Annex 2.A: Feasibility Study

Monrovia Metropolitan Climate Resilience Project

United Nations Development Programme
Environmental Protection Agency of Liberia

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Table of Contents

1. Executive summary

1.1. Country Profile and Baseline

Liberia is a West African country, bordered by Sierra Leone, Guinea and Côte d'Ivoire. The country is divided into 15 administrative counties. The capital city of Monrovia is located in Montserrado County, as is the Monrovia Metropolitan Area (MMA) — comprising the Greater Monrovia Area as well as suburban communities and towns that lie along the coast of the county. As of 2008, the population of the Montserrado County was ~1.3 million people, the bulk of which (58%) fell within the age range of 15–64 years.

Approximately 54% of the national population of 4.7 million people lives in poverty, with a large gender disparity in monthly income. On average, ~45% of employed people across the country receive a monthly salary of between 6,000 and 15,000 Liberian Dollars (US$15–US$70). Within the MMA household income is not sufficient to meet the market rate of decent housing, particularly within the capital. Consequently, a large percentage of Monrovia's population dwell in informal settlements, which make up ~70% of all available residential space in the city. These settlements are poorly developed, overpopulated and are characterised by high rates of poverty, poor sanitation conditions and a pronounced prevalence of diseases. These trends are likely to increase with the impacts of the COVID-19 pandemic as poverty rates are projected to increase with per capita income contracting and food prices rising[1].

Livelihoods in the MMA are dominated by small-scale trade, fishing and fishery-related livelihoods. These activities are exerting pressure on coastal ecosystems, including mangroves, adjacent to the MMA, particularly as a result of a high dependency on wood fuel (e.g. for charcoal production and fish drying). Overharvesting of mangrove trees, combined with other anthropogenic pressures, are having profound negative impacts on these wetland ecosystems. Consequently, the natural buffer provided by mangroves is being removed, leaving coastal communities increasingly vulnerable to climate change induced coastal erosion processes and threatening livelihoods dependant on ecosystem services provided by the mangroves. These anthropogenic pressures compound with the negative impacts of climate change on these ecosystems to exacerbate the overall threat posed to mangroves systems.

Coastal communities in the MMA have minimal adaptive capacity and low resilience to climate change impacts. Given that these communities mostly live in temporary and/or poorly constructed homes with minimal protection from sea or storm surges, the predicted increases in sea-level rise (SLR) as well as the frequency of storms and sea-surges is expected to have catastrophic impacts. Housing safety, livelihoods and human wellbeing are at risk.

1.2. Climate change trends

Climate models predict that Monrovia will warm by up to 2.65 ± 0.84°C by 2080, aligning with predictions of warming throughout the country. Predictions of precipitation changes vary from a 36% decrease to a 21% increase in wet season rainfall. The overall ensemble prediction across emission scenarios indicates a slight increase in wet season rainfall of 1.54 ± 11.09% by 2050 and 1.92 ± 13.21% by 2080. Overall, warmer and wetter conditions are likely to develop

[1] World Bank. 2020. The COVID-19 Crisis in Liberia: Projected Impact and Policy Options for a Robust Recovery. Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/34271/Liberia-Economic-Update-The-COVID-19-Crisis-in-Liberia-Projected-Impact-and-Policy-Options-for-a-Robust-Recovery.pdf?sequence=4&isAllowed=y

across most of the country and particularly in the coastal zone by 2080. Predicted increases in the intensity of rainfall events has negative implications for communities prone to flooding.

Many regions of Liberia, including the MMA, are prone to flooding as a result of heavy rainfall, poor drainage and the construction of buildings along waterways. Informal settlements are particularly at risk. In addition to infrastructure damage and the disruption of transportation networks and civil services, poor sanitation and waste management structures pose an extreme health risk to residents.

In addition to the impacts of rising temperatures and changes in precipitation patterns, sea-level rise (SLR) and coastal retreat pose a significant challenge for adaptation along the coastline of the MMA. Significant coastal erosion and shoreline retreat is already taking place, leading to the loss of land and recreational beaches, and this is predicted to accelerate under climate change conditions. In addition, mangrove forests, which provide a range of ecosystem services and livelihood support in the Mesurado Estuary, are directly threatened by SLR as rising water and accumulating sediment threaten their survival through changes in inundation duration, frequency and salinity levels. Overall, the impacts of climate change threaten coastal communities, ecosystems and livelihoods.

1.3. Key climate change impacts in Monrovia

Coastal erosion, sea-level rise and increased flooding will have substantial negative socio-economic impacts for coastal communities in Liberia. Destruction of private property, inundation or undermining of dwellings will be particularly threatening for poor coastal communities with limited adaptive capacity. In addition, infrastructure and assets within the MMA that are critical to Liberia’s economy are at risk. Power suppliers, industry and health institutions with a conservatively estimated value of US$ 765 million within the MMA are likely to be impacted. The loss of civil and health services is of considerable concern as climate change impacts along the coastal zone are likely to include an increased risk of water- and vector-borne diseases such as cholera and malaria.

In addition, coastal livelihoods — particularly fishing — are at risk from climate change impacts. Fisheries contribute significantly to food security within the MMA. Ocean acidification, intense storms, rising ocean temperatures and shifting upwelling patterns are likely to reduce fish stocks within the coastal zone. The loss of mangroves – through SLR and anthropogenic pressure – which act as nursery habitats for a number of economically important fish species will further reduce available stock. As well as reductions in the fisheries sector, predicted climate change impacts on agriculture across Liberia — including increased temperatures and shifts in the onset, duration and intensity of the rainy season — are likely to contribute to reduced food security within the MMA.

1.4. Previous and current coastal protection and adaptation responses, best practices and lessons learned

There are very few examples of previous or current coastal protection work in Liberia. Coastal zone management has been managed by several institutions — including ministries, agencies, private sector and environmental civil society organisations — operating independently. Previous interventions include, *inter alia*: i) improving and upgrading coastal protection; ii) improving disaster risk management; iii) supporting alternative livelihoods; iv) developing coastal management policies; v) building capacity for monitoring and forecasting coastal dynamics; and vi) establishing effective knowledge management and dissemination structures.

1.5. Needs, gaps and barriers for scaling-up coastal adaptation

Several critical needs should be met to support the scaling up of coastal adaptation in Liberia and the MMA. These include: i) institutional strengthening; ii) human capacity development; iii) infrastructural/hard structural development; and iv) adaptation planning. Integrated coastal management approaches are required to replace disconnected site-specific interventions and plans. Gaps in coverage of coastal protection works as well as in forecasting of sand movement dynamics need to be addressed. Similarly, gaps in infrastructure design that intensify vulnerability, and in technological and technical capacity for collecting, analysing and using biophysical data should be managed. The coverage and capacity of institutional service providers should be increased and effective coordination between sectors and ministries achieved. In addition, adequate financing is required for repairing and preventing future damage to infrastructure from climate change impacts.

1.6. Potential coastal protection solutions

Innovative interventions are required to reduce the impact of climate change on the MMA coastline and reduce the rate of coastal erosion. Specifically, interventions are required to: i) protect settlements and assets; ii) safeguard coastal livelihoods; iii) protect cultural and heritage sites; and iv) protect fragile ecosystems such as mangroves in the Mesurado Wetland. Three approaches to coastal protection were considered, including engineering ‘hard’ coastal defence structures, ‘soft’ natural or social interventions or a combination of both. Analyses identified four options for coastal protection along the MMA coastline, namely: i) rubble mound groynes to block longshore sediment transport; ii) breakwaters to force wave-breaking; iii) revetments to stabilise the shoreline; and iv) retreat and leave the coastline vulnerable. Of these, options analysis suggests that the most appropriate coastal defence option for the project to support is the construction of a revetment at West Point.

1.7. Recommendations for project interventions

Effectively addressing predicted climate change impacts and meeting the adaptation needs of coastal communities within the MMA will require a range of interventions. Engineering solutions are required to address accelerated coastal erosion and SLR, supported by institutional strengthening, technology transfer, capacity building, awareness-raising and the establishment of a management plan for the Liberian coastal zone.

2. Country profile and baseline

2.1. Background

Liberia is one of the world's least developed countries and is still grappling with major challenges as a legacy of the country's civil war (1989 to 2003). Economic growth began to recover after the war and since then Liberia's economy has been one of the fastest growing in Africa. Economic and social gains made by Liberia in the post-civil war period from 2000–2010 were severely curtailed by the outbreak of the Ebola virus and subsequent epidemic between 2014 and 2015. The current COVID-19 pandemic poses a new threat to the Liberian economy. External demand for Liberian exports is expected to decrease and may disrupt investment in the export-oriented mining, agriculture, and forestry sectors [2]. Liberia faces multiple development challenges caused in part by the loss of basic infrastructure during the 14-year civil war. Among the coastal population, social indicators — such as access to health, education and employment — are very low, and there is widespread gender inequality. Many of these communities are vulnerable to the impacts of climate change including accelerated coastal erosion, sea-level rise (SLR) and increased pressure on ecosystems — which these communities depend on for their livelihoods and food security. Additionally, the agricultural and forestry sectors have limited adaptive capacity and resilience to climate variability.

Climate projections under Representative Concentration Pathway (RCP) 8.5 predict a sea-level rise of 75 cm by 2100 along Liberia's coast, as well as an increase in the frequency of high-intensity storms resulting in an increased offshore significant wave height [3] (Figure 1). The combined effect of these climate impacts will rapidly increase the rate of coastal erosion in Monrovia, threatening local populations and coastal infrastructure, specifically at the settlement of West Point.

[2] World Bank. 2020. The COVID-19 Crisis in Liberia: Projected Impact and Policy Options for a Robust Recovery. Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/34271/Liberia-Economic-Update-The-COVID-19-Crisis-in-Liberia-Projected-Impact-and-Policy-Options-for-a-Robust-Recovery.pdf?sequence=4&isAllowed=y

[3] The significant wave height is the average height of the highest one-third of all waves measured which is equivalent to the estimate that would be made by a visual observer at sea. The significant wave height profile along Liberia's coast is shifting towards an increase in the occurrence of all large waves. The return period of extreme storm events that historically occurred once every 100 years are projected to decrease to 1 in 40 years under RCP 4.5 and 1 in 25 years under RCP 8.5 by the year 2100.

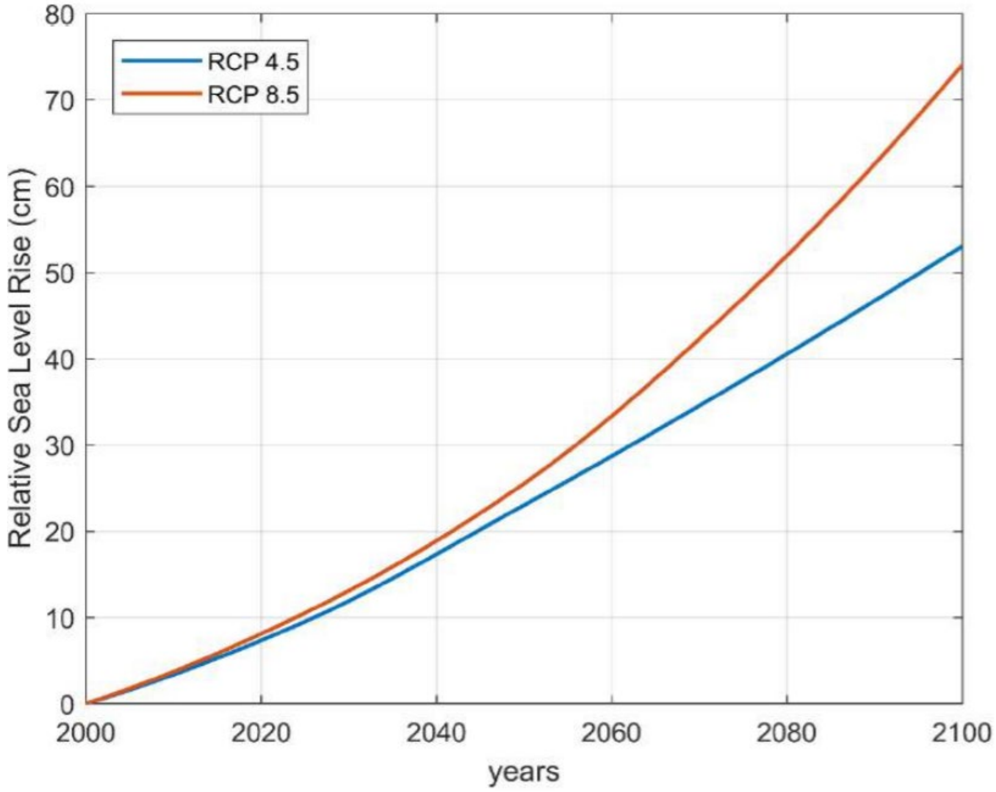


Figure 1. Projected relative sea level rise for RCP 4.5 and RCP 8.5.

Administratively, Liberia is divided into 15 administrative counties. The capital of Monrovia and the Monrovia Metropolitan Area are administratively part of the Montserrado County. West Point is one of the most vulnerable communities along Monrovia's coast, and is located within the Montserrado County. The vulnerability of West Point results from it being an impoverished and densely populated informal settlement situated on a narrow spit between the coast and the Mesurado Wetland, with dwellings built right up to the shoreline. In the last decade[4], coastal erosion has caused the shoreline to regress by more than 30 m, leading to the loss of at least 670 dwellings and threatening public spaces and boat launching sites that are critical to fishery-based livelihoods.

The limited availability of land along the coast has led to unplanned urban expansion into the mangrove forests of the Mesurado Wetland in Monrovia (Figure 2). This urban expansion, along with the harvesting of natural resources has increased the pressure on this wetland, which provides ecosystem services to coastal communities — including the provision of critical breeding habitats for economically-important fish species. Please see section 5 of this document and Annex 2.D for further details on these mangroves.

[4] 2008 to 2018

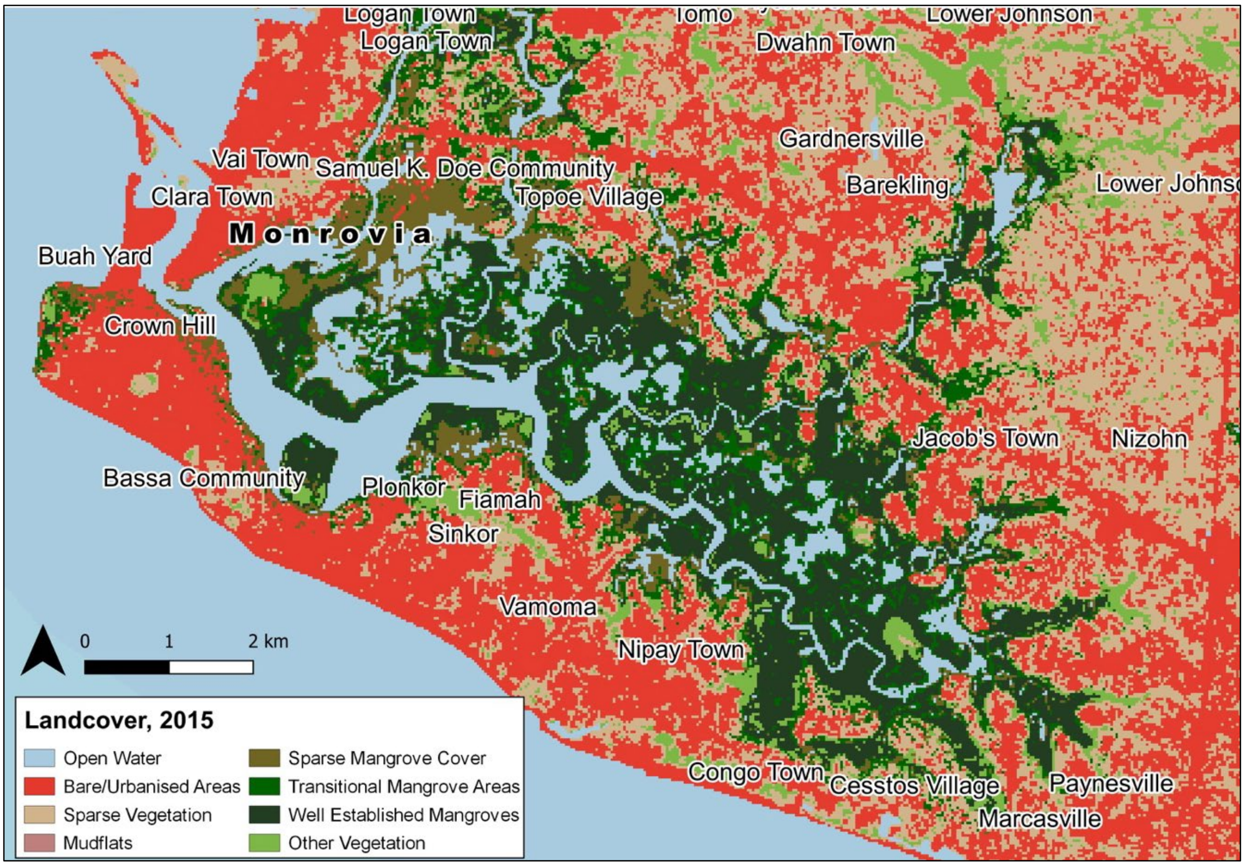


Figure 2. Landcover map of 2015 ESA data showing the proximity of the Mesurado Wetland to built-up and urbanised areas.

2.2. Definition of the Liberian coastal zone and the Monrovia Metropolitan coastal area

The Monrovia Metropolitan Area (MMA) is a mix of the Greater Monrovia Area as well as suburban communities and towns that lie along the coast of Montserrado County, encompassing Paynesville to Brewerville with parts of Sinkor, Gardnerville, Johnsonville, Brewerville, Stephen Tolbert, Barnesville, New Georgia Estates, Capitol Hill, Water Side, Bushrod Island area and Gardnerville. These settlements — referred to as major urban centres in Monrovia — perform urban functions such as local and international trade, production of goods and services. Many of the settlements are underdeveloped and are characterised by congestion in terms of houses and people, high poverty, poor sanitation conditions and high prevalence of diseases.

The Maritime Authority Act of Liberia only has a descriptive definition of the coastal zone which is outlined as follows:

“Coastal Zone” is “the interface or transitional space between two environmental realms: the land and the sea”. It also refers to the "Liberia Coastal Zone" as “the interface or transitional space between the land coast of the Republic of Liberia and the ocean or sea, rivers, lakes, or streams along the coast”. The same Act says that "Coast" refers to “the land part of the coastal zone adjacent to the high-water line”. The land area of the coast depends on the public use assigned to it in a program of integrated coastal management, in accordance with such criteria as: control of residential, tourism (sea, marine, etc.), commercial and industrial development; protection of vulnerable species and habitats; aesthetic protection of the coastline; protection of water quality; and prevention of erosion and degradation of coastal resources. "Maritime Zones" and "Internal Waters" refer to the zones and waters defined by the Maritime and other laws of the Republic of Liberia, pursuant to the United Nations Convention on the Law of the Sea, signed on 10 December 1982 at Montego Bay, Jamaica. The terms include, but are not limited to, the territorial sea, the contiguous zone, the internal waters, the exclusive economic zone and the continental shelf of the Republic of Liberia[5].

