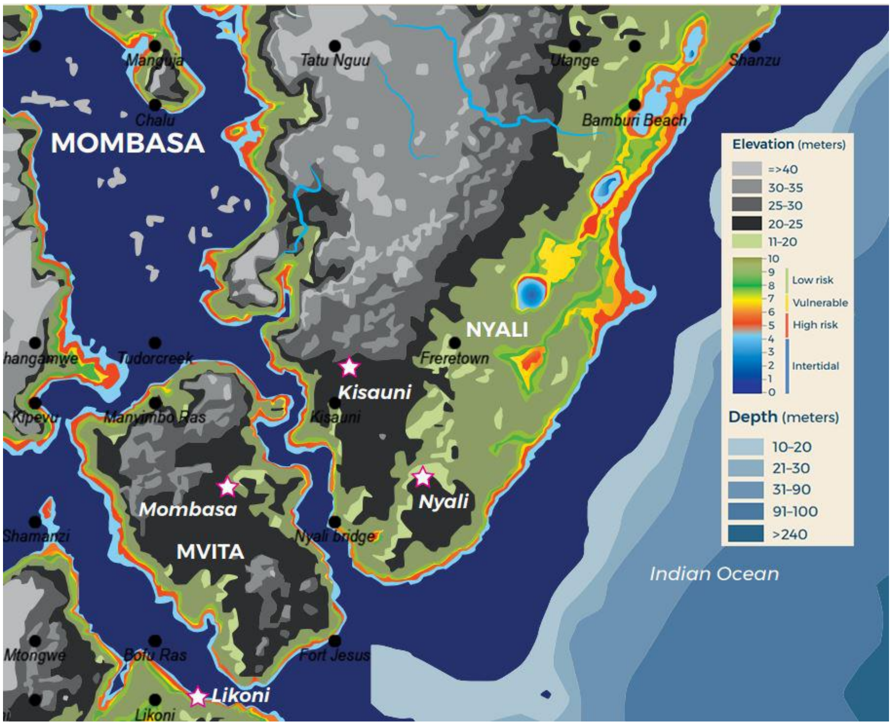
Plate 4.10: Destruction of Mangrove and Corals

4.4.1.3 Rising sea levels

The increasing levels of the Indian ocean pose a challenge to the low-lying areas in the mainland north and some parts in the mainland south. However, the main island

[4] Interviewee #6 on death of Mangrove at Tudor Creek in Mombasa

which is also the central district is raised on a carbonate rock about 6m above the current high tide levels (Obura, 2020). The areas exposed to sea rise flooding include areas of Bamburi Shanzu and some parts of Freretown and Changamwe (Map 4.18).



Map 4.17: Flood Mapping & Flood-prone areas in Mombasa City

(Source: Obura D., 2020)

The red zones in map 4.18 show the areas most prone to coastal flooding whereas the grey zones are the least affected areas. The analysis is based on the elevation of the respective zones starting from the ocean level, 0 meters to the topmost level of 40 meters. The classification is divided into four zones. The lowest being the Intertidal zone starting from 0-4 meters mainly including beach areas and creeks. The second category is the high-risk zone ranging from 4-6 meters. It includes the areas around Bamburi and some parts of Nyali and Tudor Creek. The third category is the vulnerable zone between 7-8 meters and includes significant parts of Shimol la Tewa and Shanzu. The last category is the low-risk zone lying between 8-10m and includes a greater percentage of Mainland North.

4.4.1.4 Destruction of marine habitats

The destruction of marine habitat is attributed to both coastal erosions, warming of the Indian ocean, and also human-induced practices including pollution and destructive fishing practices.

4.4.2 Urban Area Challenges

Mombasa City County is the only city in Kenya where the entire population is urban (KNBS Population Census, 2009). Correspondingly, the city is the smallest county in Kenya with geographical coverage of 222.82 km^2. Owing to the small geographical area and rapid urbanization the city has a higher population density and a rapid urbanization rate, thus experiencing considerable development challenges. The climate-related challenges experienced in the urban setting of Mombasa include Urban flooding, Increasing urban temperatures, water scarcity, and food insecurity.

4.4.2.1 Urban flooding

Flooding in the city of Mombasa is a common phenomenon and has become more frequently linked to heavy precipitation associated with climate change. Among other factors exacerbating the situation include increased pervious surfaces, inadequate and clogged drainage systems as a result of poor waste management, lack of detention areas to allow slow infiltration, insufficient stormwater management practices, among others.

Plate 4.11: Urban flooding within Mombasa city

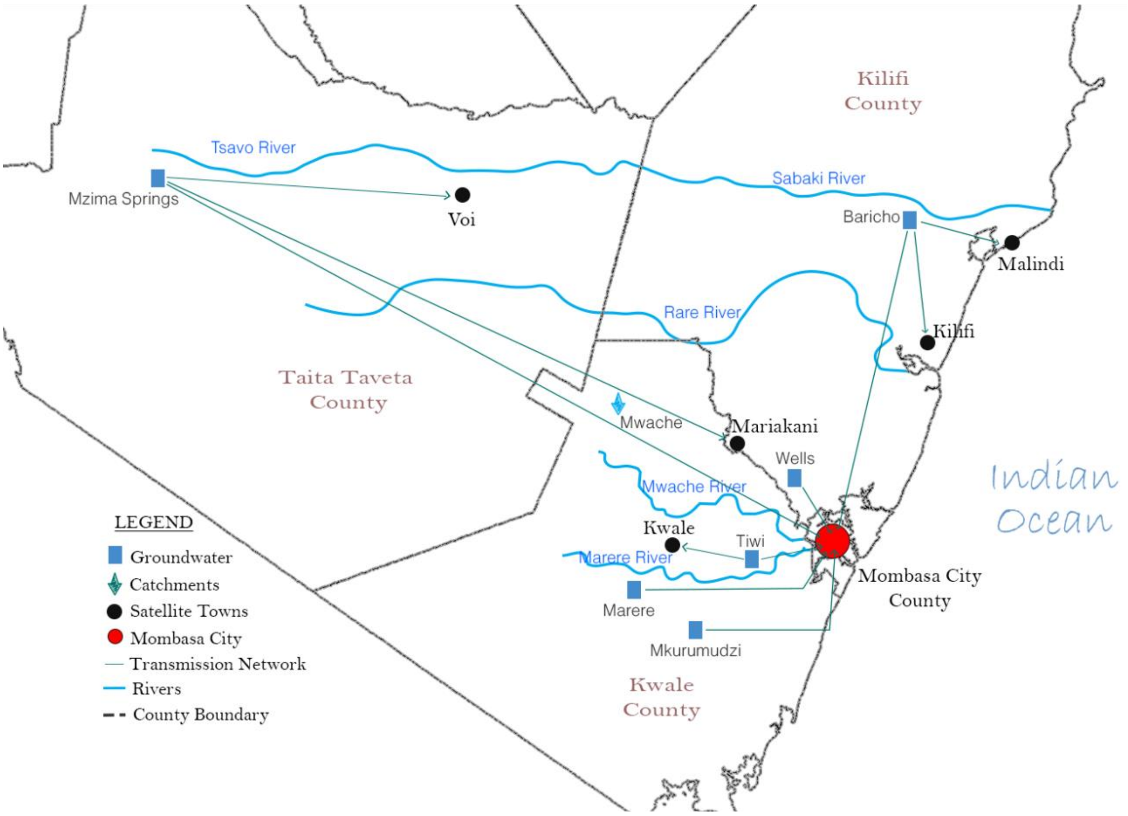
4.4.2.2 Increasing urban temperatures

Mombasa city has high average temperatures and humidity standing at 27 and 65 per cent, respectively. The temperatures and humidity have been increasing to the extent of uncomfortable levels (Awuor et al., 2008). This is attributed to several factors including the changing climate patterns, effects of the urban heat island phenomenon, and inadequate softscapes within the city. Increasing temperatures within the city are anticipated to have negative effects such as heat stress (on land and sea)[5], ecosystem disruption, loss of biodiversity, and increased energy demand for cooling purposes.