2.3. Demographic characteristics

There are an estimated 938,383 households in Liberia, with an average household size of 4.26 persons per household. Households are larger in urban areas (4.37) than rural areas (4.16). Out of a population of approximately 4 million persons, 48.5% are male and 51.5% female. Liberia has a young population (Figure *3*) with almost one in three Liberians being less than ten years of age. The working-age population (those aged between 15 and 65) accounts for 52.7% of the total population; while only 2.6% are 65 years or older[6].

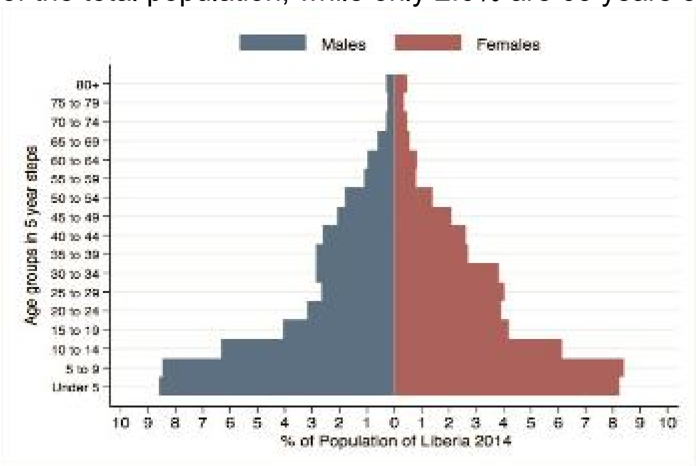


Figure 3. Age pyramid by gender (LISGIS 2016).

According to 2008 census data[7], the population of the Montserrado region is approximately 1.3 million, with an approximate population age breakdown of 40% 0–14 years, 58% 15–64 years, and 2% 65+ years. These population figures are, however, outdated. The GoL has established that the population has grown significantly over the last decade, but there are no more recent official population statistics to reference.

2.4. Education

The national literacy rate is estimated to be 66.7% and residents of urban areas are more likely to be able to read and write than those of rural areas (76.0% versus 50.1%). The gap between men and women is even larger. While 80.4% of males are reported as literate, only 54.8% of females are[8]. Regional differences are strong, with a relatively high literacy rate in Montserrado (80.4%) compared to other regions.

In the past, barriers to obtaining any level of formal education in Liberia included limited accessibility, restricted financial means as well as inadequate schooling. As a result, illiteracy

[5]Liberia Maritime Authority Act of 2010, (2010)
[6]LISGIS 2016 Household Income and Expenditure Survey 2014 Statistical Abstract
[7] Liberia, I.S.G.S., 2008. National Population and Housing Census.
[8]LISGIS 2016 Household Income and Expenditure Survey 2014 Statistical Abstract

is much more common among the older generations as a considerably lower proportion of those aged 60 and older have ever attended primary school (18.7%). The improved rates of formal education can be mostly seen in those under the age of 30. Liberians between 15–19 years of age are much more likely to have any level of formal education (87.4%). Some barriers to education have been lowered and so accessibility has improved and illiteracy is not as prevalent as it was in previous generations.

Despite some improvements in access to education, the impact of poverty remains for the vast majority of Liberians, with formal education, primary school as their highest level of formal education attained (43.2%), followed by senior high school (27.9%), and junior high school (20.8%). The costs associated with schooling has been noted to restrict some children from obtaining further education, despite schooling being 'free', transport, supplies and food remain a barrier to school attendance for many in Liberia[9]. Less than 10% of those with formal education have a university degree, whether a Bachelor's degree or a more advanced degree[10].

A gender bias is also present with regards to the highest educational achievement. Women are less likely to go to university than men, and more likely to only have gone to primary school if they have formal education.

2.5. Housing

The majority of dwellings in Liberia are made of mud and sticks (40.5%). Concrete and cement blocks (25.2%) and mud bricks (22.2%) are the next most common building materials. There are significant differences between rural and urban dwellings. In rural Liberia the use of mud and sticks and mud bricks are ubiquitous (94.4%). In the urban parts of the country concrete and cement blocks, as well as zinc, iron, and tin, make up nearly 50% of building materials. Sheets of zinc, iron or tin are used to roof the vast majority of dwellings in the country (81.7%) and nearly all roofs in urban areas (92.5%)[11].

A large proportion of the West Point community live in temporary and/or poorly constructed homes with minimal protection from sea or storm surges. For this combination of reasons, the community's capacity to adapt to climate change is limited, and they have low overall resilience. Climate change induced sea-level rise (SLR), increasing frequency of storms and sea-surges interaction combined with wave and currents is expected to have catastrophic impacts in terms of housing safety, disrupting livelihoods, destroying homes and resulting in a loss of human lives.

The income capacity of the majority of the population is not proportionate with the market rate of decent, formal housing within the city. Hence, a larger percentage of the city's population dwells in informal settlements, including in the mangroves of the Mesurado wetland. A careful observation of the city, both in the heartland and hinterland, reveals that approximately 70% of the city's residential settlements are considered to be informal.

2.6. Income and poverty

The rate of unemployment in Liberia is low, nationally it stands at 2.8–4.5% in urban areas and 0.8% in rural areas. This is largely because people have to find some means of income to sustain themselves including in the informal sector. The highest regional rate of unemployment

[9] Williams, J., Bentrovato, D. and UNESCO International Institute for Educational Planning (IIEP), 2011. Education and fragility in Liberia.
[10] Ibid.
[11] Ibid.

is the 5.4% recorded for Montserrado, the lowest percentage is the 0.7% reported in the North Central Region[12].

Having limited access to new skills, high dependency on traditional skill sets and practices (e.g. fish drying) and general low education levels makes these communities primary and vulnerable targets to climate change and climate change impacts. In such contexts, the main challenge to any project design is the scope of needs that have to be addressed. The engagement of the population in numerous socioeconomic activities can create both negative and positive environmental impacts. From an economic standpoint, the production of goods and services — although they provide income generation, can generate air, water, and land pollution (see Annex 2.D). These productive activities can also lead to increased migration and congestion, which fosters conditions for the spread of diseases while also constraining scarce resources.

Livelihoods and income generating activities in the project area are dominated by small-scale trade in the commercial districts of Paynesville, Duala and Water Side. There are also around 20,000 people dependent on fishing- and fishery-related livelihoods within the coastal communities of New West Point, King Gray Town, Kru Town and Banjor. More generally, fishing provides 65% of the animal protein needs of the country and contributes around 3.2% to Liberia's GDP. The marine fisheries sector accounts for approximately 15% of the GDP of the country[13]. Industrial fishing vessels land their catches at the fishing pier in the Free Port of Monrovia.

Approximately 60% of the total domestic catch is landed by artisanal fisher folk, using several types of canoes and fishing gear, including 200–800m long beach seines. Approximately 40,000 fisher-folk and fish processors (mongers) and their families live in the 139 communities in coastal counties. Together they operate ~3500 canoes of which 8% are motorised. The largest numbers of canoes operate in Montserrado and Grand Bassa County.

Artisanal fisheries operating along the coast are mainly domestic Kru fishers and their families, and the Fanti and Popo fishers and their families who migrated to Liberia from Benin, Ghana and Côte d'Ivoire. The coastal fishing communities of Liberia are considered very vulnerable due to: i) seasonality of fishing activities and absence of safety at sea; ii) conflicts with industrial fishing (and between migrants and local fishermen); iii) economic shocks (e.g. wars, exchange rates, climate impacts); and iv) disease (malaria, pneumonia and diarrhoea).

Alongside fishermen communities there is an estimated 100,000 non-fishermen who generate income by associated activities that include: charcoal production for fish drying and household cooking, fish-drying itself, and vendor selling of dry fish on the streets of the MMA towns.

These activities in combination with the negative impacts of climate change are placing very high pressure on the wetland and forest ecosystems adjacent to the MMA, due to high usage of wood for energy (e.g. charcoal production and fish drying) (see Annex 2.D for further details on timber demand due to energy-inefficient practice of open fires for fish cooking and smoking). Aside from mangroves, other tree types are now under threat as well (e.g. rubber tree, and other prime forests vegetation). The destruction of mangroves for energy continues to deplete certain species using mangroves as habitats. Mangroves provide a natural buffer against storms and floods and are a nursery ground for aquatic and non-aquatic species, which are important for mangrove ecosystems and ecosystem services for coastal communities. Many fish, crabs, birds and other wildlife adopt mangrove ecosystems as breeding, feeding and

[12] LISGIS 2016 Household Income and Expenditure Survey 2014 Statistical Abstract
[13] United States Agency for International Development (USAID). 2014. Liberia - Environmental Threats & Opportunities, 118/119 Assessment

nursery habitats. SLR also threatens mangrove systems as the trees are vulnerable to inundation as the forests cannot migrate inland because of spatial restrictions imposed by urbanisation. This combination of SLR, mangrove overcutting and other anthropogenic pressures, which is suffocating the wetland ecosystem, is causing a decline of this natural buffer service and therefore indirectly negatively adding to climate change induced erosion processes and livelihoods decline of coastal wetland communities. Once a mangrove area is deforested the roots of mangroves will no longer support soil and soil will be mobilised in the form of sediment transport (as mud, fine coarse silts and sand) downstream causing erosion of riverbanks and congesting riverbeds, and increasing the likelihood of flooding during the rainy season.

2.7. Land use patterns and development

The land use pattern includes industrial land use such as the Industrial Park, Free Port of Monrovia and the Freezone Industrial Area all located along the Somalia Drive road. These industrial areas support industries for manufacturing and packaging of cement, paint, aluminium, cement, rubber polymers and household supplies. There are also historical sites (Providence Island), commercial and residential zones (Paynesville, Sinkor, Congo Town, and Duala) etc.

Within the MMA there are infrastructures of national significance including government buildings, foreign diplomatic missions and embassies, J.F.K Hospital, James Spriggs Payne Airport, University of Liberia and several hotels.

Some of planned or ongoing developments in the project area include the:
- rehabilitation of the container terminal of the Free Port of Monrovia;
- development of power generation, transmission, distribution and supplies for the Mt. Coffee Hydro Project, Liberia Energy Efficiency and Access Project and West African Power Project;
- rehabilitation of the 13.2 km Paynesville-Somalia Drive road and other roads within Monrovia suburbs;
- rehabilitation of a Ministerial Complex in Congo Town;
- development of a river transport project from Paynesville to Central Monrovia; and
- development of a master plan study on urban facilities rehabilitation and improvement in Monrovia by Japan International Cooperation Agency (an implementation plan for roads, waterworks, sewers and rainwater drainage).

The existing system for management and governance of urban land use in the MMA is underdeveloped as a result of physical and social decay, reduced economic growth and insufficient capacity to provide and manage basic urban services.

2.8. Geographic context

Liberia covers an area of 111,370 km^2, of which 15,050 km^2 is water (rivers, lakes, wetlands) and the remaining 96,320 km^2 is dry land. It borders with Côte d'Ivoire to the east, Sierra Leone to the northwest, Guinea to the northeast and the North Atlantic Ocean in the South. The capital, Monrovia, is the country's largest city with an estimated population of ~1.2 million in 2016. Besides Monrovia, other important coastal cities in Liberia are (from North to South) Robertsport, Buchanan, Greenville and Harper. Inland is Gbargna, which is a road network hub and trade centre near the border with Guinea (Figure 4). Administratively, Liberia is divided into 15 administrative counties. The capital of Monrovia and the Monrovia Metropolitan Area are administratively part of the Montserrado County.

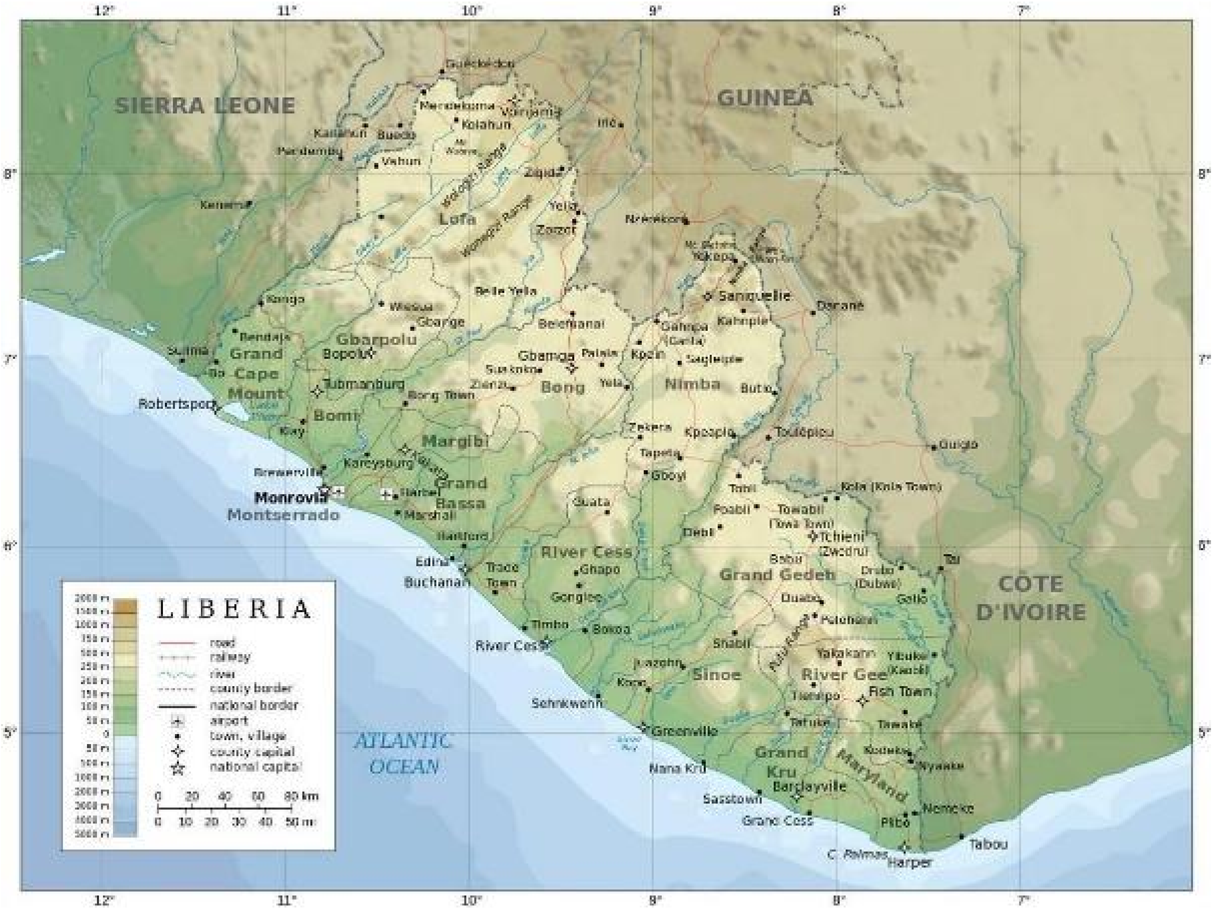


Figure 4. Topographic map of Liberia (Source: Wikipedia by Oona Räisänen[14]).

Liberia can be divided approximately into four geographical zones: the low coastal plain, the rolling hills, plateau and tablelands, and northern mountainous highlands (Figure 5).

The major rivers of Liberia are the Cavalla, the Cestos, the Lofa, the Mano, the Morro, the Saint John and the Saint Paul. Additionally, it is worth mentioning the Mesurado River and its adjacent wetland area. The Cavalla is the longest river at 515 km in length. The Mano and Morro rivers in the northwest and the Cavalla River in the southeast are boundary lines for part of the country. Most of the rivers of Liberia flow from the mountains inland in the northeast to the coast in the southeast and run parallel to each other. Among the low mountains and hills, the riverbeds are steep and irregular, with frequent falls or rapids. Many rocks, waterfalls, rapids and sandbanks reduce navigation of these rivers very far inland. Closer to the coast, the river grade becomes less, and tidal current prevent the rivers from removing sand bars and accumulations. Most streams overflow their banks regularly, and during the rainy seasons there is often severe flooding along the coastal plains. Many rivers flow along the coast for kilometres before they finally enter the Atlantic Ocean.

[14] https://commons.wikimedia.org/wiki/File%3ATopographic_map_of_Liberia-en.svg)

Figure 5. Geographical zones of Liberia: low coastal plain, rolling hills, plateau and tablelands, and northern mountainous highlands[15]

The highest point entirely within Liberia is Mount Wuteve at 1,440 m located in the West African Mountain range; however, Mount Nimba is higher at 1,752 m and is shared with the country of Guinea and Cote d'Ivoire. The lowest point of the country is the Atlantic Ocean. The coastal plain of Liberia is characterised by lagoons, mangrove wetlands, river deposited sandbars, riparian and coastal vegetation. This zone extends up to 65 km inland with a maximum altitude of 50 m. The Liberian coastland predominantly runs in a NW-SE direction and is 579 km long. In terms of recent sedimentation, it is almost completely built from sand.

The coast of Sierra Leone comes out as a major junction between a predominantly muddy mode of sedimentation in Guinea and Guinea-Bissau to the north and a sandy mode in Liberia and the rest of the West African coast to the south[16]. The Liberian coastline is also partially intersected by rock outcrops (capes) which often form the origin point of numerous coastal settlements as well.

Along the Atlantic Ocean, the Liberian coastline comprises a series of swash-aligned barrier beaches and enclosed lagoons, mangrove swamps, multiple prograded beach ridge plains and rocky headlands and river-deposited sandbars[17,18]. The nature and location of these features has been controlled by the availability of sediment, the wave energy levels and the inherited shoreline morphology.

[15] (Worldatlas: http://www.worldatlas.com/webimage/countrys/africa/lgcolor/lrcolor.htm).
[16] Anthony, E.J., (1991), Coastal progradation in response to variations in sediment supply, wave energy and tidal range: examples from Sierra Leone, West Africa, Géodynamique 6 (l), 1991: 57-70. ASR
[17] Ibid.
[18] Hadden, R.L., (2006), The Geology of Liberia: a Selected Bibliography of Liberian Geology, Geography and Earth Science, US Geological Survey Library

2.9. Current Climate Conditions

Because Liberia lies south of the Tropic of Cancer and only a few degrees north of the equator, there is minimal variation in the length of days between seasons. The tropical solar radiation is intense, and the radiation is uniform across the country. Temperature in Liberia is determined by its tropical location near the equator, where the sun is almost perpendicular to Earth year-round. In general, temperatures remain warm throughout the country, and there is minimal change in temperature between seasons[19]. The same climate conditions occur along the entire Liberian coastal zone, including the MMA.

2.9.1. Climate and Winds

The climate of Liberia has two seasons: a rainy and a dry season. The main two components determining the climate in Liberia are the West African Monsoon, which prevails during the Northern Hemisphere Summer (JJAS), and the East African Monsoon with rains during spring (MAM) and autumn (OND).

The notable features of the West African Monsoon are the low level south-westerly flow from the Atlantic Ocean and the Inter-Tropical Convergence Zone (ITCZ) north of the equator (Figure 6). This front consists of a belt separating the trade winds circulation of the northern and the southern hemispheres. Its position fluctuates between 6°N in January and 18°N in August, as also illustrated in Figure 6. In the dry season the ITCZ is located in the south of Liberia, whereas it is located to the north in the rainy season[20] . Because Liberia is positioned close to the equator, and it borders the Atlantic Ocean, the climate is generally mild and humid. During the rainy season, the climate is governed by South Atlantic sub-tropical high winds called the Southwest Monsoon of the Maritime Tropical Air — mostly between April and October. The dry season is affected by the Harmattan wind. The Harmattan is a cold, dry, and dusty north-easterly trade wind that sweeps over the lower part of West Africa from Sahara to the coast in December and the early months of every year. The Harmattan permeates the atmosphere, filling the air with a delicate, dust-filled haze. Deforestation and drought in the Sahel have affected the climate, lengthening the dry season by almost a month in some areas.

[19] Ibid.
[20] UNDP, 2006; Royal Haskoning, 2008

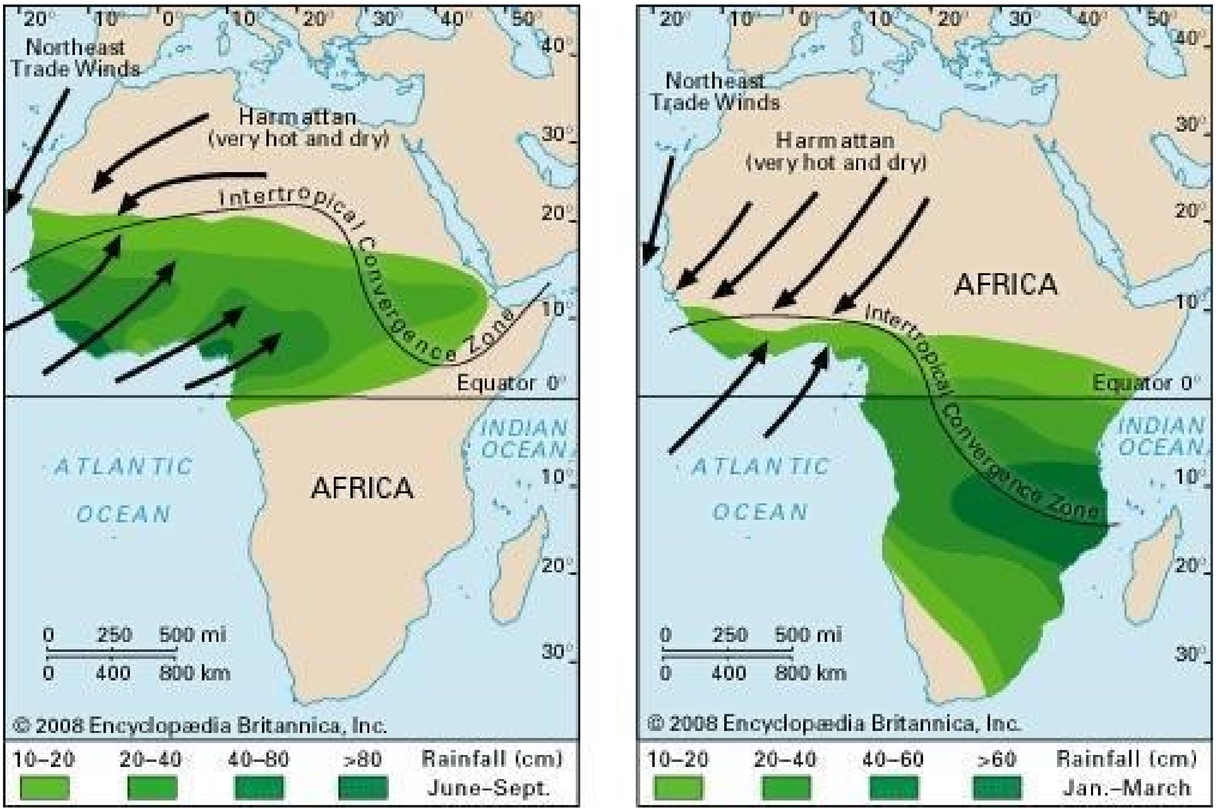


Figure 6. West African and East African monsoon and ITCZ over Africa (Encyclopaedia Britannica).

2.9.2. Temperature

Temperatures in Liberia are strongly influenced by season. Temperatures during the rainy season are relatively low because of near complete cloud cover, and minimal diurnal variation in temperature occurs. Temperatures along the coast in the rainy season are generally higher than inland as the south-westerly air stream pushes clouds inland, providing coastal regions with more clear sky and solar radiation. In contrast, temperatures in the dry season, when cloud cover is minimal or non-existent, are higher, and the diurnal range is much greater. Nights during the dry season can be cool, partially due to the Harmattan winds.

The average temperatures over the whole country ranges from 27–32° C during the day and from 21–24° C at night[21]. The interior has hot days and cool nights during the dry season. The highest temperatures occur between January and March and lowest between August and September[22].

2.9.3. Rainfall

More rain falls in Liberia than in other areas of West Africa. The relative humidity is high throughout the country, and averages from 70–90 %, particularly along the coast.

The continental and maritime masses of air alternate their movements back and forth, and from north to south. This brings some seasonal differences in rainfall intensity. Monsoon rainfall over most of West Africa occurs generally during the June through September period (Figure 6 left panel). In Liberia, the rainy season begins in April or May, and reaches a peak in July through September, and tapers off again in October. Monrovia and Buchanan, on the coastal plains,

[21] Stanturf, J. A., Goodrick, S. L., Warren Jr., M. L. and Stegall, C. M. 2013. Climate change vulnerability in Liberia. USAID/Liberia
[22] United Nations Development Program (UNDP) and Environmental Protection Agency (EPA) of Liberia. 2006. *State of the Environment Report for Liberia 2006,* Monrovia.

receive heavy rain earlier in the season, then they experience a period of reduced rainfall called the “middle dries” before heavy rains return in August. In the south-eastern part of the country, the rainy season begins in April and lasts for two or three months, and then is followed by a drier period of two or three months. Then a second rainy season begins in September and lasts until November. The “middle dries” are not dry enough to be called a true dry season[23]. The movement of the ITCZ largely determines mentioned seasonal variations. The months of heaviest rainfall varies between different parts of the country, but are normally experienced in June, July and September. Rainfall is irregular, and the rainy season varies in intensity and begins earlier at the coast than in the interior.

Average annual rainfall along the coastal zone is over 4,000 mm[24]. The greatest amount of rainfall, 5,200 mm, occurs at Cape Mount, Monrovia and diminishes inland to ~1800 mm on the central plateau[25].

2.10. Coastal processes

Over the last decade, the most pronounced environmental threat at the Monrovia coast has been coastal retreat. Along large stretches, particularly New Kru Town and West Point, significant coastal retreat has taken place leading to loss of land and recreational beaches. The following sub-sections elaborate the on biophysical factors that have resulted in this scenario by summarising the bathymetric, tidal and wave conditions which characterise the nearshore and offshore environment of Monrovia.

2.10.1. <u>Bathymetry</u>

Offshore and nearshore bathymetry are the primary parameters affecting wave propagation in Monrovia. The nature of wave climate in turn determines the magnitude of the forcing behind coastal erosion, which is the main coastal hazard affecting Monrovia. This study combined topographic and bathymetric data derived from three sources: i) shuttle radar topography mission (SRTM) elevation data; ii) Navionics bathymetric charts; and iii) a bathymetric survey of Monrovia’s coastal waters during October 2018 (Figure 7).

[23] Hadden, R.L. 2006. The Geology of Liberia: A Selected Bibliography of Liberian Geology, Geography and Earth Science, US Geological Survey Library
[24] United Nations Development Program (UNDP) and Environmental Protection Agency (EPA) of Liberia. 2006. *State of the Environment Report for Liberia 2006,* Monrovia.
[25] Encyclopaedia Britannica

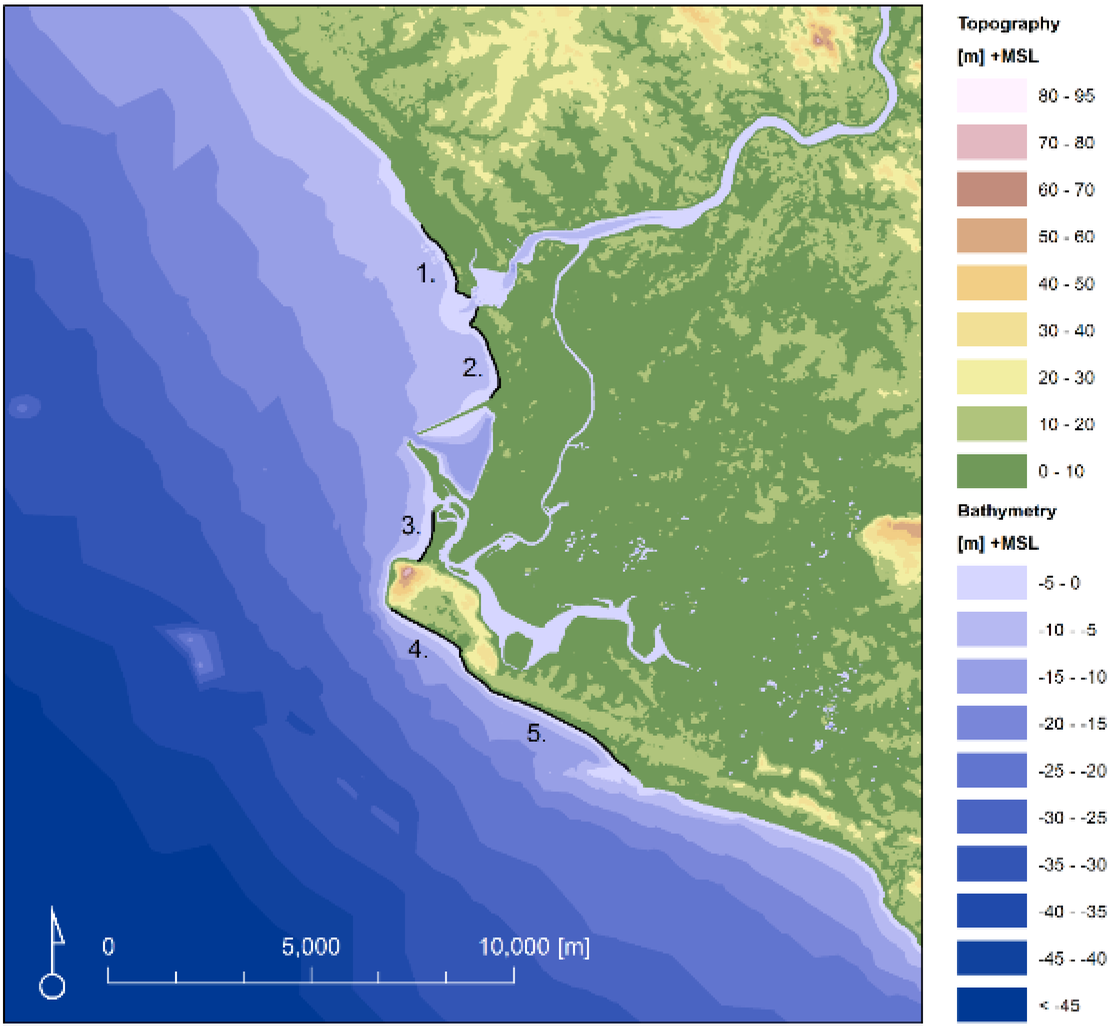


Figure 7. Combined bathymetry and topography for Monrovia coastal area, including the five coastal sections under assessment.

The following observations interpreted from the topographic and bathymetric map are pertinent to the Monrovia area:

- Cape Monrovia is clearly visible with a peak in terrain elevation of approximately 80 m above mean sea-level (AMSL).
- This topographical feature has affected how the Monrovia coastline has developed over time. At the leeside of the cape, the coastline bends to the north, backing low-lying land with an average terrain elevation of 0–10 m AMSL.
- The nearshore coastal profile is characterised by relatively gentle slopes. Coastal section 4 and 5 have a slightly steeper slope in the range of 1V:200H to 1V:250H, whereas coastal sections 1, 2 and 3 (located in the lee of Cape Monrovia) have a gentler slope of approximately 1V:350H to 1V:400H.

2.10.2. Tides

The coastal waters offshore of Monrovia are characterised by semi-diurnal tides, meaning that there are two high-tides and two low-tides daily. The periodic tidal variation for Monrovia's coastal waters has been determined by means of an analysis of astronomic tidal constituents, obtained from a local tide station. The tidal constituents have been obtained at Monrovia from the International Hydrographic Organisation (IHO) data bank. Based on these tidal constituents, a time-series dataset in excess of 20 years has been constructed, from which the tidal levels are estimated (Figure 8). This period is considered to give representative tidal levels since the duration of measurements exceed one lunar nodal cycle (18.61 years). Table 1 shows the resulting tidal levels[26] with respect to mean sea-level (MSL) and lowest astronomic tide (LAT).

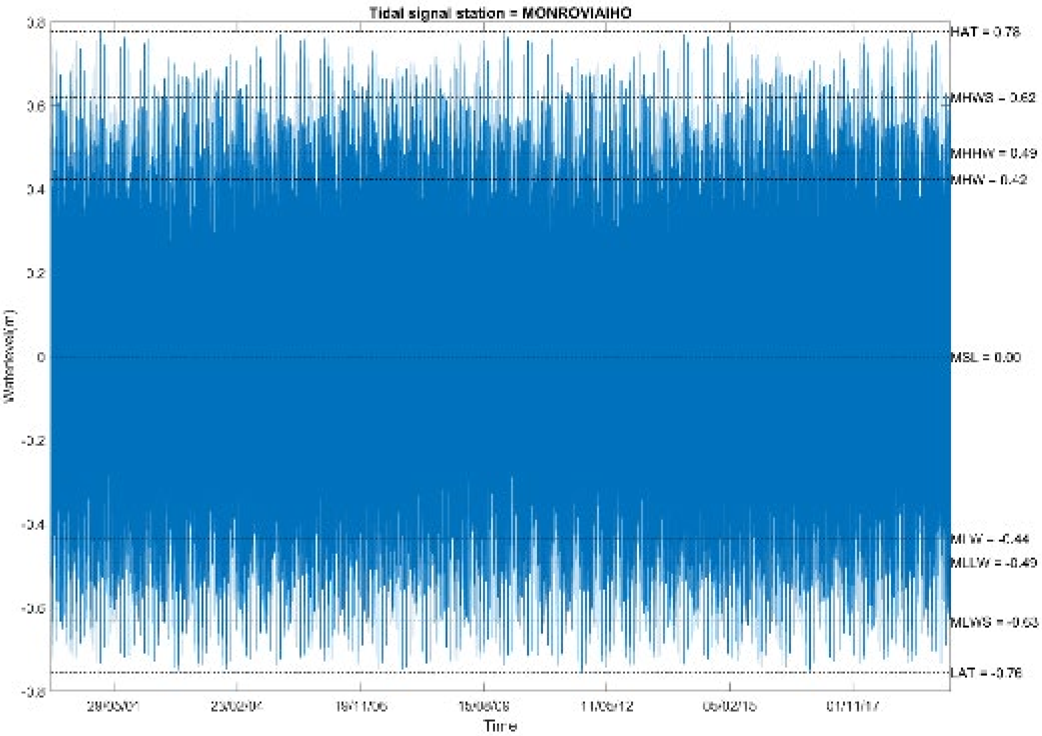


Figure 8. Tidal signal of more than 20 years at the tidal gauge of Monrovia (source: IHO).

Table 1. Tidal datums at the project area (with respect to MSL and LAT in the year 2000).

Datum	m +MSL	m +LAT
HAT	0.78	1.54
MHWS	0.62	1.38
MHHW	0.49	1.25
MHW	0.42	1.18
MSL	0.00	0.76
MLW	- 0.44	0.32
MLLW	- 0.49	0.27
MLWS	- 0.63	0.13
LAT	- 0.76	0.00

2.10.3. Waves

The coast of Liberia is subjected to persistent, long-period ‘swell waves’. Swell waves are generated by distant weather systems (i.e. storms) in the South Atlantic Ocean. This is in contrast to wind waves, which are generated by local winds. Swell waves travel over long

[26] Please note that these values are considered to be with respect to the sea-levels in the year 2000

distances — often thousands of kilometres — and disperse into uniform wave-groups with long wave-periods (which can be more than 20 seconds). The local wave climate can therefore be described as relatively uniform in terms of wave direction (i.e. south-south-west) and wave-period. The above-mentioned swells are highly energetic, leading to strong waves breaking onto the relatively steep, sandy shorelines of Monrovia. Seasonal changes to significant wave heights have been observed as follows: during the rainy season (May to September), the average significant wave height is 1.75 m (with maximum heights up to 3.5 m) and; during the dry season (October to April), the average significant wave height is smaller at ~1 m.

Figure 9 shows the significant wave height and peak-period wave roses for the offshore profile of Monrovia, where the direction/orientation of the roses shows the peak wave direction. The relevant findings based on the above-mentioned wave roses are: i) the uniformity of the wave direction; and ii) the existence of two distinct systems — namely, the dominant south-south-westerly swell system and the less-dominant south-south-easterly system. It is noteworthy that both systems may occur simultaneously.

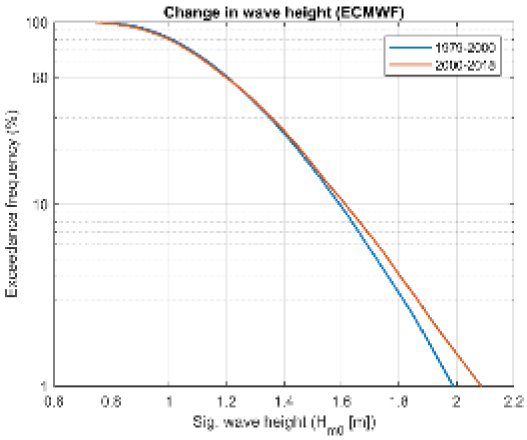


Figure 9. Observed impact on wave height last two decades based on ECMWF hindcast data (left) and NOAA hindcast data (right).

Figure 10 shows the monthly distribution of the offshore significant wave height for Monrovia, with a clear indication that seasonal variation is a significant factor. During the months from April to September, average significant wave heights are higher at 1.75 m, compared to an average height of 1 m in October to March. The significant wave height in the calmer months is relatively uniform, specifically the distribution of waves is relatively small. In the stormier season, the distribution widens and the most extreme waves can be expected (Figure 11).