4.4.2.3 Water scarcity

The increasing population within Mombasa city has resulted in increased demand for water for both drinking and domestic consumption. Mombasa City primarily sources water from reservoirs outside the county and supplements with boreholes. However, the changing weather conditions have resulted in a reduced availability of the resource resulting in rationing of water services. As of 2016, the county had a water supply deficit of 152 million litres (152,000m^3) of water in a day with a total demand of 200 million litres (200,000m^3) daily, yet receiving only 48 million litres (48,000 m^3) per day. The issue is exacerbated by dilapidated water distribution infrastructure that results in water leaking and reducing the efficiency of the distribution network. This deficit is fulfilled by some digging boreholes and private water suppliers. It also creates a situation of excessive rationing to the extent of some areas receiving 3 times in a week[6]. Alternative water sources are being explored such as desalination and the construction of dams to increase water supply. NBS interventions and water-sensitive urban design can equally assist in addressing the water challenge in Mombasa City. The main aquifers and water sources of Mombasa City include Baricho in Kilifi Count, Mzima spring in Taita Taveta County and Marare and Mkurumudzi from Kwale County. These sources are connected to Mombasa and other satellite towns via transmission links (Map 4.18).

[5] Interviewee #1on increasing temperatures in Mombasa
[6] Interviewee #5 on water rationing in Mombasa



Map 4.18: Water Sources & Catchment area of Mombasa City

(Source: Adopted from Ojwang et al., 2017)

As depicted by map 4.18, most water sources are springs, wells and rivers, vulnerable to drought and extreme weather conditions. There is a need to explore other options such as rainwater harvesting and desalination of seawater to boost water security within the City.

Plate 4.12: Water Scarcity and Long queues of people fetching water

Plate 1.12 show people queuing to access water with their 20-litre water gallons. With increasing drought within the region, water scarcity is anticipated to be more severe if alternative water sources are not explored.

4.4.2.4 Food insecurity

Food insecurity is a critical aspect within the city, with the increasing urbanization rates and changing weather conditions, food insecurity is significant within the county more so in the informal settlements (Integrated Food Security Phase Classification, 2020). The city has mainly small-scale farmers in its peri-urban areas who primarily rely on rainfed agriculture. The city relies on the Kenyan hinterland and neighbouring countries such as Tanzania for vegetables and fresh products. However, the changing weather patterns are adversely affecting the agricultural productivity within the City and also the other parts of the country.

4.4.3 Wetlands and Creeks

Tudor and Port-Reitz Creeks are the main wetlands and riparian reserves within Mombasa. The wetlands are affected by factors such as pollution, loss of biodiversity, and saltwater intrusion.

4.4.3.1 Pollution

The city lacks a proper waste management system thus resulting in pollution of wetlands and creeks. This in turn affects biodiversity and marine organisms.

Plate 4.13: Wetland Pollution in Creeks and riparian reserves

4.4.3.2 Loss of biodiversity

This challenge is attributed to both anthropogenic and climatic factors. The climatic factors include rising levels of the ocean, increasing water temperatures warming the ocean which in turn result in coral reefs bleaching and corresponding death. It also results in the loss of mangrove species within the wetlands and creeks.

4.4.3.3 Saltwater intrusion

Saltwater intrusion is attributed to the rising sea levels, which results in seawater intruding the inland wetlands which serve as breeding habitats for marine. As a result, it reduces the fish levels which in turn affects the fishing activities resulting in economic damages to fishermen. In the estuaries, it affects freshwater biodiversity and plant species too.

4.4.3.4 Erosion and Sedimentation

This challenge is prevalent mainly during heavy precipitations. Due to inadequate best practices of stormwater management, the city experiences heavy runoff in a strong precipitation event. The wetlands receive the runoff along with waste and silt causing pollution, siltation, and also eroding the banks.

4.5 Discussion

Mombasa city faces several climate-change-related challenges as discussed above. The prominent ones include extreme weather events consisting of increasing temperatures and scarce intense rainfall patterns within the urban areas which often cause uncomfortable temperatures and urban flooding respectively. Extreme weather events have equally extended the dry periods within urban areas resulting in water scarcity and food insecurity affecting a significant percentage of the population. On the other hand, incidences of coastal erosion and sea rise along the coastline have been equally on the rise necessitating the construction of seawalls in some sections of the coastline such as the Fort Jesus area and some parts of Bamburi as a response to rising tides. The wetlands and Creeks areas have also been experiencing biodiversity loss primarily the death of mangroves which correspondingly serve as fish breeding habitats. This has been worsened by anthropogenic factors including the felling of mangroves, mushrooming informal settlements on wetlands, and poor solid and liquid waste disposal practices. These challenges, therefore, call for sustainable ecological interventions to ensure environmental sustainability, urban resilience, and climate adaptation in the urban ecosystem.

The nature-based intervention that can be adapted to address the coastal erosion challenge and rising sea levels in Mombasa could include the planting of mangroves and seagrasses along with the vulnerable parts of the coastline and the areas close to human settlements. This would help stabilize the sediments and prevent erosion while also protect the shoreline from a storm, strong waves, and floods. The mangroves would equally enhance water quality and filter pollutants thus improving the general health of the marine ecosystem. In areas around Nyali and Bamburi restoration of vegetated dunes and salt marshes could help in stabilizing the shoreline and control coastal flooding and erosion. The death of coral reefs on the other hand could be mitigated by enforcing sustainable agricultural practices upstream and areas adjacent to the shore thus reducing over-reliance on pesticides and destructive cultivating practices that could lead to erosion and sedimentation downstream. Sustainable management of the stormwater runoff within urban area basins that feed into the ocean should equally be encouraged to minimize runoff, pollutants, and sediments deposition into the ocean. Proper management of solid waste and civic education on the importance of coral reefs is equally necessary to ensure the protection of coral reefs. This would in turn create a flourishing environment for coral reefs, increase marine ecosystem biodiversity and in turn restore economic activities and livelihoods of local communities dependent on the marine ecosystem for their sustenance.