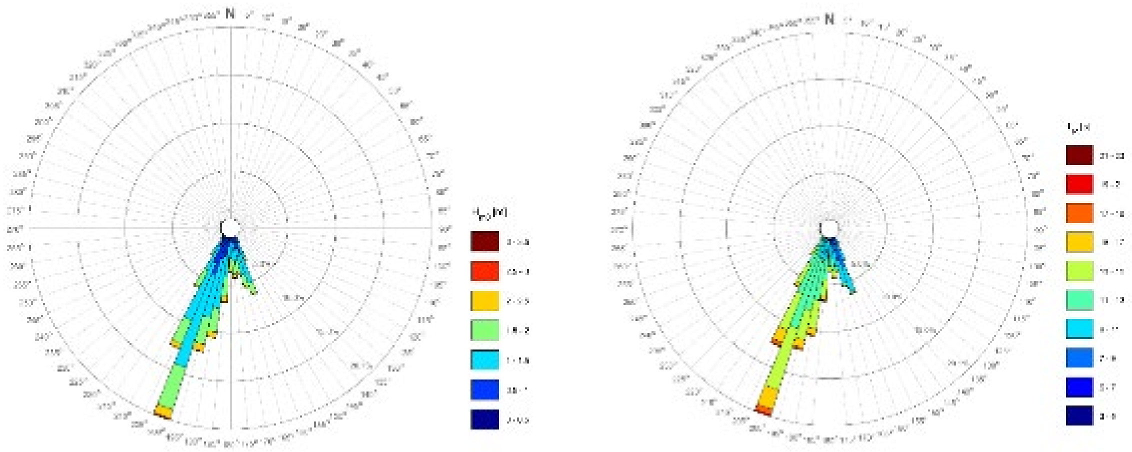


Figure 10. Wave height and peak period rose of the NOAA hindcast data set at 6°N 11°W.

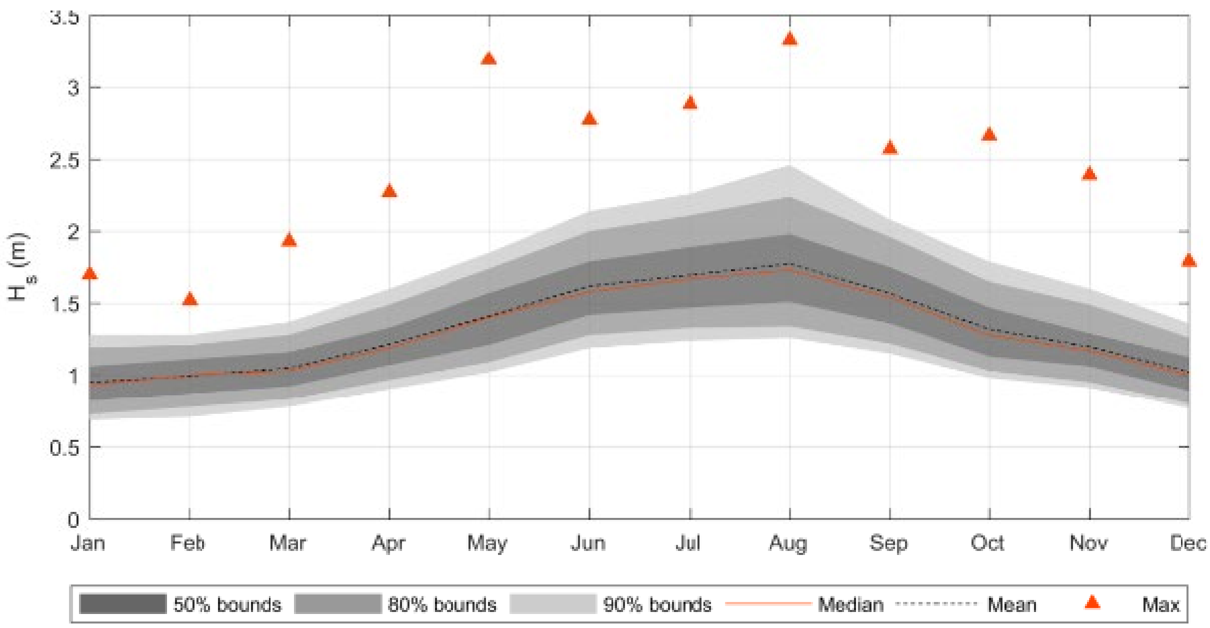


Figure 11. Monthly distribution of the offshore significant wave height.

2.10.4. Extreme wave conditions

Extreme wave conditions were determined for the offshore conditions of Monrovia by means of an Extreme Value Analysis (EVA) and then extrapolated to nearshore conditions using the spectral wave model (Figure 12). The EVA was undertaken primarily on the swell waves of the offshore wave climate, to ensure homogeneity in the data set. The figure below shows the deviation between wind and swell waves based on a constant, deep-water wave steepness of 0.017 — where higher steepness indicates wind waves (shown in orange) and lower steepness indicates swell waves (shown in blue). This figure shows that swell is the primary factor in influencing wave height offshore of Monrovia.

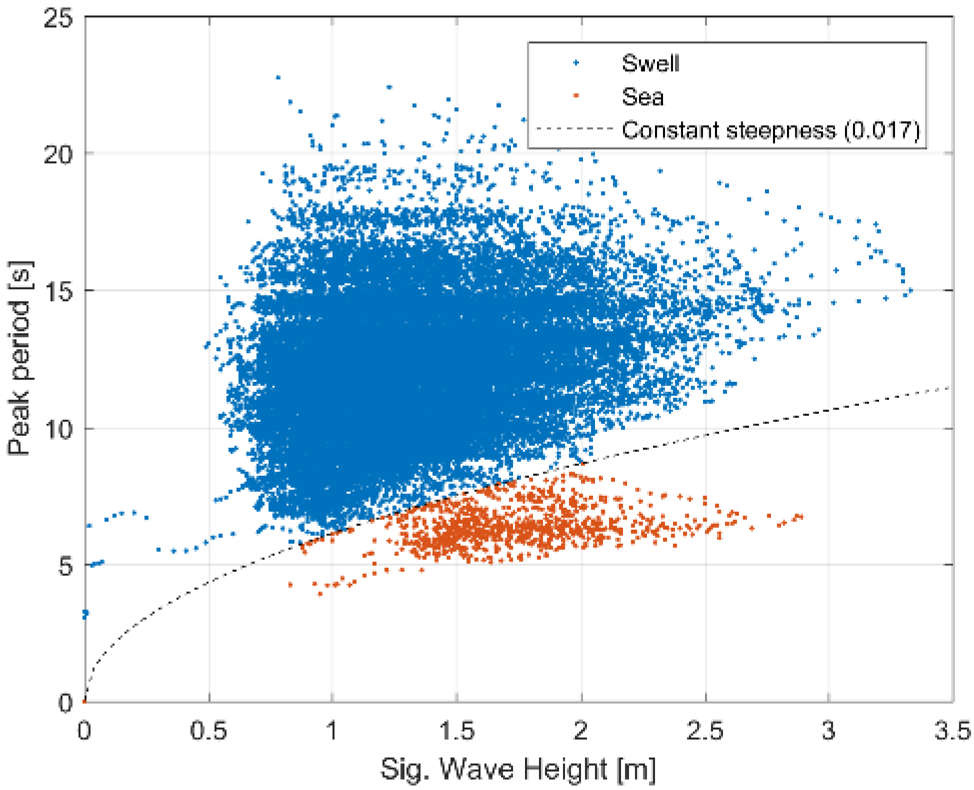


Figure 12. Deviation swell (blue) and wind waves (orange) based on a constant steepness of 0.017 (black dashed line).

3. Climate change projections, trends, impacts and attribution

3.1. IPCC scenarios and projections

The global forecasts of the Fifth Assessment Report of the International Panel on Climate Change (IPCC) show several scenarios for climate change in the future. The most recent set of scenarios are Representative Concentration Pathways (RCPs). The RCPs describe four different 21st century pathways of greenhouse gas (GHG) emissions — measured in CO_2 equivalent — and atmospheric concentrations, air pollutant emissions and land use. The RCPs have been developed using Integrated Assessment Models (IAMs) to input a wide range of climate model simulations in order to project their consequences for the climate system[27].

In the best-case scenario, RCP 2.6, global annual GHG emissions peak between 2010-2020 and decline shortly after the peak. In the scenarios for RCP 4.5 and 6.0, emissions peak in 2040 and 2080, respectively, followed by a decline. Lastly, in RCP 8.5, emissions continue to rise throughout the 21st century.

Although the IPCC clearly states that the scenarios do not have an associated likelihood of occurrence, the lack of sufficient mitigation efforts to date has made the scenario of 2.6 very unlikely. It is already known that the Paris Agreement won't be met in time, and hence the GHG emissions have continued to rise and will not likely decline before the end of 2020. Thi scenario has therefore been omitted in further reporting.

[27] IPCC Synthesis report, 2014

To show the bounds of the climate change effects, the most and least conservative climate change RCP scenarios have been assessed in this study: RCP 4.5 and RCP 8.5. All relevant effects of these scenarios, such as the impact on mean sea-level, extreme wave conditions and sediment exchange of the rivers have been considered. The anticipated effects of the above-mentioned global RCP scenarios are discussed at the regional and local level in the following sections.

3.1.1. Projections for West Africa

Although there are still gaps in the available data, there is increasing evidence of warming over terrestrial regions across Africa, consistent with anthropogenic climate change. Depending on the emissions scenario, global climate simulations of temperature over West Africa project a range between 3-6°C above the 20th century baseline. A similar range is produced with regional climate change models that are used to downscale global climate simulations.

Over the last several decades, West Africa has undergone a decrease of precipitation starting in the 1950s. This led to a particularly dry period in the 1970s and 80s. This was followed by a slight increase in precipitation until present, and future climate projections show a slight increase of total precipitation and a longer rainy season[28].

A gradual warming, which varies spatially, of up to 0.5°C per decade has been observed. Projected climate change for West Africa indicates continuous and stronger warming of 1.5-6.5°C, and a ~30% wider range of precipitation uncertainty. Most countries in the region will have to cope with shorter rainy seasons, arid and semi-arid conditions, longer dry spells and more frequent extreme rainfall. Such conditions can produce considerable stresses on agricultural activities, water resource management, ecosystem services and urban planning[29].

3.1.2. Projections for Monrovia, Liberia

An overall ensemble mean of 16 climate models across three emissions scenarios suggests that Monrovia will warm by: i) 1.92 ± 0.65°C by 2050 and 2.65 ± 0.84°C by 2080 during the dry season; and ii) 1.61 ± 0.35°C by 2050 and 2.60 ± 0.79°C by 2080 during the wet season[30]. Atmosphere-Ocean General Circulation Models (AOGCMs) are consistent in predicting warmer conditions throughout Liberia, However, AOGCM predictions of precipitation in Liberia are inconsistent. Projected precipitation changes in Monrovia range from 36% decreases to 21% increases in wet season rainfall. In trying to address this uncertainty in the CMIP5 AOGCMs in future projected precipitation, a dynamically downscaled dataset in Coordinated Regional Climate Downscaling Experiment (CORDEX) — for the years 1951–2100[,31] was used to try resolve the locally driving features. The outputs of this downscaled data for Monrovia (6° 18' 48" N, 10° 48' 5" W) was then analysed using the ClimPACT[32] methodology.This methodology seeks to present temperature, rainfall and heatwaves from the ten driving general circulation models (GCMs) used in the CORDEX downscaling. The following results are based on this analysis. The slopes presented are a simple linear regression, where a positive slope with a

[28] Reide, J.O., Posada, R., Fink, A.H., Kaspar, F. 2016. What's on the 5th IPCC Report for West Africa? *Adaptation to Climate Change and Variability in Rural West Africa*: 7-23.
[29] Sylla, M.B., Nikiema, P.M., Gibba, P., Kebe, I, Klutse, N.A.B. 2016. Climate Change over West Africa: Recent Trends and Future Projections. *Adaptation to Climate Change and Variability in Rural West Africa*: 7-23.
[30] Ibid.
[31] Available online at: https://cordex.org/
[32] Available online at: https://climpact-sci.org/

significant p-value ($p < 0.05$) indicates that an index is expected to increase over time and a negative slope with a significant p-value ($p > 0.05$) indicates that an index is expected to decrease over time.

Precipitation
The overall prediction across emission scenarios gives a slight increase in wet season rainfall of 1.54 ± 11.09% by 2050 and 1.92 ± 13.21% by 2080 (Table 2)[33]. Additionally, future projections indicate that while annual precipitation is projected to increase the number of wet days is projected to remain relatively constant (Figure 17). The increased rainfall occurs mostly during the early months of the rainy season, beginning in the southeast in May and extending west along the coast in June and July, implying more intense rainfall events[34]. Further to this, future projections indicate that the number of days receiving more than 10mm and 20mm of rainfall will increase toward the end of the century (Figure 18). Future projections of the number of consecutive wet days per year indicate slight increases for the 25th and 50th percentiles and a slight decrease for the 75th percentile, under RCP4.5. Under RCP8.5, the number of consecutive wet days is projected to increase for the 25th percentile and decrease for the 50th and 75th percentiles.

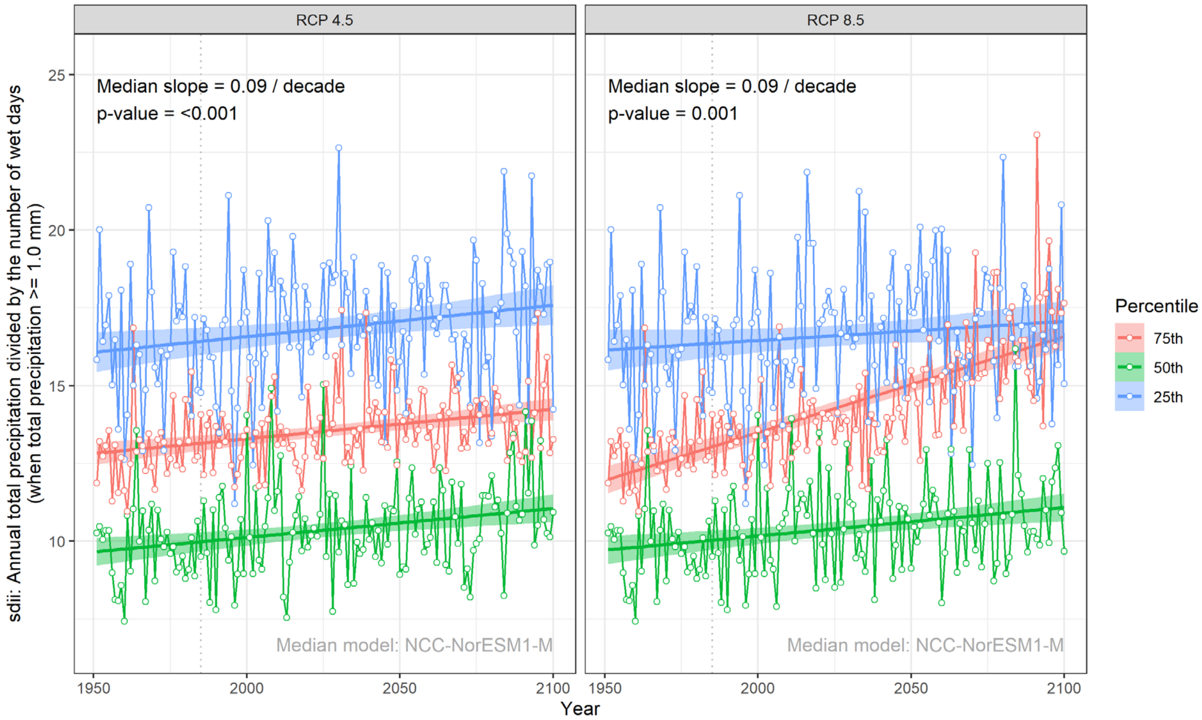


Figure 13. Annual total precipitation divided by the number of wet days (total precipitation >= 1.0 mm).

[33] Sylla, M.B., Nikiema, P.M., Gibba, P., Kebe, I, Klutse, N.A.B. 2016. Climate Change over West Africa: Recent Trends and Future Projections. *Adaptation to Climate Change and Variability in Rural West Africa*: 7-23.
[34] Ibid.

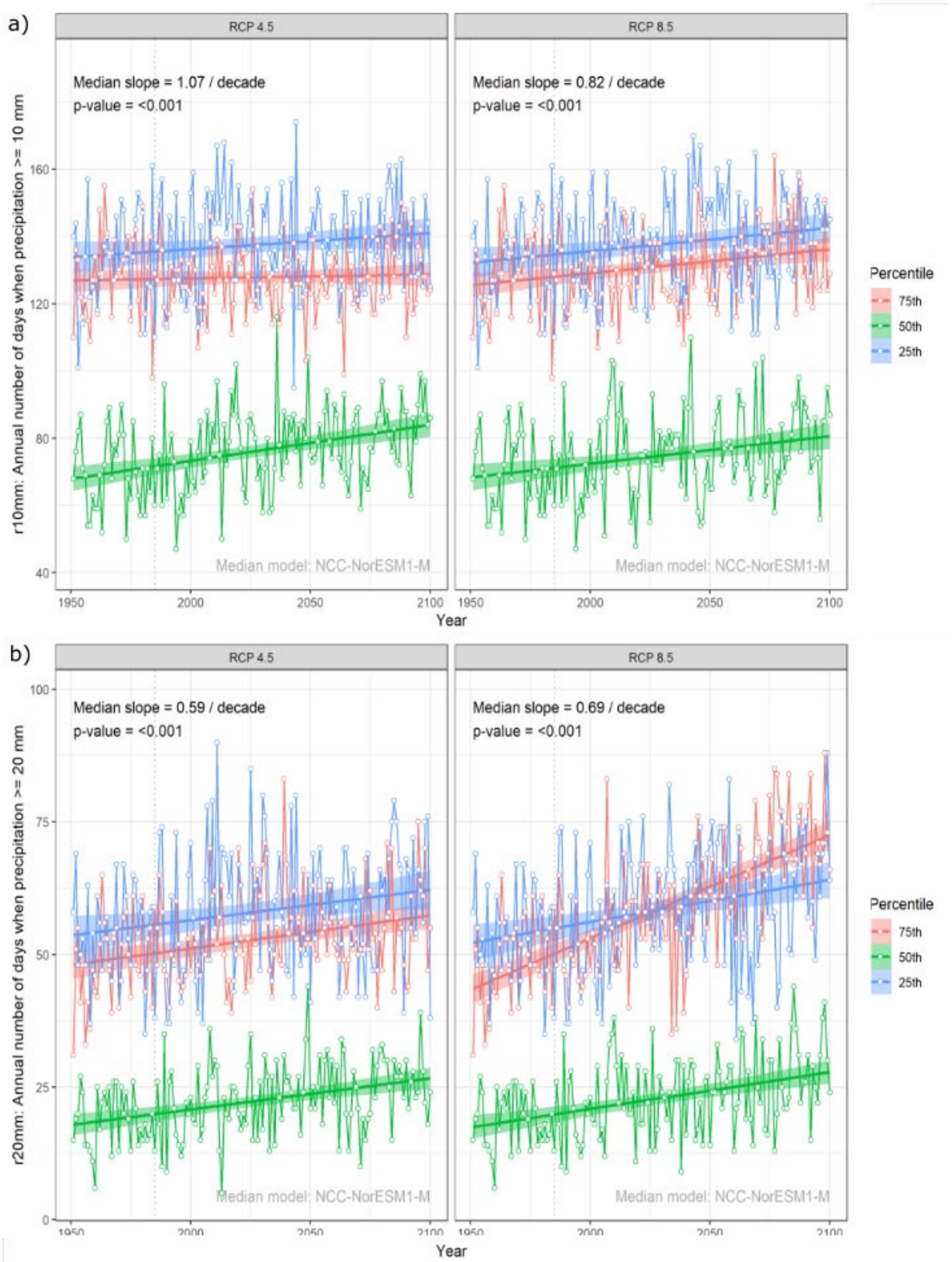


Figure 14. Annual number of days where precipitation is a) >=10 mm and b) >=20 mm.