Among the NBS strategies able to address the increasing temperature in Mombasa include increasing trees and vegetation within urban areas. Trees modify local climate by lowering surface and air temperatures via providing shade and also enhances urban cooling through evapotranspiration. In the context of urban areas, trees can be planted along streets, parking lots, residential lawns, utility corridors, parks, and urban voids. This would in turn reduce extreme temperatures within urban areas and also enhance stormwater infiltration by increasing softscapes within urban areas. Urban flooding caused by extreme rainy events could be mitigated by: rainwater harvesting, creating green roofs and rooftop gardens, permeable pavements, increasing natural open spaces, constructed wetlands, bioswales, and bioretention areas. These solutions can be implemented at the edges of parking lots, sidewalks, streets, residential neighbourhoods, and compacted lawn areas. Roof gardens and green roofs on the other hand can be implemented on the rooftops of commercial and residential buildings within the city. These measures form a wider network of sustainable urban drainage systems that can slow down stormwater runoff thus increasing the time of infiltration while reducing the overwhelming of the drainage systems. The measures could equally enhance water security within the city since the harvested rainwater could be diverted for domestic consumption. Stormwater infiltration would enhance ground aquifer recharge hence restoring and improving the quality of groundwater as well.

In the context of creeks and wetlands in Mombasa, loss of biodiversity has been a significant challenge, mainly loss of mangroves in areas such as Tudor and Mwache Creeks. This is a primarily human-induced factor as a result of felling mangroves for aquaculture, construction and coastal development, and commercial reasons among other factors. However, there are also climate-related factors mainly due to sedimentation and erosion. This situation can be remediated via promoting conservation and restoration of mangrove forests while also enhancing sustainable agricultural practices upstream that would reduce erosion, excessive use of pesticides, and sedimentation downstream. Correspondingly, proper solid and liquid waste management could equally reduce pollution of the creeks and wetlands. Constructed wetlands can greatly enhance the management of liquid waste through the provision of measures to treat raw sewage, agricultural and industrial effluent before releasing to wetlands and creeks as it is at the moment in the case of Shimo La Tewa prison. Recycling should be encouraged to reduce solid waste generation and composting can be done for organic waste generated from Kongowea and Marikiti markets among other fresh produce markets within the city. Civic education on recycling and waste handling are equally important to the local community to ensure proper waste management from the household level to a city-wide scale.

Table 4.5: Summary of NBS Interventions for Mombasa City

Vulnerability Zone	Problem	Proposed NBS Intervention
Coastal Areas	Coastal Erosion & Flooding	- Planting and Restoring Mangroves - Planting seagrasses
	Rising sea levels	- Restoring vegetated dunes

		- Planting Mangroves
	Coral reefs loss	- Proper solid waste management along with coastal areas - Civic education on coral reefs - Promoting sustainable agricultural activities like using biological methods to control pests and rotating crops among others.
Urban Areas	Increasing urban temperatures	- Planting of trees along streets and sidewalks, utility corridors, parking lots, residential lawns - Increase more natural surfaces - Using permeable pavements in parking lots, sidewalks
	Urban flooding	- Creating green roofs and rooftop gardens in buildings - Permeable pavements along sidewalks and parking lots. - Constructed wetlands - Constructing bioswales and bioretention - Rain gardens - Softscapes with natural shrubs & vegetation - Increase and trees
	Water scarcity	- Rainwater harvesting - Recycling of wastewater like constructed wetlands & Waste stabilization ponds. - Education & awareness on water conservation - Alternative water sources: e.g., Desalination
Wetlands & Creeks	Loss of biodiversity	- Conservation and restoration of mangrove - Ensure sustainable agricultural practices - Planting of natural vegetation

	Destruction of fish habitats	- Planting of mangroves - Native revegetation
	Pollution	- Recycling of waste - Composting of organic waste - Proper handling of stormwater runoff

4.6 Strategic Implementation of NBS in Mombasa City

The implementation of NBS requires strategic planning, cooperation and mobilization of different agencies, private and governmental departments, policies, and financial resources from different agents to ensure successful implementation. Below is a breakdown of the implementing agencies of the different NBS interventions based on the three broad areas of the vulnerability identified above, which include Coastal Areas, Urban Area and Wetlands & Creeks.

4.6.1 Coastal Areas

The implementation of nature-based interventions within the coastal areas would require liaising of the different county government departments, community and national government authorities and bodies. These include authorities such as the National Environmental Authority, Fisheries and Marine Research Institute, the County Department of Environment, Agriculture & Fisheries and Kenya Wildlife Services among others (Figure 4.13).

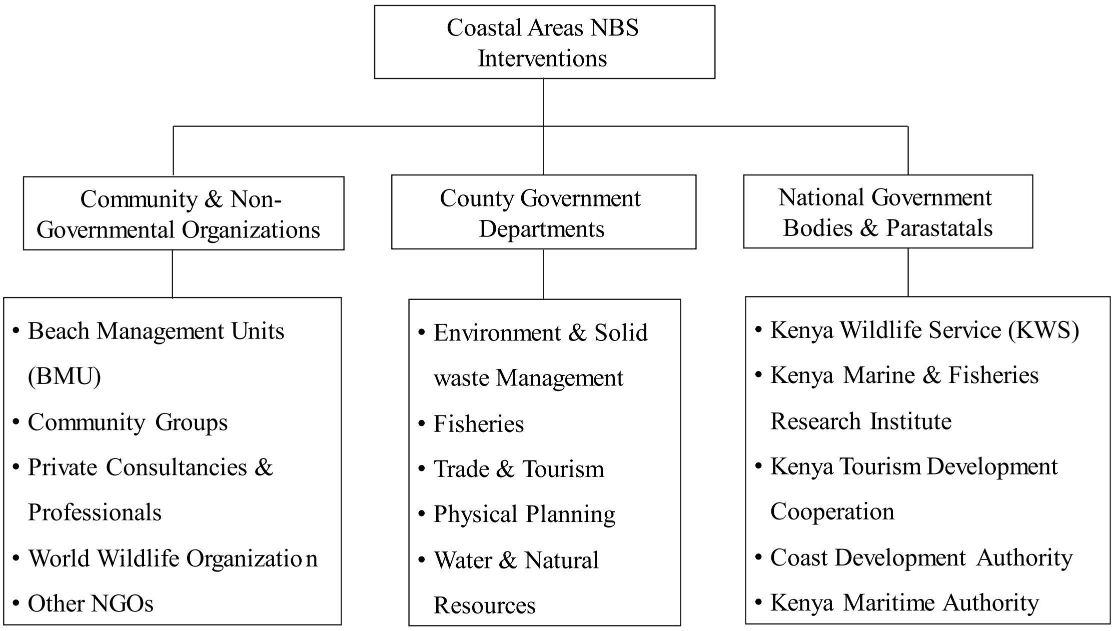


Figure 4.12: Coastal NBS Intervention Implementation Agencies in Mombasa City

Figure 4.14 shows an illustration showing a cross-sectional view of Coastal NBS interventions applicable in the context of the Mombasa Coastline. Map 4.19 on the other hand illustrates the spatial of the coastal zone within Mombasa city and applicable NBS interventions.