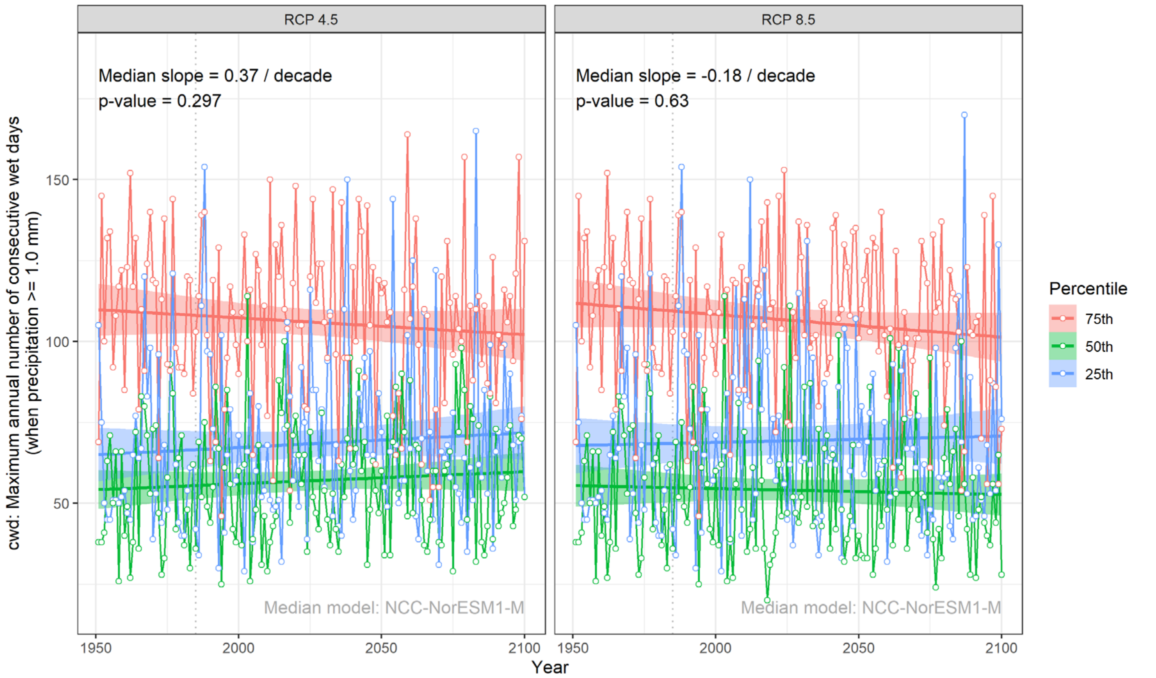


Figure 15. Maximum annual number of consecutive wet days (with precipitation >= 1.0 mm).

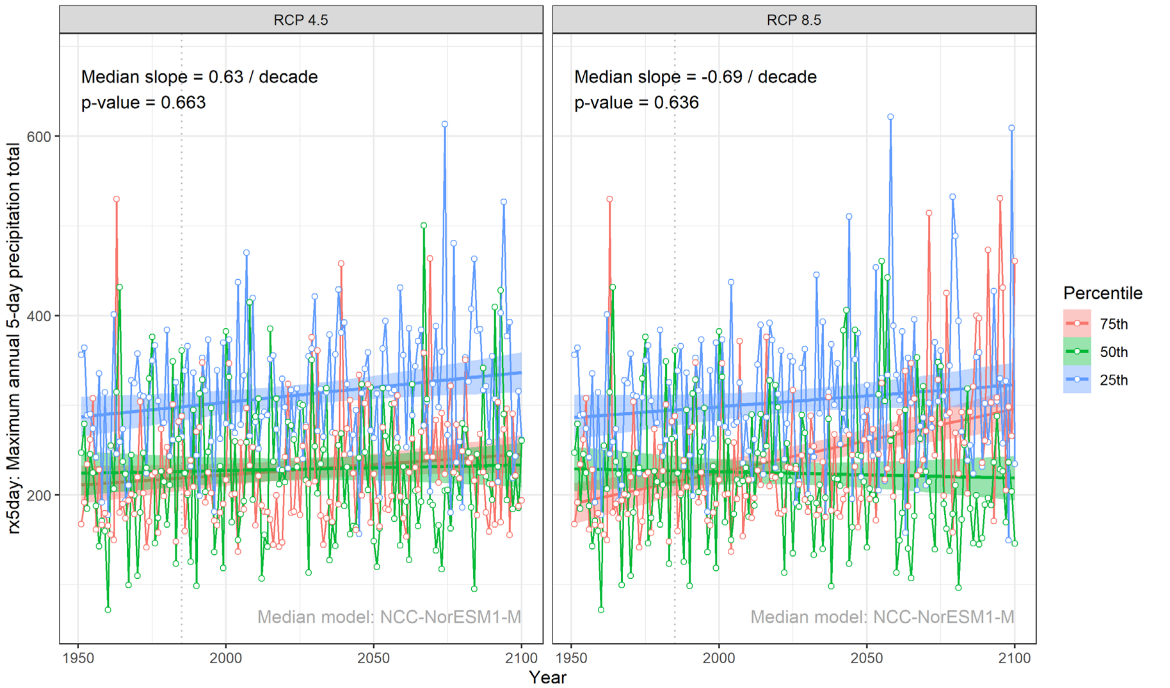


Figure 16. Maximum annual 5-day precipitation total.

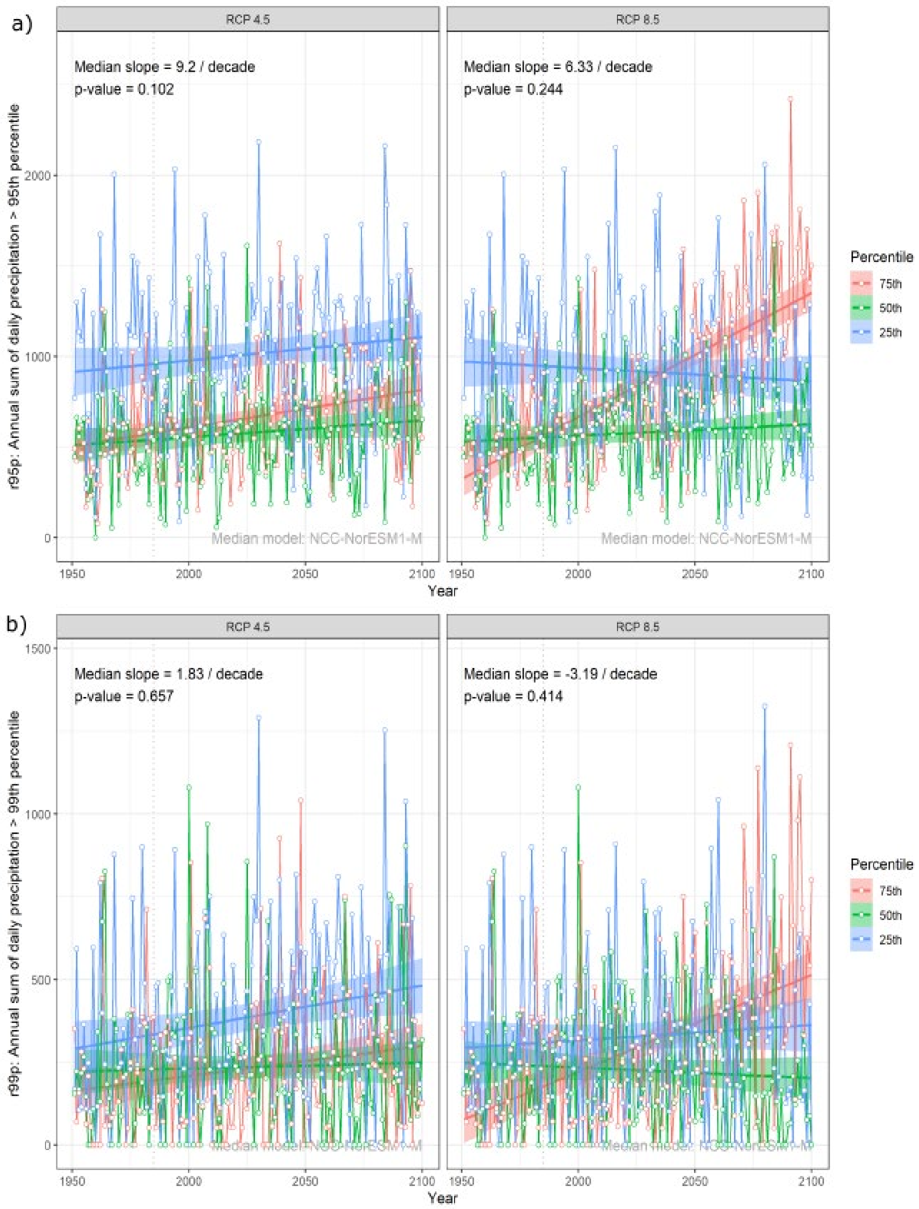


Figure 17. Annual sum of daily precipitation a) >95th percentile and b) >99th percentile.

Temperature

Projections indicate that maximum temperatures will increase toward the end of the century. Within these projections, the number of days above 30°C per year (Figure 22) and the number of days contributing to events where six or more consecutive days experience maximum temperatures above the 90th percentile (Figure 23) are predicted to increase significantly. Additionally, the mean annual difference between maximum and minimum daily temperatures is projected to decrease significantly (Figure 24).

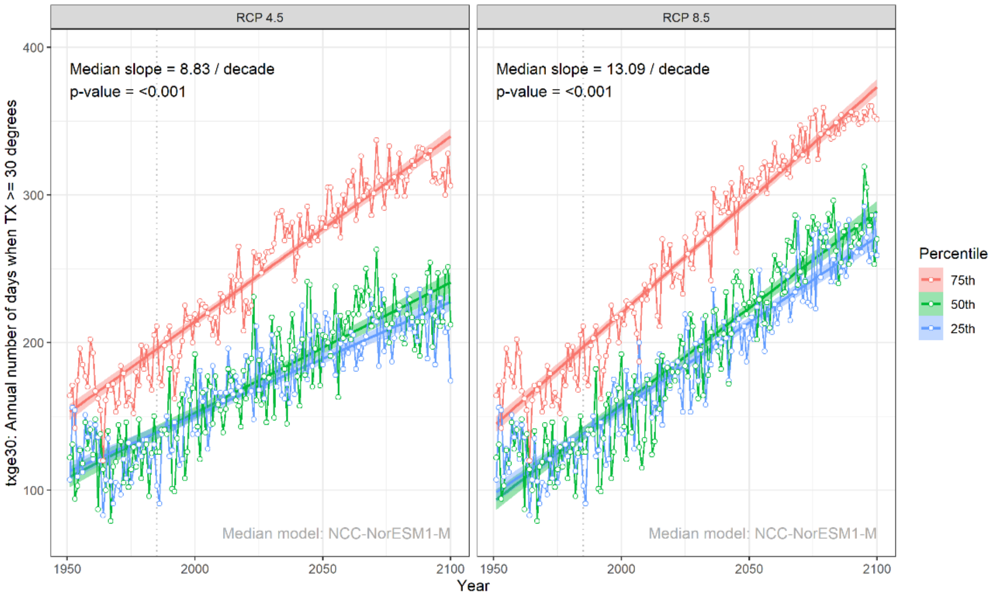


Figure 18. Annual number of days where maximum temperature >= 30°C.

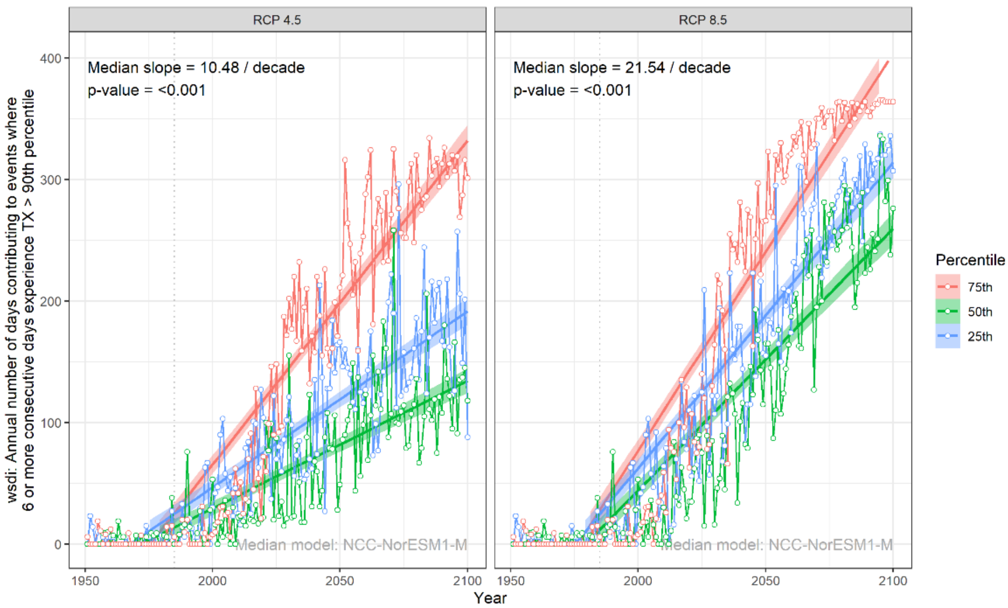


Figure 19. Annual number of days contributing to events where six or more consecutive days experience maximum temperatures >90th percentile.

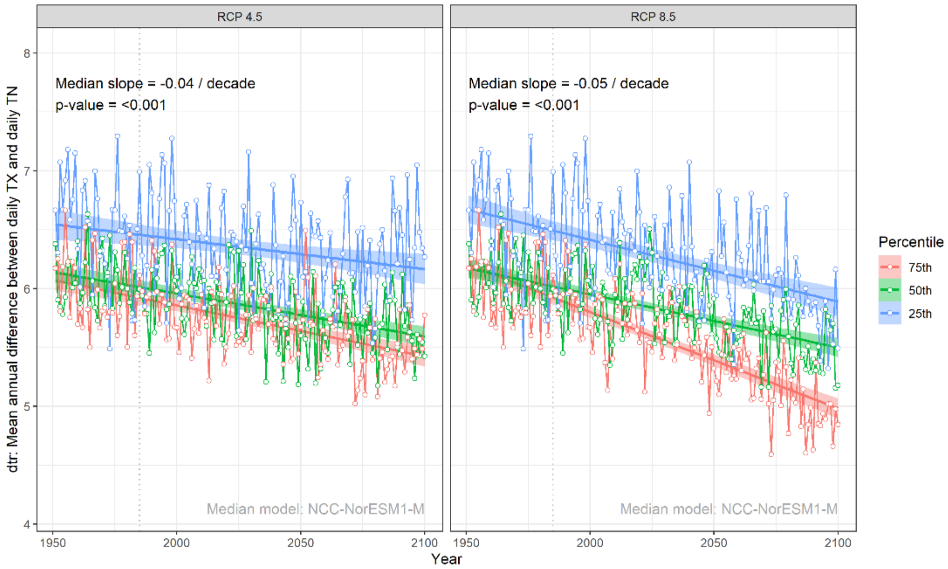


Figure 20. Mean annual difference between maximum daily temperature and minimum daily temperature.

Heat waves

Projections of heat waves indicate that their duration (Figure 25) will increase significantly toward the end of the century, despite the number of discreet heat wave events (Figure 26) projected to only increase slightly or even decrease — except for the 25th and 50th percentiles under RCP4.5. In addition, the magnitude of these events is projected to increase (Figure 27).

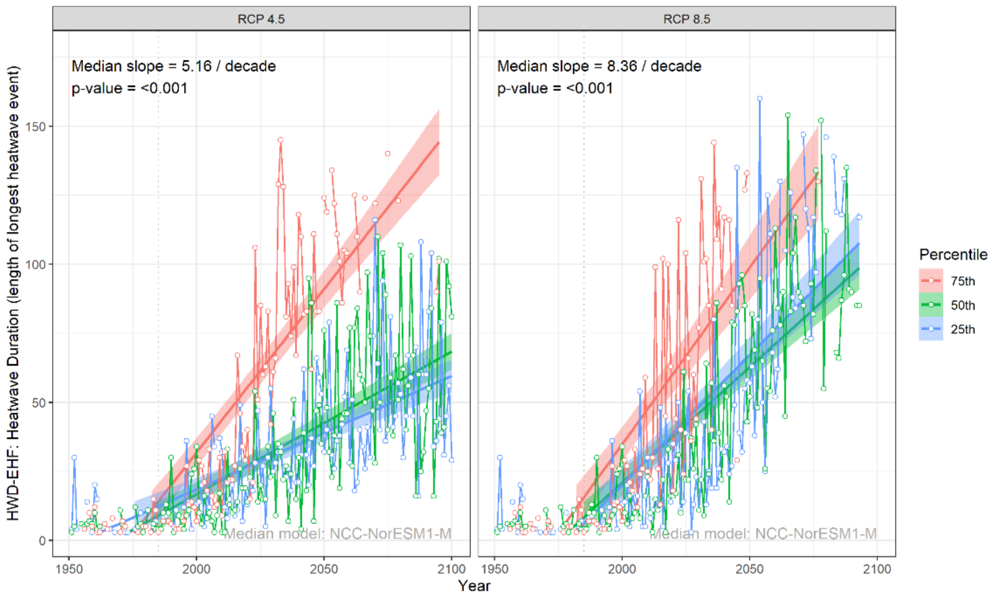


Figure 21. Heatwave duration (length of longest heatwave event).

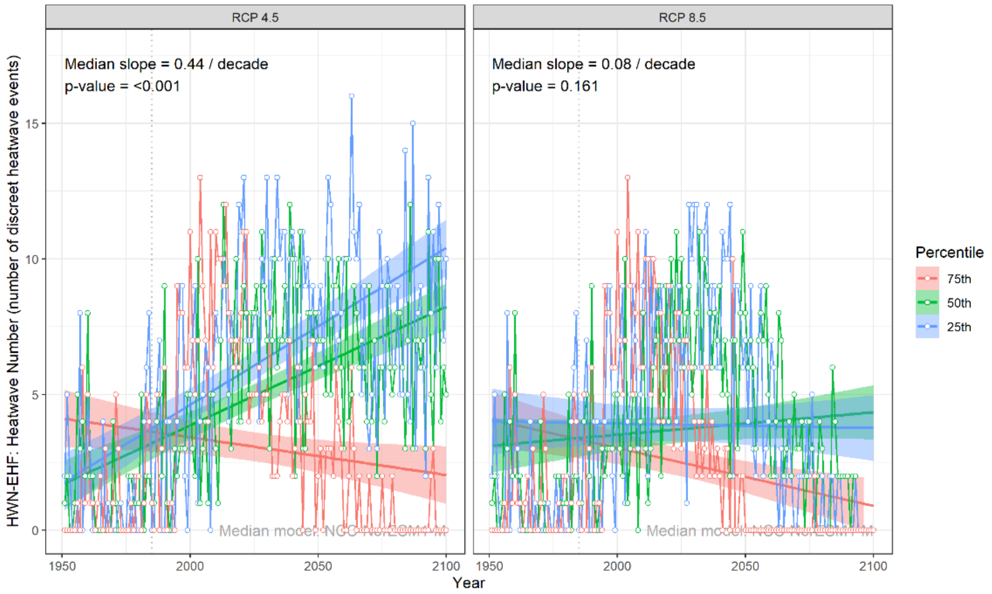


Figure 22. Heatwave number (number of discrete heatwave events).

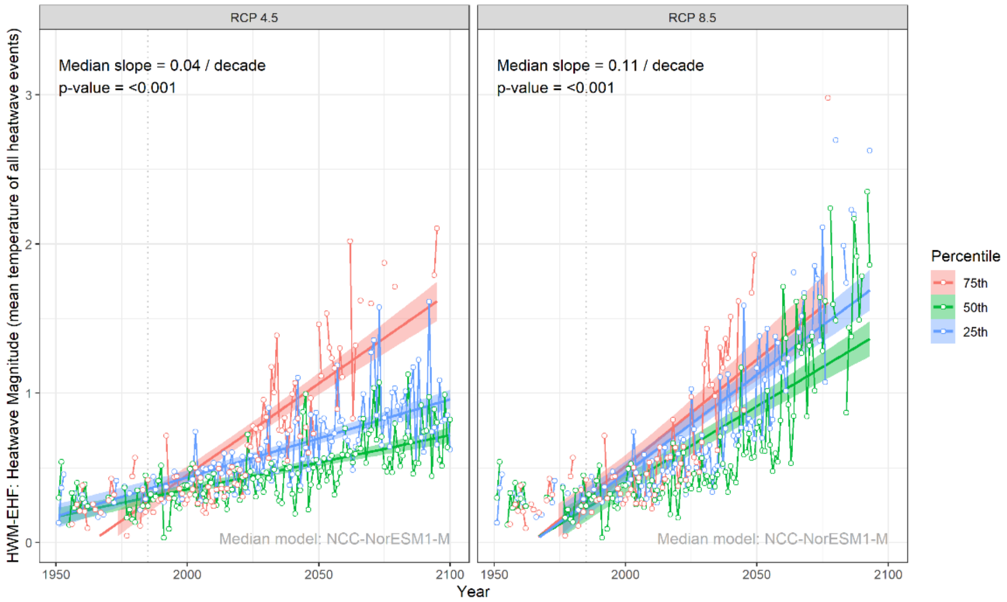


Figure 23. Heatwave magnitude (mean temperature of all heatwave events).

In conclusion, projected temperature and precipitation changes for 2050 and general trends for 2080 are a warmer and wetter climate in most of the country, particularly in the coastal zone.

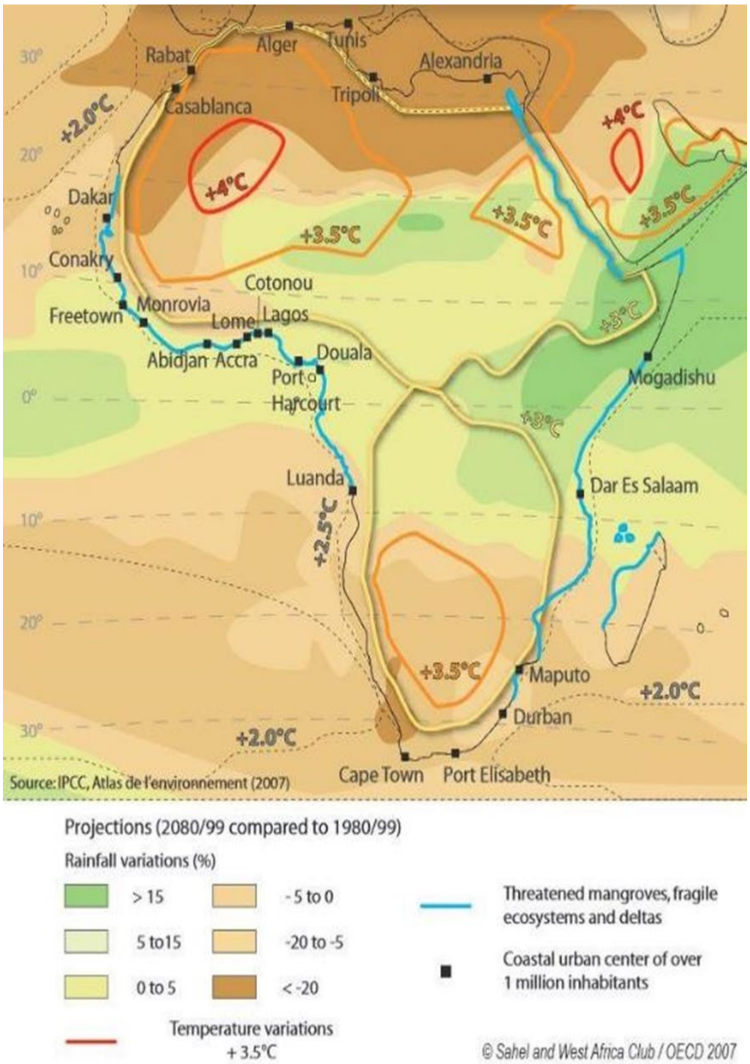


Figure 24. An overview of projected climate change in Africa[35].

[35] OECD Atlas on Regional Integration in West Africa.

Table 2. Potential change in temperature (°C) and percent change in rainfall for the dry (Dec-Feb) and wet (Jun-Aug) seasons at Monrovia[36].

Monrovia		Dry Season				Wet Season			
		B1	A1B	A2	Mean	B1	A1B	A2	Mean
2050 Temperature	Mean	1.54	2.15	2.07	1.92	1.30	1.79	1.75	1.61
	Std Dev	0.48	0.53	0.77	0.65	0.29	0.28	0.27	0.35
	Min	0.50	0.91	-0.07	-0.07	0.62	1.26	1.13	0.62
	Max	2.19	3.02	3.19	3.19	1.76	2.30	2.14	2.30
2080 Temperature	Mean	1.90	2.83	3.22	2.65	1.85	2.75	3.21	2.60
	Std Dev	0.47	0.57	0.81	0.84	0.45	0.56	0.63	0.79
	Min	1.10	1.91	1.26	1.10	0.80	1.57	1.85	0.80
	Max	2.68	3.81	4.77	4.77	2.75	4.01	4.35	4.35
2050 Precipitation	Mean	0.63	6.31	3.94	3.63	0.88	1.50	2.25	1.54
	Std Dev	-5.50	1.00	-2.00	-1.50	10.28	11.79	11.81	11.09
	Min	-22.00	-26.00	-24.00	-26.00	-26.00	-25.00	-25.00	-26.00
	Max	20.22	24.40	28.55	24.21	16.00	20.00	20.00	20.00
2080 Precipitation	Mean	6.13	6.50	11.13	7.92	3.13	1.94	0.69	1.92
	Std Dev	23.10	31.49	40.49	31.86	11.52	14.20	14.46	13.21
	Min	-25.00	-47.00	-35.00	-47.00	-29.00	-36.00	-32.00	-36.00
	Max	55.00	92.00	125.00	125.00	18.00	18.00	21.00	21.00

Current trends of climate change impacts

The changes in conditions resulting from changes in climate are causing two major impacts in Monrovia: i) flooding; and ii) coastal erosion resulting in shoreline retreat. This section focuses on these two main impacts, while the more indirect impacts of climate change are discussed further in Section 4.

3.2. Flooding

Flooding — as a result of heavy rainfall, poor drainage and the construction of buildings in high risk areas such as waterways — is an ongoing challenge in Monrovia and other parts of Liberia (Figure 13). In communities where floods pose a regular threat, particularly in the rainy season, human health and well-being are at risk. Monrovia cities lack adequate sanitation and waste management. As a result, during floods, faecal matter and other waste materials are deposited along the streets. In addition, to pollution from human waste, there is also potential for hydrocarbon spills into waterways as a result of flooded petrol stations. This water pollution subsequently results in residents lacking access to safe drinking water. Bottled water for drinking is an expensive commodity, and many members of the community are underprivileged.

The impacts of flooding in Monrovia are being intensified by climate change causing increases in annual rainfall, as well as an increase in frequency of heavy rainfall events. Additionally, as climate change continues to cause sea-level to rise, the coastal communities of Monrovia are increasingly affected by flooding.

[36] Ibid.

Figure 25. Left: Flooding on the main street along the Freeport community, Monrovia; Right: Flooding in Old Road, Monrovia[37].

3.3. Coastal erosion and shoreline retreat

Shoreline retreat along the coast of Monrovia is being caused by accelerated coastal erosion. Along large stretches of Monrovia's coast, particularly New Kru Town and West Point, significant retreat has taken place (Figure 14 and Figure 15). This leads to a loss of land and recreational beaches. This has an impact on fishing and houses in these communities, as landings for fishing boats are continually eroded and the land where houses are situated becomes more unstable and erodes away (Figure 15). The impact of coastal erosion and shoreline retreat on housing in West Point could result in these communities expanding into the Mesuarado Wetland mangroves, in search of land to re-settle. This expansion would place additional pressures on the ecosystem goods and services of the mangroves outlined in Section 4.3.1.

[37] Photos: A. Tumbey.

Figure 26. Position of the coastline at West Point and the mouth of the Mesurado Wetland in 2008 and 2018.

Figure 27. Left and right: Coastal erosion at West Point[38].

A major cause of accelerated coastal erosion is a more intense wave climate. Wave height distribution in the area offshore of Monrovia has increased over the past two decades (Figure 16). Trends show that the higher waves, particularly the 10% highest waves, are getting higher and increasing between 3-5%.

[38] Photos: A. Tumbey.

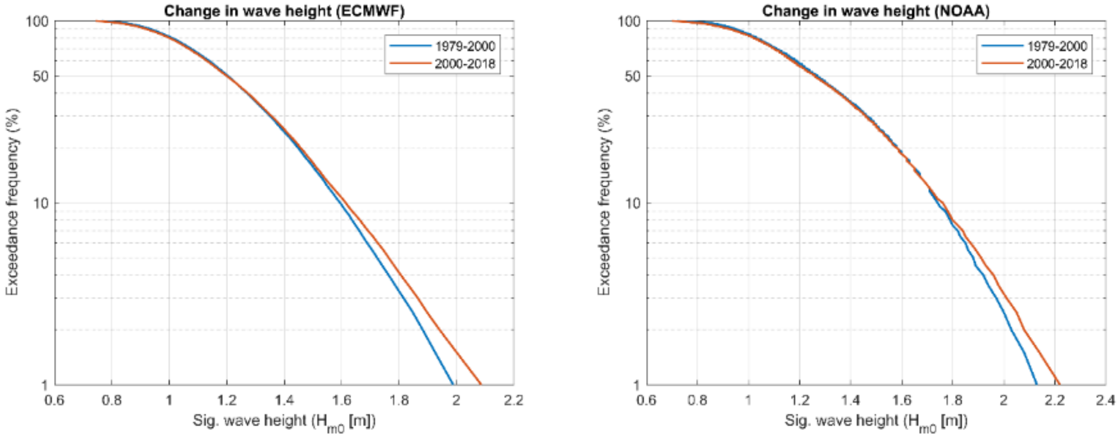


Figure 28. Observed impact on wave height last two decades based on ECMWF hindcast data (left) and NOAA hindcast data (right). Data was extracted for offshore location 6°N 11°W.

Following the established observed trends and impacts of climate change in Monrovia, an assessment of anticipated future trends and impacts is necessary to support a robust climate rationale for the project. To this end, appropriate scenarios and projections are described in the following sections.

3.3.1. Methodology

The technical methodology used for this assessment incorporates the anticipated impact of the IPCC climate change projections and scenarios on coastal erosion.

Two types of coastal erosion are considered: i) structural or chronic coastal retreat, which is affected by sediment deficit and the Bruun Rule[39]; and ii) storm erosion. The first is a continuous process while the latter is caused by the retreat after an extreme storm event with a specific return period. Thus, storm erosion should be considered as an additional form of coastal retreat to structural coastal retreat and is therefore also treated separately.

Coastal erosion is affected by several forcing mechanisms, which include: i) near shore wave conditions; ii) sea-level rise; iii) run off and temperature; and iv) storm wave conditions (Figure 29). The climate change impact on each forcing mechanism has been assessed in order to determine the impact of climate change on coastal erosion overall.

[39] The Bruun Rule describes a linear relationship between sea-level rise and shoreline recession based on equilibrium profile theory, which asserts that shore face profile maintains an equilibrium shape, and as sea level rises the increasing accommodation space forces this equilibrium profile landward and upward to preserve its shape relative to the new sea level.

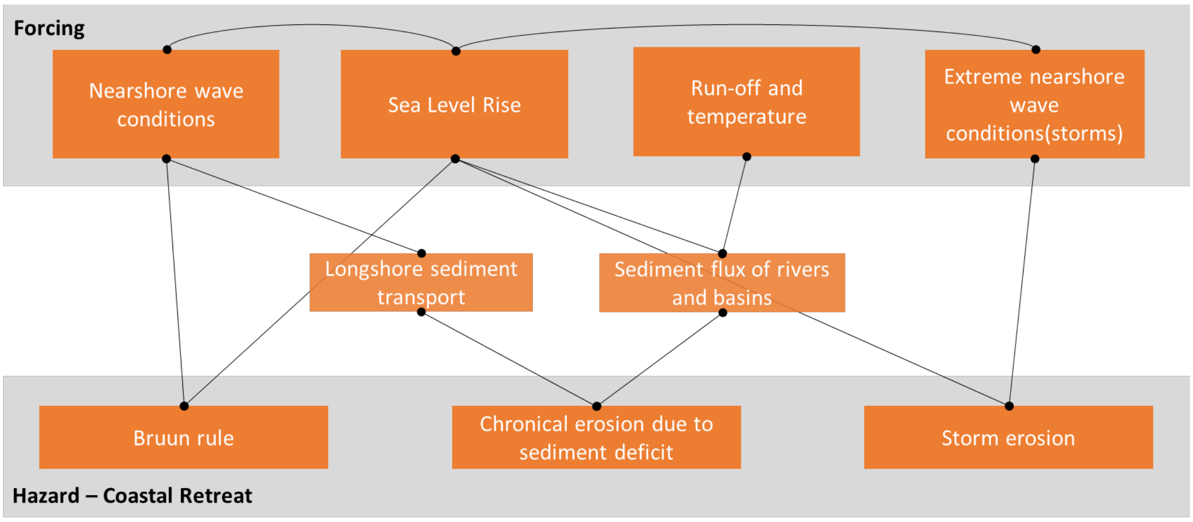


Figure 29. The interrelation between forcing mechanisms and coastal retreat. The two middle boxes show the most important processes involved in coastal erosion.

3.3.2. Climate change impacts on forcing mechanisms of coastal erosion

Sea-level rise

There is evidence that sea-level rise, caused by global warming, is increasing globally. Further to this, since at least the start of 20th century, the average global sea-level rise rate has been accelerating. The three main reasons global warming causes global sea-level rise are i) expansion of oceans; ii) ice sheets losing ice faster than formed by snowfall; and iii) glaciers melting at higher altitudes.

Relative sea-level rise (RSLR) is the sum of three major components: i) global mean sea-level change; ii) regional spatial variations in sea-level change; and iii) land movement, both subsidence and tectonic.

The RSLR based on different climate models is provided by IPCC AR5[40]. These projections are available for all for RCPs and as time series. Methodologies for developing regional and local scenarios are widely established and used. Here the 'intermediate' methodology[41] has been applied.

Figure 30 shows the resulting relative sea-level rise projections for the two RCP scenarios for the period 2000 to 2100 (which is the average of the lower and upper bound). The worst-case scenario (RCP 8.5), shows a projected relative global sea-level rise of almost 75 cm for the year 2100.

[40] The Fifth Assessment Report of the IPCC, published in 2014
[41]Nicholls et. al., 2011

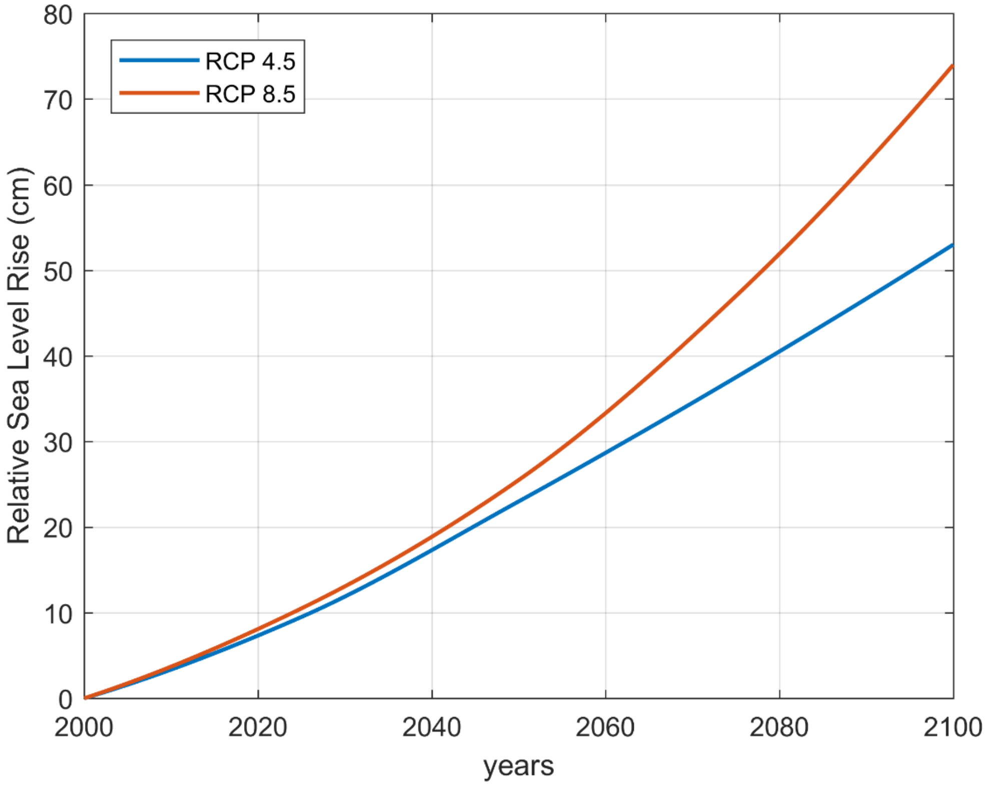


Figure 30. Projected relative global sea-level rise for RCP 4.5 and RCP 8.5.

The projected relative sea-level rise over the last two decades (2000–2018) has been compared to the satellite global sea-level rise observation[42]. The regional variation in sea-level rise in this area is relatively small, and comparison with global sea-level rise is therefore justified. Current sea-level rise is very similar to the projections and the present level is in between the least and most conservative scenario (Figure 31).