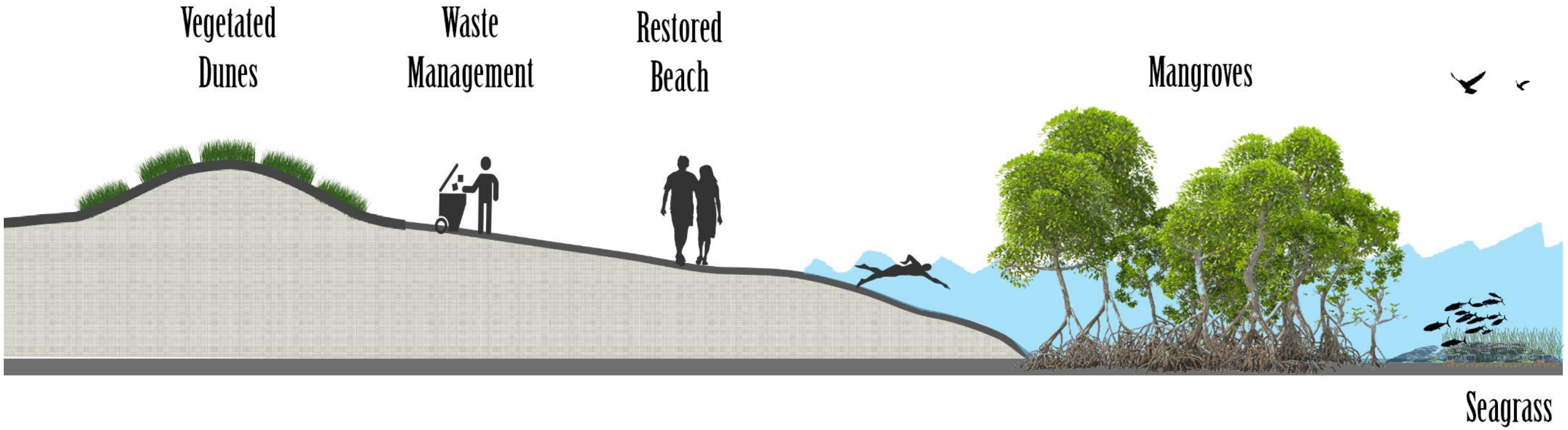
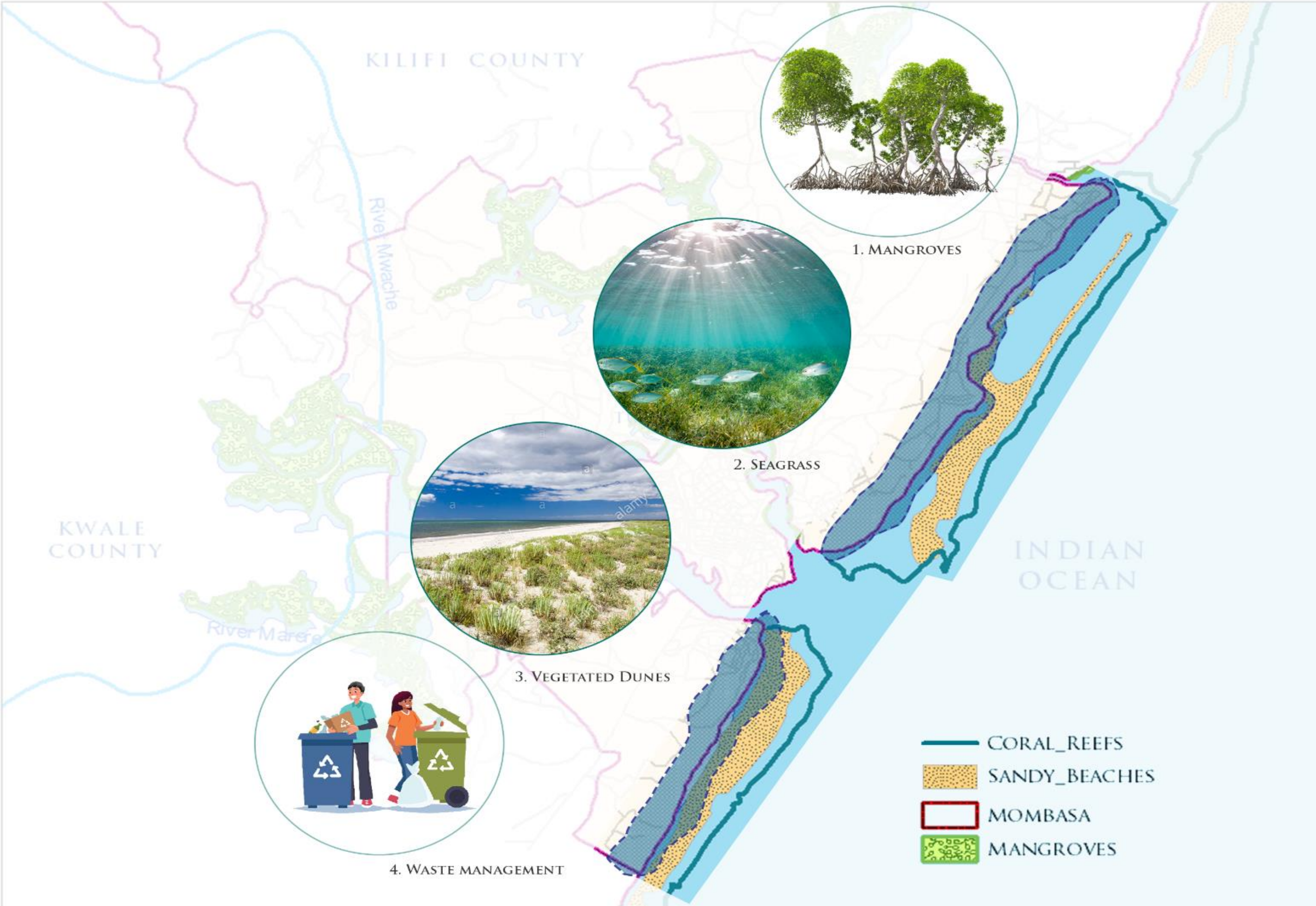


Figure 4.13: A cross-sectional illustration of NBS solutions in Coastal Mombasa

(Source: Author, 2021)



Map 4.19: Mombasa Coastal Area NBS Interventions

4.6.2 Urban areas

NBS intervention within the urban context would require interventions from a variety of stakeholders at different levels. It includes the community, civil societies, international development agencies, county government agencies, national government agencies and other relevant stakeholders within the urban arena. In areas where there is an overlap of functions such as urban roads maintenance like Kenya Urban Roads Authority (KURA) and the county department of transport and Infrastructure, there is a need for an inter-departmental agency consisting of either side to foster the implementation of the solutions. Several key players are needed to facilitate the smooth implementation of NBS solutions within the urban context of Mombasa City (Figure 4.15).