[42] Global sea-level rise observation data produced by NASA

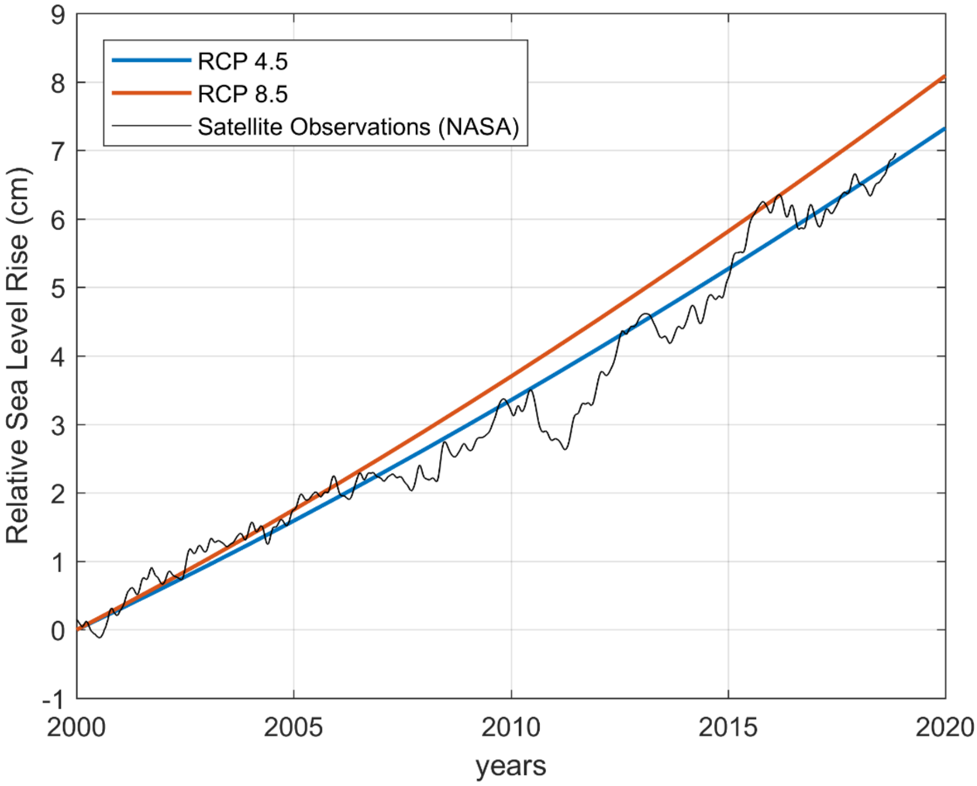


Figure 31. Observed and projected relative sea-level rise for RCP 4.5 and RCP 8.5.

Wave conditions

The wave climate has changed during the last decade, with evidence showing that waves are increasing in height. This increase, which is considered to be caused by climate change, is also found in future projections.

To assess the effect of climate change on the wave conditions, run-off and temperature, the main sources available are Global Circulation Models (GCM's). There are more than 60 different GCMs developed and used by many different research institutes around the world. For both scenarios, RCP4.5 and RCP8.5, collective GCMs are used as input for global wave models. This results in global wave statistics, including significant data on wave height, wave period and wave direction. The resulting wave data have been analysed at a location offshore of the coast of Monrovia (6°N 11°W) to assess the relative impact of climate change on the offshore wave conditions (Figure 32).

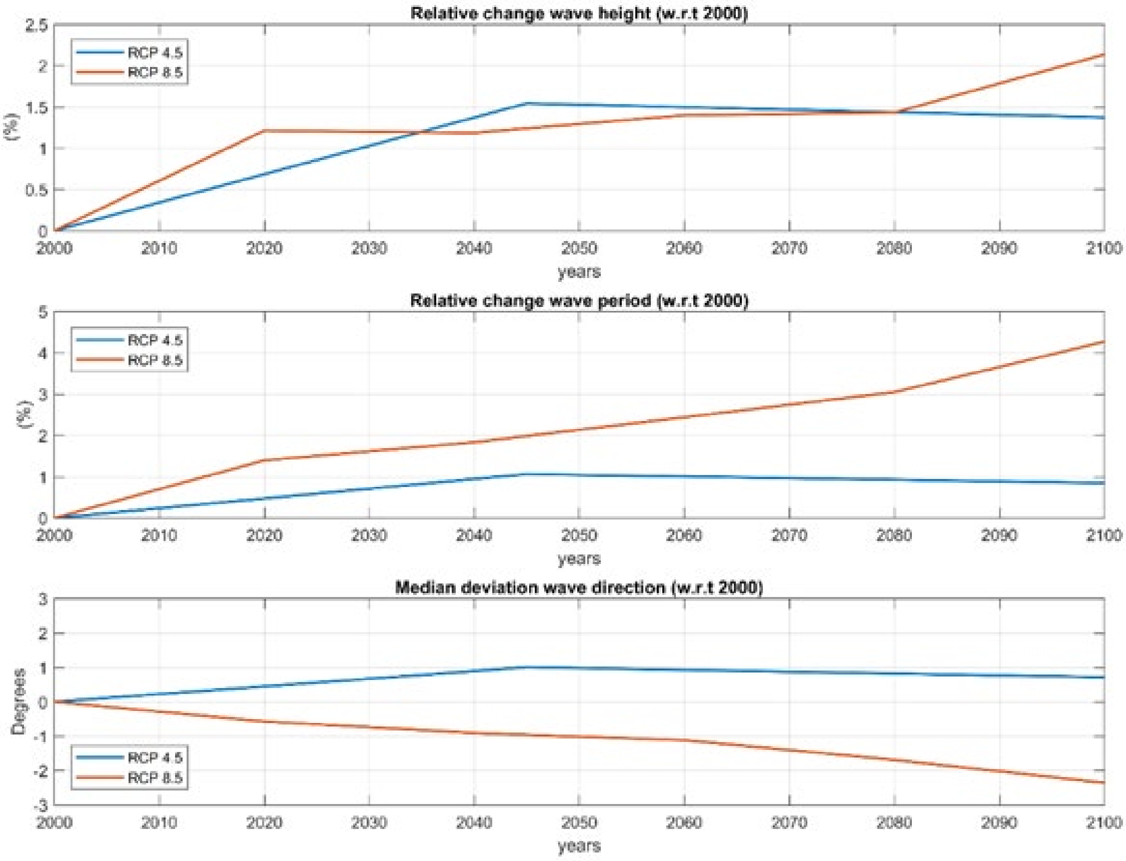


Figure 32. Changes in wave conditions, upper panel: relative increase in wave height (%), middle panel: relative increase in mean wave period (%), lower panel: median deviation of wave direction in degrees (positive values means clockwise, negative means anti-clockwise – nautical convention of wave direction: coming from with 0 degrees is North).

From this assessment, it can be determined that:

- For both scenarios the wave heights increase, with the highest increase with RCP8.5. Note that the highest waves increase more compared to the lower waves.
- For both scenarios the wave periods increase, with significant more increase for scenario RCP8.5.
- For scenario RCP4.5 the wave direction deviates to more westerly waves (clockwise turn), while for RCP8.5 the wave direction becomes more southerly/easterly (anti-clockwise turn). Note that for both scenarios the higher wave angles (westerly) shows a larger deviation (compared to the median) than the southerly waves.

Storm conditions

The results from the global wave model ensembles (Figure 32) are used to assess the relative increase of storm magnitudes. This is done by evaluating the wave height with a 10-year return period for several time slices of each ensemble. The relative increase has been determined by taking the average of the relative increase of all the ensemble members of each scenario.

Figure 33 shows the relative increase of the significant wave height of the extreme wave heights (10-year return period).

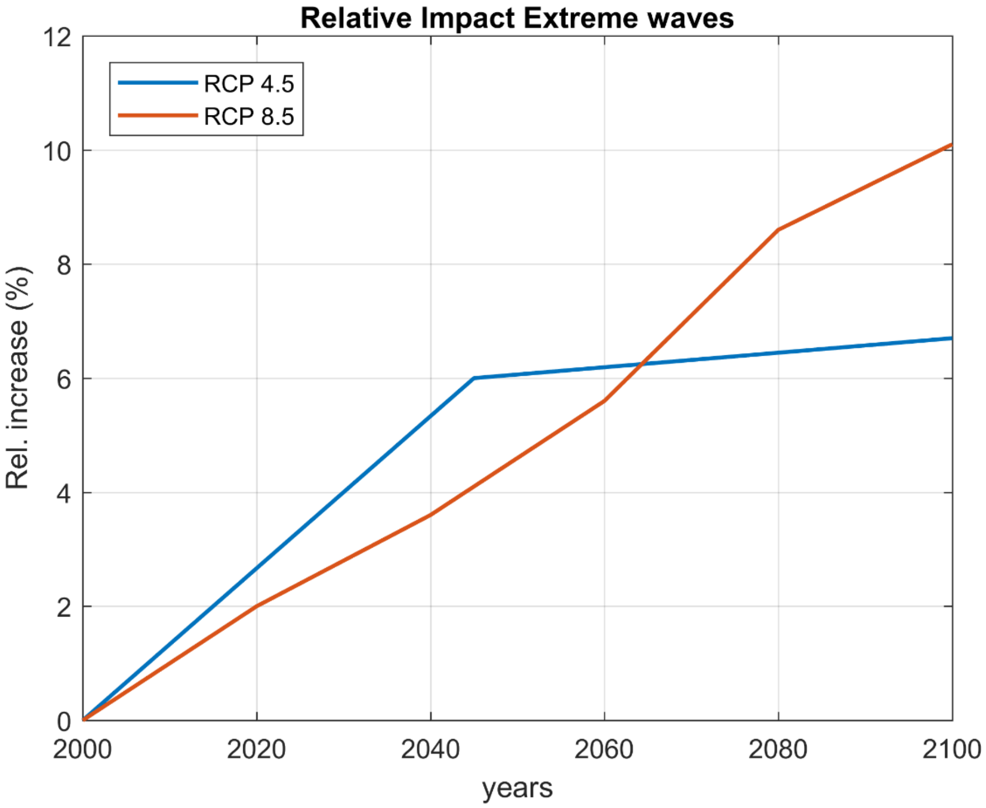


Figure 33. Relative impact on storm conditions (wave height) for RCP4.5 and RCP8.5.

This also means that storms occur more frequently. The storm with a 100-year return period in the year 2000 will have a smaller return period in 2100 due to climate change. The following figure shows the extreme value distributions of the offshore significant wave height for both scenarios in 2100.

From this it can be concluded that due to climate change the 100-year wave height will have a return period of approximately 40 years with RCP4.5 and 25 years with RCP8.5 in 2100. Which means that with RCP4.5 this storm will occur 2.5 times more often and with RCP8.5 four times more often.

3.3.3. Climate change impacts on coastal processes

The Bruun rule

The Bruun rule is the shift of the equilibrium beach profile due to sea-level rise, leading to coastal retreat (Figure 34[43]). The resulting coastal retreat is linearly dependent on sea-level rise, profile slope and depth of closure. The depth of closure, the critical depth for which the profile is morphologically active, is in turn dependent on local wave conditions.

[43] FitzGerald, D.M., Fenster, M.S., Argow, B.A., & Buynevich, I.V. (2008). Coastal Impacts Due to Sea-Level Rise. DOI:10.1146/annurev.earth.35.031306.140139

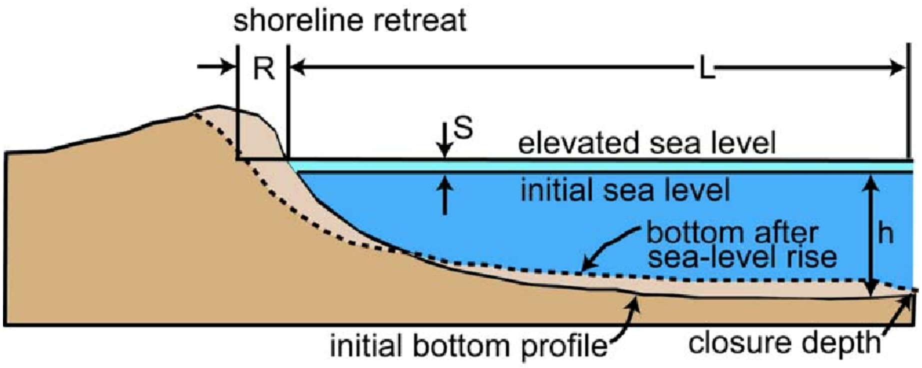
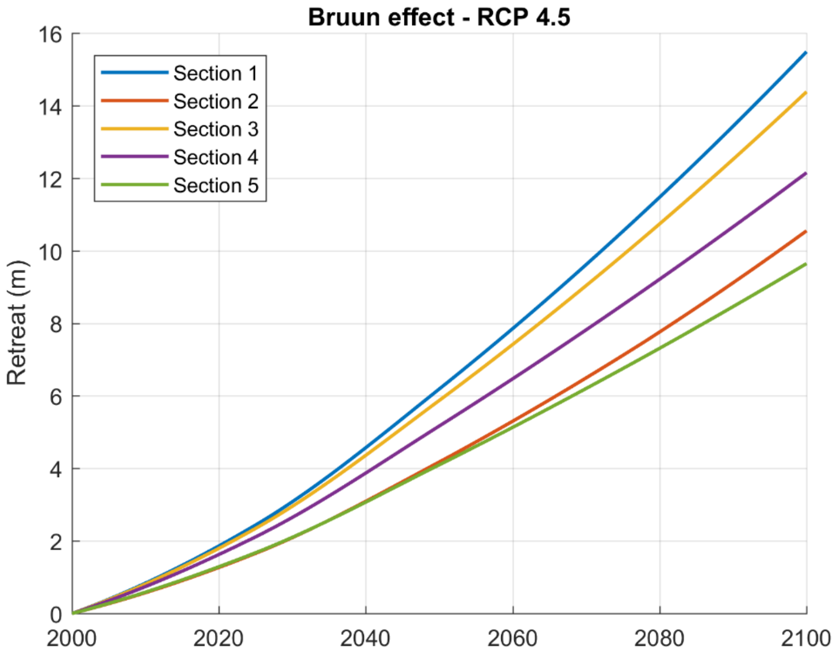


Figure 34. Schematic representation of the Bruun effect. An increase in ***S*** causes a shoreline retreat ***R*** due to erosion of the upper beach and sediment deposition offshore.

Depth of closure and beach profile slope of the Monrovian coastline, divided into five coastal sections, have been determined to estimate the retreat based on the Bruun rule for RCP scenarios 4.5 and 8.5 for the coming decades, while including the effect of changing wave conditions. The resulting coastal retreat for each coastal section (Figure 35) shows that the coastal retreat for RCP8.5 is more.



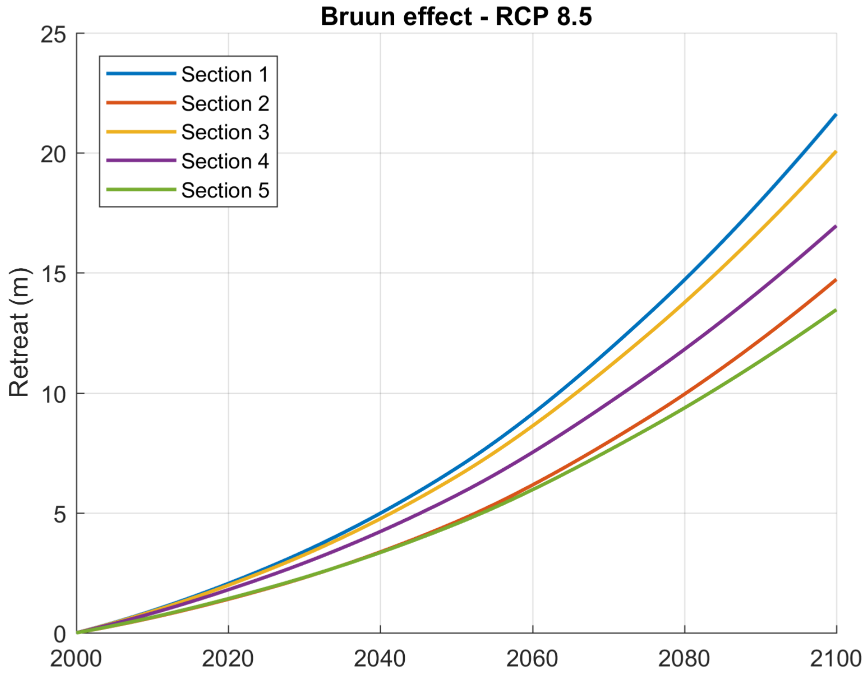


Figure 35. Coastal retreat due to the Bruun effect for RCP 4.5 (top panel) and RCP 8.5 (lower panel).

Sediment deficit

The coastal system of Monrovia can be described as a large sediment balance system, which is affected by coastal and riverine process. A change in this balance is likely to lead to a sediment deficit along certain stretches of the coast. Sediment deficit will ultimately lead to erosion and coastal retreat.

Longshore sediment transport is an important process in controlling sediment deficit and is induced by the strong wave breaking of the swell waves arriving oblique to the coastline. A larger wave height wave period and angle of impact will result in an increase of the longshore sediment transport. Wave angle of impact is particularly of importance, as this determine the magnitude and direction of the longshore sediment transport. In cases where coastline direction matches the dominant wave direction closely, the longshore sediment transport approaches zero and the coastline is considered to be in an equilibrium.

Based on the description above, it is important to note that the coastal retreat is not dependent on the longshore sediment transport magnitude itself, but rather on the alongshore variation of longshore sediment transport.

The longshore sediment transports for transects of the five Monrovian coastal sections, example in Figure 36, are calculated using the nearshore wave climates, taking RCP4.5 and RCP8.5 climate scenarios into account (Figure 37).

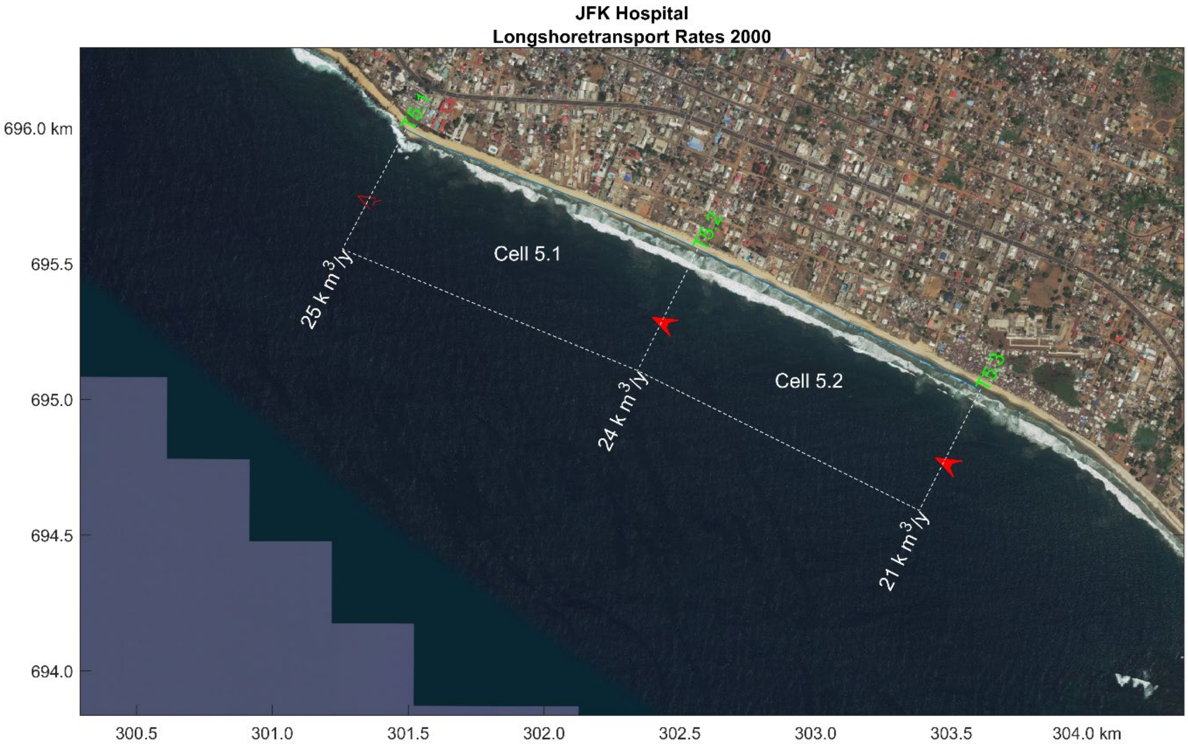


Figure 36. The defined coastal cells of section 5 including annual sediment transport rates.