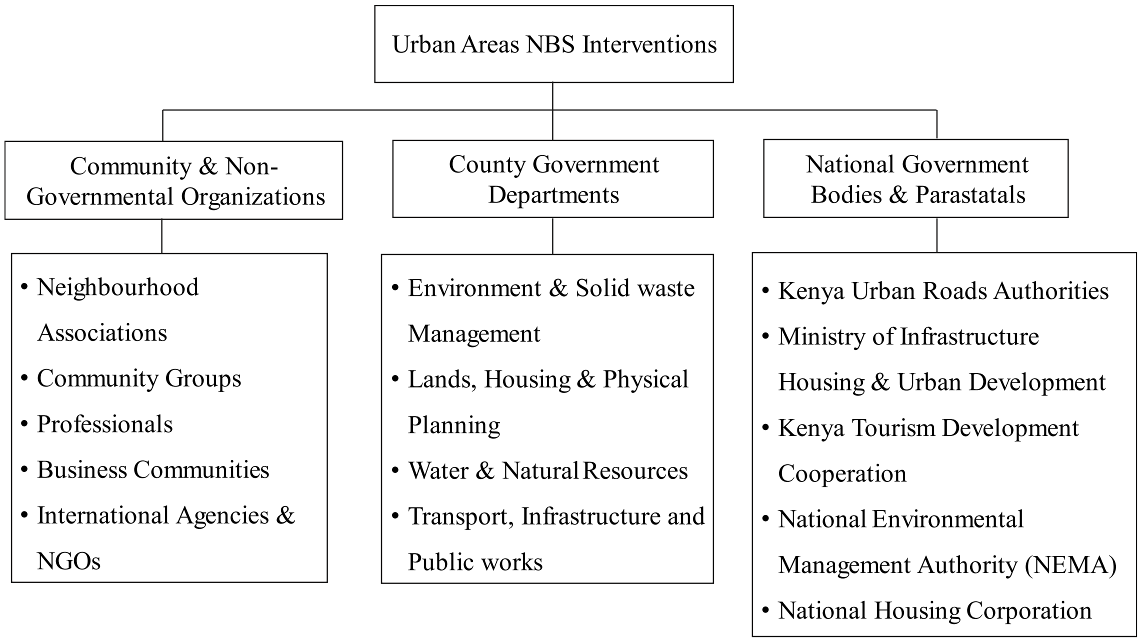


Figure 4.14: Urban NBS Intervention Implementation Agencies in Mombasa City

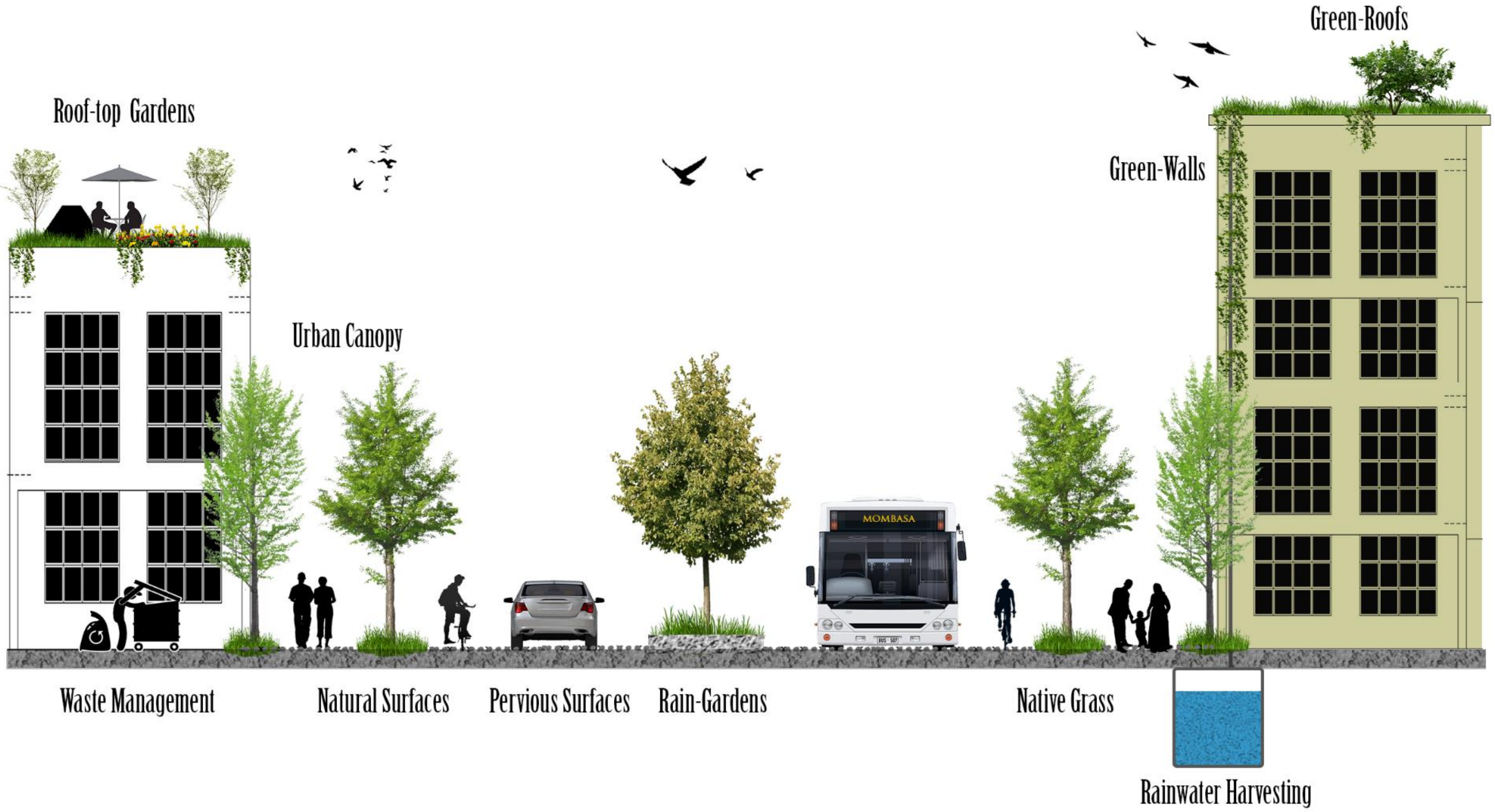


Figure 4.15: A cross-sectional illustration of NBS solutions in the Urban area of Mombasa

(Source: Author, 2021)

Map 4.20: Mombasa Urban Area NBS Interventions

4.6.3 Wetlands and Creeks

In the context of wetlands and creeks collaboration of different actors within the city is essential to realise the fruitful implementation of the NBS interventions. However, a regional coordinated effort and perspective are fundamental since most of the wetlands are cut across different counties and also originate from areas outside Mombasa City. Regional bodies such as Coast Development Authority (CDA) can play a critical role in ensuring efficient wetland and creeks management within Mombasa and its environs (Figure 4.17).

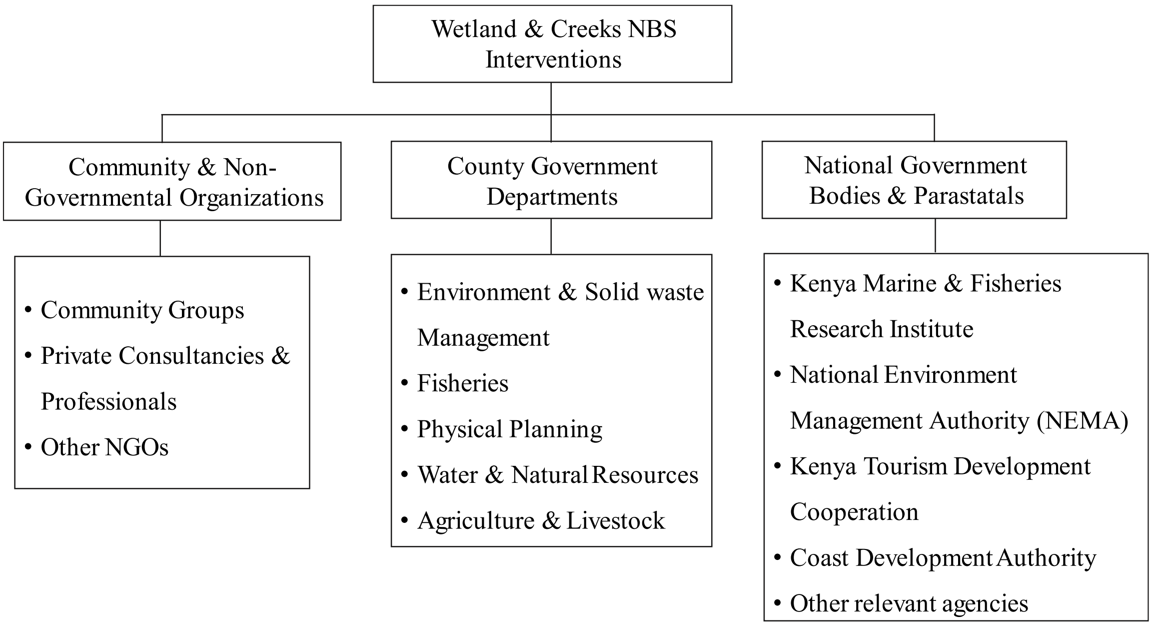


Figure 4.16: Wetland & Creeks NBS Intervention Implementation Agencies in Mombasa City.

Map 4.21: Mombasa Wetlands & Creeks NBS Interventions

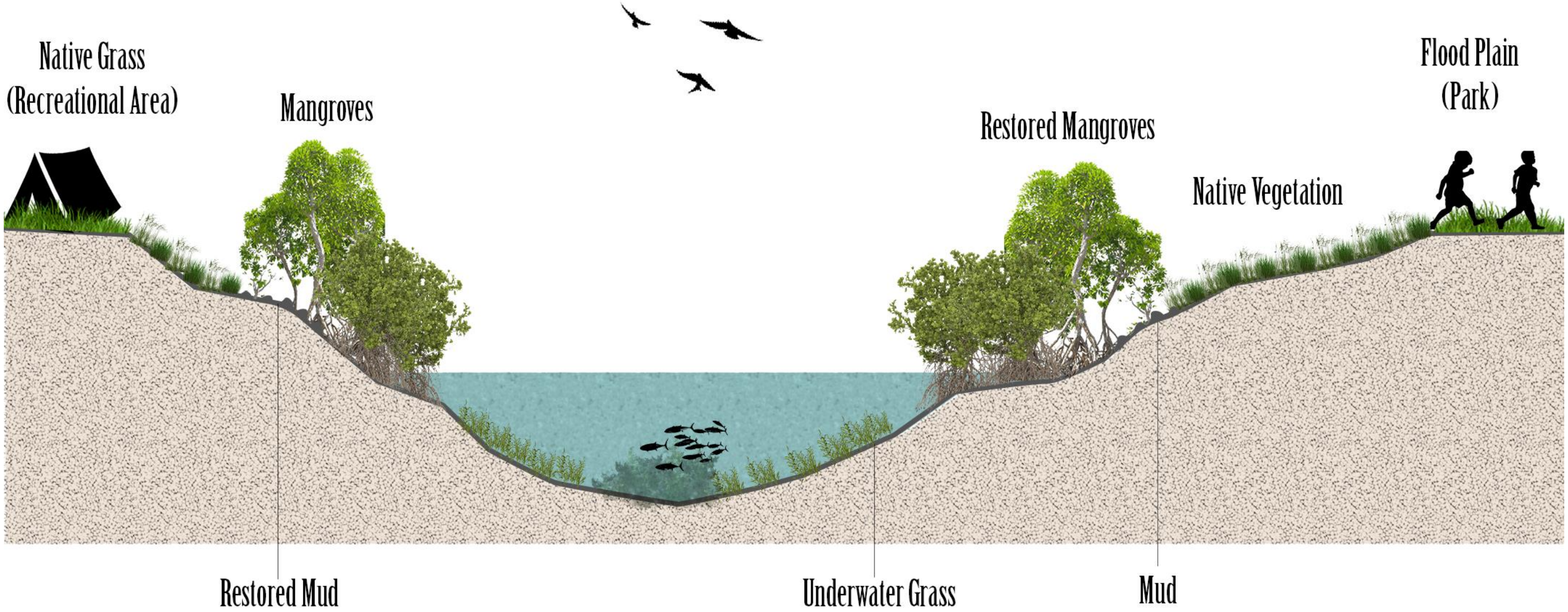


Figure 4.17: A cross-sectional Illustration of NBS solutions in Creeks & Wetlands of Mombasa

(Source: Author, 2021)

4.7 Bottlenecks of NBS implementation in Mombasa

The bottlenecks towards implementation of NBS interventions in Mombasa include inadequate awareness by both the local communities and the authorities on nature-based solutions and their importance, poor prioritization of development projects[7], lack of technical capacity on implementation of the solutions, inadequate funds, competition of space with other uses within the main urban area, reluctance to accommodate new ideas, the conflict between agencies within national and local government rendering slow implementation of development projects. These are further discussed below.

4.7.1 Inadequate awareness

NBS solutions are still new and not well comprehended by the majority of the people within Mombasa city ranging frompolicymakers to the community at large. Thus, the NBS implementation efforts could be impeded by a lack of awareness of the different strategies available and how a disregard for the potential benefits to the city and society. This factor correspondingly contributes to the lack of the desired technical knowledge for implementation and monitoring and evaluation after the implementation of the projects. To fully exploit the advantages of NBS solutions, there is a need to establish awareness and sensitization of the strategies amongst the communities and the relevant authorities.

4.7.2 Weak technical capacity

Successful implementation of the NBS strategies requires sufficient technical capacity in understanding the functioning of the ecosystem. It further necessitates an adequate knowledge of designing the strategies, implementation of the solutions and also the post-evaluation and maintenance. This also includes evaluating the economic benefits of the solutions and appreciating the probable trade-offs including optimization of the available level of expertise. This challenge can be dressed through multi-level cooperation between the different County departments, National governments agencies, NGOs, Private Consultants, and other key stakeholders to share skills and expertise in the NBS implementation.

[7] Interviewee #1 on development challenges in Mombasa

4.7.3 Insufficient funding

Some NBS solutions require significant funding in the initial implementation and also maintenance to ensure they operate to their optimal capacity. Mombasa City being a relatively low-income city, there are competing needs of financial resources whereby authorities struggle to distribute the meagre resources in addressing other pressing development challenges such as inadequate housing, solid and liquid waste management, inadequate infrastructure, and services among others. To address this issue, there is a need to involve a variety of stakeholders in the implementation of NBS and explore the different options of public-private partnerships to ensure their success.

4.7.4 Inadequate space

In the developed within the island zone of Mombasa, the land is a scarce commodity and has several competing uses such as housing, businesses, administrative functions, and heritage areas earmarked for preservation. Hence the area CBD of Mombasa City lacks adequate room to implement space-intensive NBS interventions such as constructed wetlands and flood plains among others. Thus, the island areas can accommodate fairly small scale NBS proposals such as trees, parklets, permeable pavements and urban greenery among others.

4.7.5 Bureaucracy & Conflicting roles

The approval processes of many projects take substantial time and involve several processes[8]. This is further exacerbated by the several departments involved in the urban environment arena such as Public Health, Department of Environment, National Environment Management Authority (NEMA), Department of Infrastructure and Public Works and Department of Physical Planning among others. This issue can be addressed through the harmonization of the roles in environmental management to an interdepartmental agency that will consist of members drawn from the different departments. This will foster the prompt implementation of NBS and other environmental-related projects

[8] Interviewee #5

Successful implementation of nature-based solutions within Mombasa would require addressing the highlighted bottlenecks to ensure the optimal realization of the benefits to be derived from the NBS interventions (Table 4.6).

Table 4.6: Bottlenecks & Accelerants of NBS in Mombasa City

Bottleneck	Accelerant
Scanty awareness by communities & authorities	Create awareness Campaigns, Information dissemination & Citizen science
Inadequate technical capacity	Conduct Capacity building workshops & Multidisciplinary collaboration
Insufficient funding	Explore PPPs, Multi-agency funding & Community Engagement
Inadequate space in fully urbanised areas	Adopt small scale NBS interventions within the more developed areas e.g., Green-streets, Parklets & Pervious surfaces.
Bureaucracy & reluctance to change	Establish an inter-departmental agency to steer NBS implementations

4.7.6 Bottlenecks in relation to NBS criticism

This section highlights the relationship between the bottlenecks of NBS implementations in Mombasa City and the overall criticisms of NBS interventions as discussed in the literature review section. It explains how the different NBS criticisms are connected to the implementation bottlenecks within the city (Table 4.7).

Table 4.7: NBS Criticism in relation to implementation Bottlenecks

NBS criticism	**NBS Bottleneck in Mombasa City**
The varieties of problems to be solved	Scanty awareness on the range of issues that can be addressed via NBS
The integrity of Naturalness of solutions	Inadequate technical capacity to maximize on NBS devoid altering the natural ecosystem
Full consideration of advantages and Disadvantages	Inadequate technical capacity to identify the full spectrum of pros and cons
Handling complex urban challenges	Scanty awareness and information relating to the scale and complexity level of issues to be addressed by NBS
Degree of non-structural & social innovations	Inadequate technical capacity and funding to research and develop social innovations related to NBS
Inclusion of all crucial stakeholders	Bureaucracy and scanty awareness resulting in the neglect of some crucial stakeholders.

4.8 Chapter Summary

The chapter discussed the city of Mombasa in detail including its geographical location, historical background, socio-economic and physiographic characteristics. It further discusses the environmental and climatic conditions of Mombasa city, the urbanization trend, and the administration and governance of the city. The chapter continues to discuss the main challenges affecting Mombasa City including both traditional and temporary challenges. It then zeroes in into climate change-related challenges facing based on three main vulnerability zones including coastal areas, urban areas, and wetlands and creeks areas. The chapter concludes with a discussion on the nature-based interventions addressing the different challenges identified in the respective vulnerability zone within the city. It also provides the bottlenecks regarding the realization of the NBS interventions.

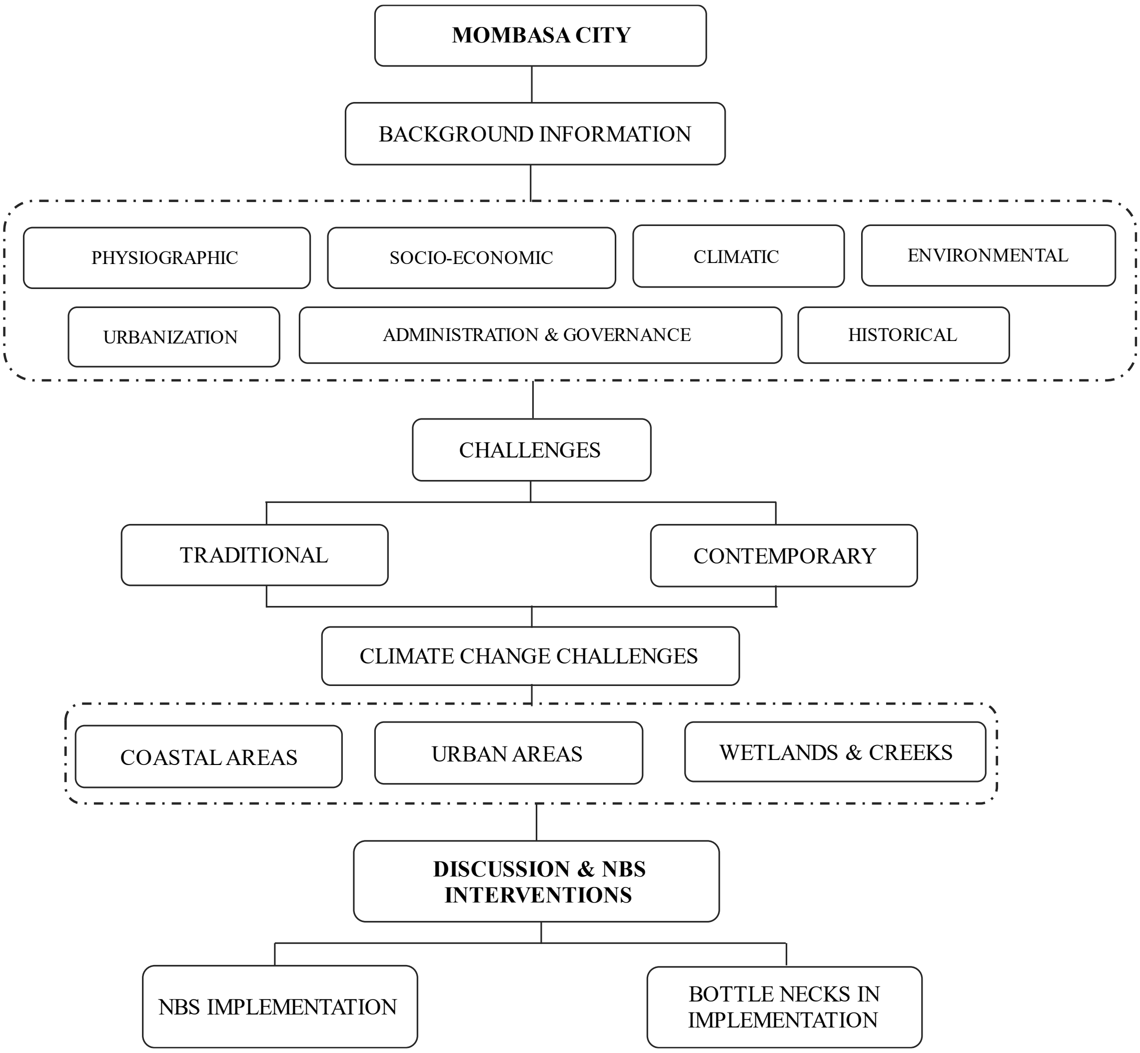


Figure 4.18: Chapter 4 Summary

CHAPTER 5

CONCLUSION

This study aimed at evaluating NBS as a strategy for mitigating climate change effects and adapting tropical cities to the changing climate dynamics. Climate change had influenced and is anticipated to continue influencing several challenges such as the frequent occurrence of extreme weather events, sea and ocean levels rising, glaciers melting in the polar and arctic regions, loss of biodiversity, increasing frequency of natural disasters, among others. These effects will significantly affect the globe and more so urban populations where the majority of human settlements are concentrated. The change in climate is projected to have significant adversities in tropical coastal cities owing to their geographical context and proximity to the ocean, warm and humid climatic conditions, lower level of economic and technological development, and inadequate capacity to adapt to the changing climate and mitigate its negative consequences. Following the discussion above, there is a need for more sustainable, easily applicable, ecologically friendly, and low-cost interventions are necessary to lessen the negative impacts resulting from the changing climate in these cities while fostering urban resilience. Thus, NBSs present a better complementary to the existing grey infrastructure. A case study of Mombasa city was evaluated since it presents a typical example of a developing tropical coastal city experiencing significant climate change-related challenges.

The overall objective of this study was to find the appropriate NBS for tropical cities like Mombasa. To realize this, the research looked at the climate change challenges in general that face tropical coastal cities. It then identified the NBS & SUD practices ideal for tropical cities. This created a strong theoretical framework to evaluate Mombasa City and how climate change has impacted the city. Three vulnerability areas were identified included coastal areas, urban areas, and creeks and wetlands. The last objective involved proposing appropriate NBS interventions that can be modified to suit the case of Mombasa City. The research utilized both secondary and primary data to gather information. It entailed a review of secondary data from journals, strategic documents, institutional data, policy documents, websites, and satellite imagery, among others. Primary data included pictures and key informants online interviews conducted via snowball sampling method.

The challenges facing tropical coastal cities include both climate and non-climate related. They include socioeconomic challenges such as rapid urbanization, urban migration, inadequate urban planning, shortage in supply of essential services & infrastructures, increasing urban poverty rates, and inadequate housing. Physical challenges include limited availability of clean water, insufficient network of water distribution, inadequate coverage of sewerage network, poor drainage capacity and rainwater handling, inadequate waste management, water shortage, inadequate connectivity, traffic congestion, inadequate public transport, lack of disaster-resilient infrastructure. The environmental challenges include environmental degradation, poor land-use practices, urban air and noise pollution, lack of child-friendly spaces, unsustainable pressure on ecosystems and biodiversity. Lastly institutional and cultural include insecurity of land tenure, inadequate enforcement of policies and bylaws, lack of political goodwill, low technical capacity, and inadequate financial resources.

Climate-related and environmental challenges in tropical cities can be mitigated using climate changes. Among the ecosystem approaches and nature-based solutions available for tropical cities include restoration of mangroves, protecting and creating urban green spaces, planting trees, restoring wetlands, protecting and increasing riparian reserves, underground water storage, rainwater management ponds to hold water during excessive runoff and discharge it to the environment at a slower rate, using of phytoremediation and Phyto-stabilisation on contaminated sites, creating of swales and artificial wetlands to accumulate, hold and biologically treat water before releasing to destination water bodies, using bioremediation, improve remediation of waste before disposal, protecting intertidal muds and salt marshes, create and maintain a coastal riparian reserve and add barriers such as dunes and beaches to create a buffer. These solutions can be adapted to create sustainable and resilient tropical cities which are correspondingly ecological friendly.

In the context of Mombasa city, a significant percentage of the challenges facing the city can be linked to rapid urbanization and climate change. The former includes increasing urban heat island effect, inadequate housing, mushrooming informal settlements, poor waste management, environmental pollution, encroachment on riparian reserves. The climate change-related challenges are categorized into three areas of vulnerability which include coastal areas, urban areas, and wetlands and creeks. Those relating to the coastal shores include flooding, erosion, reduced biodiversity, and mangrove species, rising sea level, and destruction of marine habitats. The urban areas are faced with urban flooding under extreme rainfall events, increasing warm temperatures, water scarcity, and food insecurity. The wetlands on the other hand are faced by pollution, loss of biodiversity, saltwater intrusion, and erosion and sedimentation.

The nature-based solutions available for Mombasa city in the coastal areas include planting mangroves and seagrasses, restoration of vegetated dunes, solid waste management, promoting sustainable agricultural practices. In the urban context, the best practices include planting trees along streets, sidewalks, utility corridors, and parking lots; increase natural surfaces such as creating more parks and also lawns in residential areas; using permeable pavements; having constructed wetlands; promoting green roofs and roof gardens; encourage rainwater harvesting and creating of waste stabilization ponds among others. Lastly, in the case of wetlands and creeks, the interventions include conservation and restoration of mangroves, native revegetation, and proper management of both solid and liquid waste. The bottlenecks to implementation of nature-based solutions within Mombasa city include lack of awareness of the NBS interventions from both the authorities and local communities; bureaucracy in implementation from authorities; inadequate financial resources; conflict of tasks distribution between the different government institutions and authorities and finally competitive space needs within the urban setting, among others.

NBSs are capable of addressing climate change effects within tropical coastal cities. The solutions offer multiple benefits from economic, social, and environmental. The interventions have been successfully implemented in other tropical coastal cities of Vietnam and the Philippines among others, and have proven to work for both climate change, ecological benefits, and social good. Implementation of NBS interventions in Mombasa would require vigorous education and awareness campaigns to both citizens and administrators to educate them more on nature-based solutions. The incorporation of these systems in Mombasa would foster climate resilience and urban sustainability within the city while correspondingly enhancing the living standards of urban communities by providing a quality urban environment, recreational amenities, and improved livelihood sources and economic robustness.

This study was conducted during the Covid-19 pandemic period, hence the timing served as a major limitation in terms of accessing the key informants and equally ground data collection. As a result, the study employed remote data collection techniques including online interviews of key informants via snowball method and online photographs to successfully gather the desired data and information. The core purpose of this research involved evaluating the NBS interventions applicable to tropical coastal cities that would enhance climate change adaptation and resilience in these cities. This opens a further research opportunity in evaluating the governance and implementation of NBS solutions in tropical coastal cities including measures or indicators to evaluate the effectiveness of NBS solutions in address climate-related challenges in these cities.

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