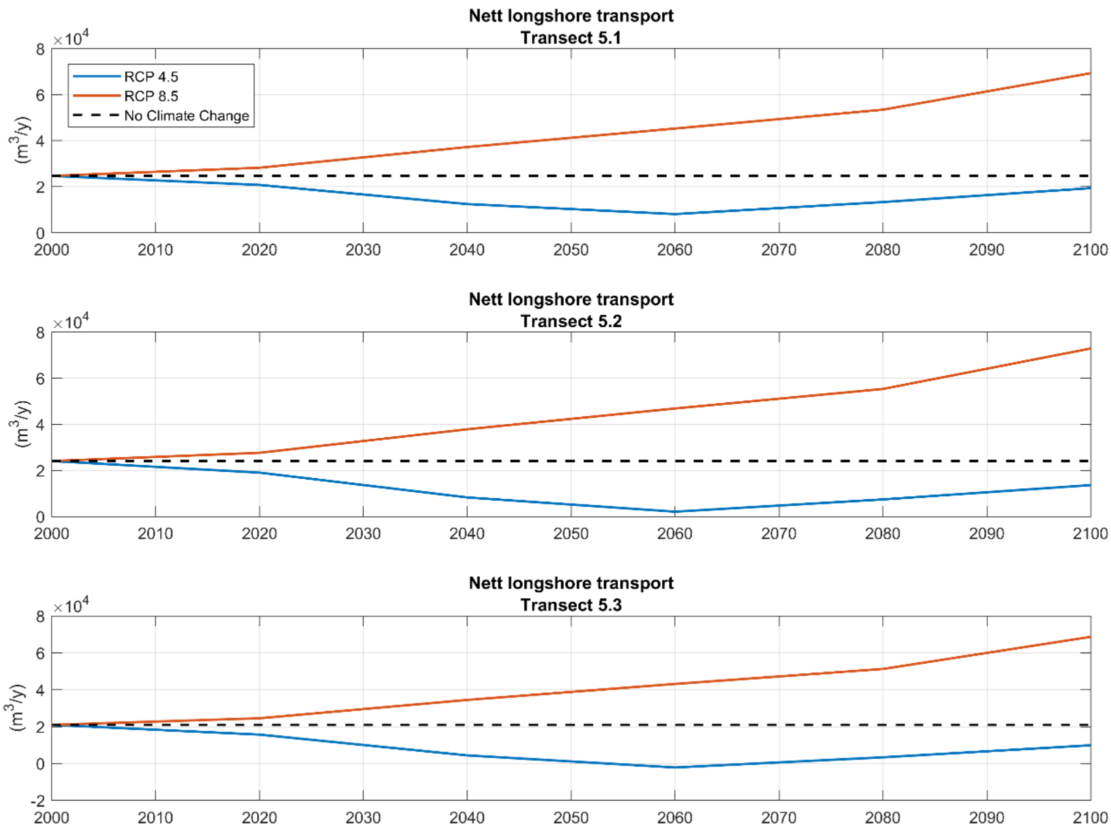


Figure 37. Annual transport rates for the three defined transects of coastal section 5 for RCP4.5, RCP8.5 and no climate change.

Based on the results, the longshore sediment transport rates for each scenario is considerably different. Due to the fact that the that the projected future wave direction deviation for scenario RCP8.5 is more south-easterly and the wave height increases, the longshore sediment transport rates increase. However, since the wave direction for RCP4.5 is more westerly, the longshore sediment transport decreases, irrespective of the fact the wave height increases. This shows the dominant effect of the wave direction to longshore sediment transport rates and illustrates the variation in all relevant variables to be considered.

These values are used to derive the cumulative sediment transport and hence balance of each coastal cell (Figure 38).

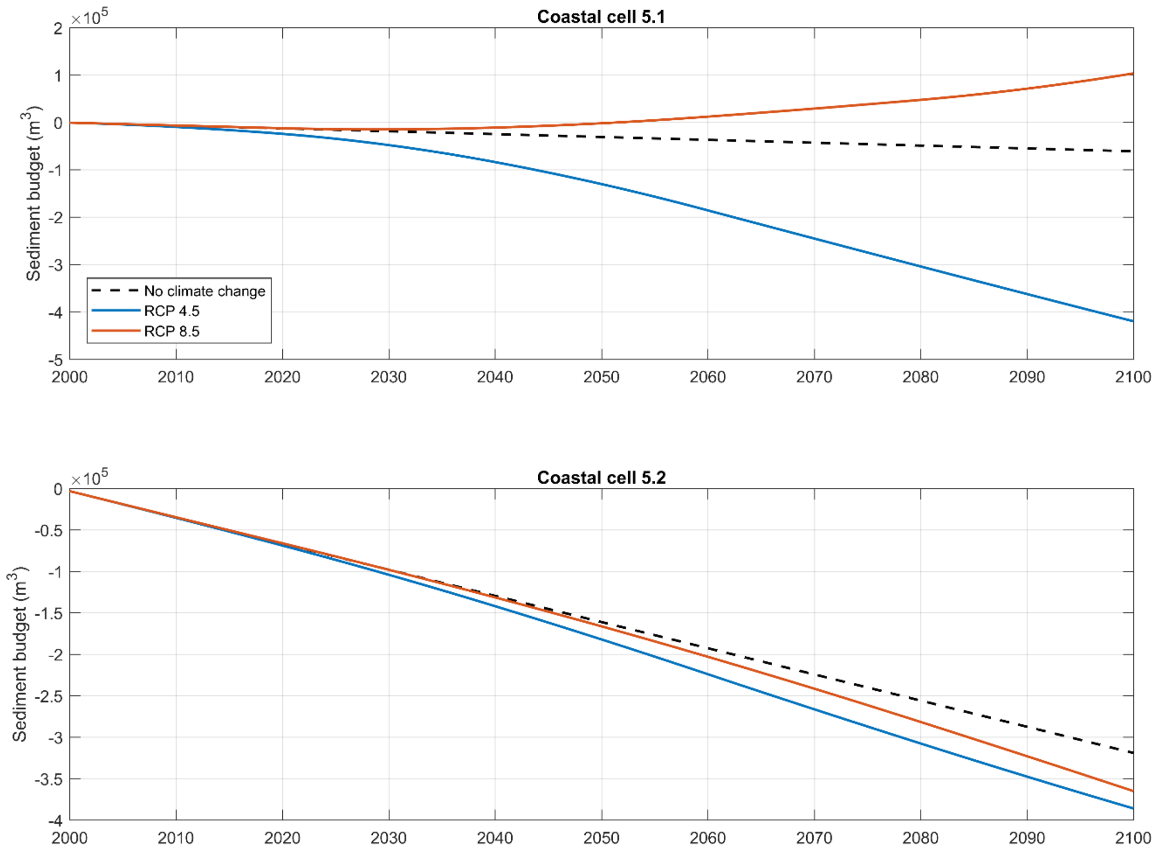


Figure 38. Sediment balance for coastal cells of coastal section 5 for RCP4.5 and RCP8.5.

3.3.4. Coastal retreat due to sediment deficit and Bruun effect

The above-mentioned processes — sediment deficit and the Bruun effect — have been combined to assess the past, present and future coastal retreat at each coastal section of the Monrovian coastline. From the results, coastal sections 2 and 3 show relatively large coastal retreat, with both substantially worsening due to climate change.

The above figures show the effect of climate change and natural processes on the coastal retreat of each coastal section over the last two decades and future projections. The calculated values are compared to the observed coastal retreat over the last decade with use of satellite images.

Two satellite images of each coastal section are compared one taken on January 30, 2008 and one on March 12, 2018. The average coastal retreat over the coastal sections is calculated by determining the eroded and accreted areas divided by the length of each coastal section. The areas are determined using Google Earth.

Figure 39 shows an example of West Point (coastal section 3), where the red areas show the eroded areas and the green areas show the accreted areas.

Figure 39. Eroded and accreted areas between 2008 (left) and 2018 (right) at coastal section 3.

This results in the following observed coastal retreat values between 2008 and 2018 and calculated coastal retreat for both RCP4.5 and RCP8.5 and no climate change (Table 3). It is clear that the observed coastal retreat is very much in line with the calculated coastal retreat, particularly for the calculated values including the effect of climate change and substantiates therefore that the observed coastal retreat is also driven by climate change.

Table 3. Observed and projected coastal retreat between 2008 and 2018 for RCP4.5 and RCP8.5 and no climate change.

	Eroded	Accreted	Total Eroded	Length	Average coastal retreat 2008-2018 (m)			
	(m^2)	(m^2)	(m^2)	(m)	Observed	No CC	RCP 4.5	RCP 8.5
Section 1	20000	7250	12750	1950	6.5	5.4	6.6	6.8
Section 2	61500	0	61500	1650	37.3	33.0	34.2	34.3
Section 3	137240	56000	81240	2500	32.5	17.1	28.2	28.2
Section 4	19950	0	19950	2150	9.3	10.0	11.0	11.1
Section 5	10700	0	10700	3750	2.9	1.4	2.4	2.1

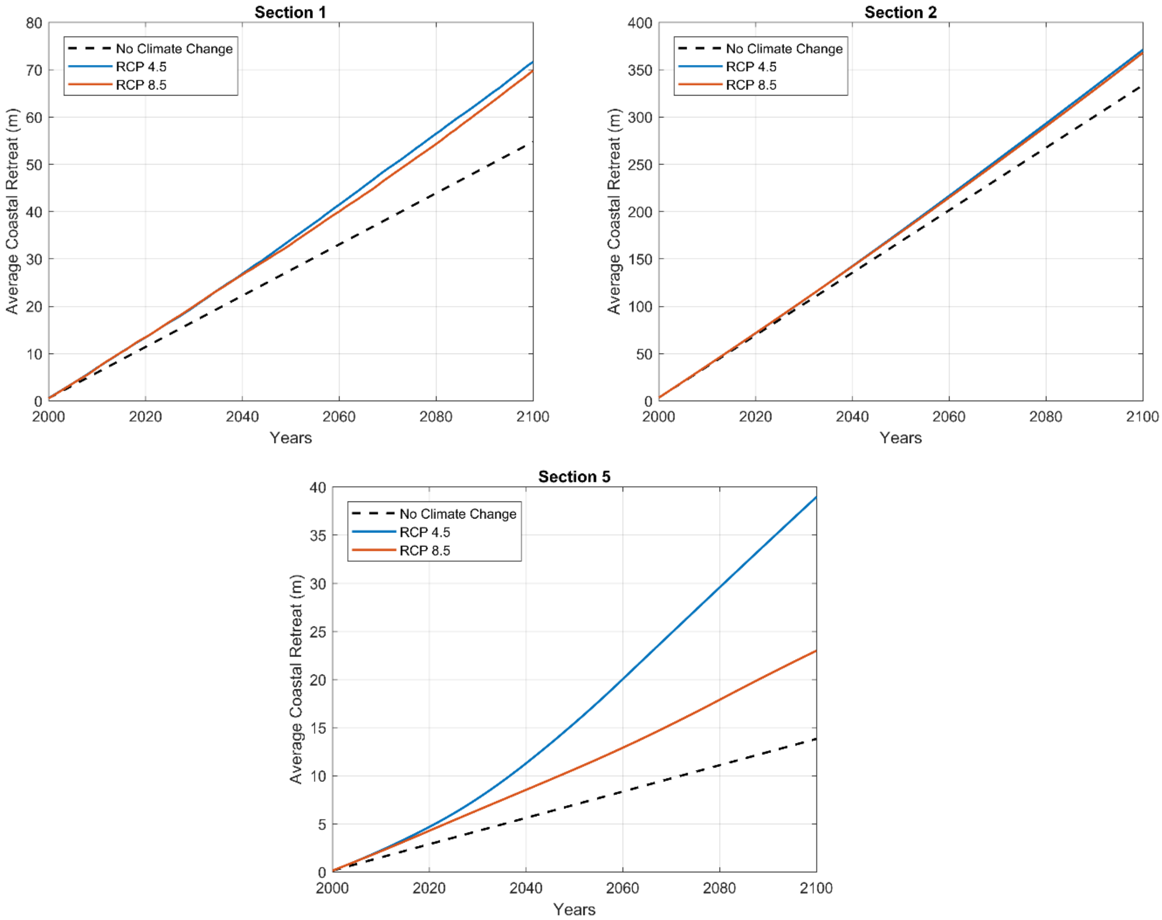


Figure 40. Coastal retreat due to sediment deficit and Bruun effect for each section and RCP4.5, RCP8.5 and no climate change.

4. Key climate change impacts in Monrovia

4.1. Climate change impacts on communities and economic assets

The anticipated adverse socio-economic impacts of the combined effects of sea-level rise (SLR), coastal erosion and an increased incidence of regular coastal flooding are potentially catastrophic for coastal communities in Liberia. The two most significant impacts include the destruction of private property[44] and the inundation or destruction of family dwellings. Within the MMA, low income areas are most vulnerable to these impacts because of high population densities, limited adaptive capacity and low financial reserves. Areas particularly at risk include Bushrod Island[45] and West Point as well as numerous communities in close proximity to the Mesurado Wetland and those situated along the Atlantic Seaboard. Limited financial resources within these communities mean that houses are often poorly constructed using non-permanent materials (such as plastic, straw and salvaged timber) and are not established on solid foundations. As a result, many of the houses within these communities are not only in danger of being destroyed but also pose a safety threat to their inhabitants, particularly under climate

[44] Including personal valuables, boats, fishing equipment, markets stands and other livelihood equipment as well as stoves and other household items.
[45] Notable communities on Bushrod island include New Kru Town, Clara Town and Duala.

change conditions. As conditions worsen, it is likely that many people in these communities will become permanently displaced by the continual flooding and loss of shorelines.

In addition to potential loss of private property and dwellings, climate change impacts along the coastal zone are likely to include an increased risk of contracting water- and vector-borne diseases such as cholera and malaria. This risk is further compounded by poor sanitation and water provisioning, whereby practices such as open defecation and use of unsealed latrines can threaten to contaminate open water supply areas as a result of increased flooding and SLR. As these threats develop, many people will likely be compelled to abandon these areas while they are still reliant on the surrounding mangrove ecosystems for resources.

Besides the aforementioned impacts on housing and private property, climate change will have significant impact on infrastructure and assets within the MMA that are critical for Liberia's economy — based on assessments conducted by civil engineers. These assets and infrastructure include the: i) Liberia Electricity Corporation's substation, which is the main power station within the MMA; ii) Freeport area, which is one of the most important industrial areas within the MMA; iii) petroleum refinery; iv) numerous businesses and health institutions, including the largest public hospital in Liberia. These assets are conservatively estimated to be worth more than US$ 765 million.

4.2. Climate change impacts on coastal livelihoods and food security

4.2.1. Agriculture

Agriculture is not a major livelihood activity within the MMA, however, climate change impacts on agriculture across Liberia is likely to contribute to reduced food security within the MMA. Projections indicate that increased temperatures and shifts in the onset, duration and intensity of the rainy season are likely to result in reduced agricultural productivity for subsistence and commercial farmers alike. The change in aridity index to climate projections in 2050 can be used as an indicator of climate change, as well as the increase in average temperature of more than 2°C to assess how aridity will affect crops[46]. The change in annual aridity between the present and 2050 shows areas of potential vulnerability to drier conditions. Using the aridity index and overlaying the change map onto the main crop maps indicates that several areas are likely to experience reduced agricultural productivity. Of the two main food crops, rice is particularly vulnerable to climate change while cassava is particularly resilient because it is known to tolerate high temperatures and within-season drought as well as erratic rainfall patterns.

4.2.2. Fisheries

The fishery industry is an important economic sector with the MMA. Although it comprises a relatively small segment of the country's GDP (~3%), it underpins the livelihoods of more than 40,000 Liberians. It also contributes significantly to food security within the MMA and it is estimated that fish account for as much as 65% of animal-based protein intake.

There are several interrelated direct and indirect climate change impacts that threaten the Liberian fishery industry, which will have knock-on effects for economic productivity, food security and livelihood practices within the MMA. Climate projections indicate that sea-surface temperatures will increase in Liberian waters, which is expected to disrupt the timing and intensity of the coastal upwelling — resulting in reduced fish stocks within the Liberian coastal

[46] Based on work by Stanturf et al. (2013)

zone[47]. Additional impacts associated with climate change include increased ocean acidification and increased incidence of hypoxic zones. However, the likelihood of these impacts within Liberian water has not been studied to-date.

In Liberia, the proximate driver of the marine fisheries is the upwelling system. This complex system is temperature dependent but has not been extensively studied within the Liberian context. Increased sea temperature has been identified as one of the most prominent impacts of climate change on the productivity of marine fisheries. Changes in sea temperature and resultant fluctuations in the dynamic upwelling system are, therefore, likely to impact primary (phytoplankton) and secondary (zooplankton) productivity as well as the distribution and concentration of pelagic fish within Liberian waters. In addition to the climate change impacts of increased sea surface temperature, acidification and hypoxic zones, the current rate of SLR threatens the numerous mangrove estuaries within the Liberian coastal zone. The Mesurado Wetland, a Ramsar site within the MMA — which plays an important role as a breeding ground and nursery for many of the economically important fish species and shellfish — is at particular risk from SLR. The high-density settlements situated in close proximity to the Mesurado Wetland limit the ability of the mangroves to accrete horizontally[48] and place additional pressure on these ecosystems through unsustainable anthropogenic overuse, reducing the overall resilience of these ecosystems to climate change impacts.

Further climate change impacts that threaten Liberia's fisheries include an increase in the frequency of extreme events as well as an increase in wave intensity. These factors are likely to impact on fishing practices, reducing the number of fishing days and increasing the loss of fishing equipment. Additionally, shifts in the distribution and concentration of fish within Liberian waters will require fishermen to expend extra time and energy to locate and catch fish, further increasing financial burdens, reducing productivity and threatening food security.

4.3. Climate change impacts on mangrove forests

The sea level along the Liberian coast is projected to rise by 75 cm by 2100 because of climate change under the Representative Concentration Pathway (RCP) 8.5. The effect of sea-level rise (SLR) on mangrove ecosystems along the Liberian coast is expected to vary depending on local hydrological processes such as the sedimentation rates[49]. In coastal areas with high sedimentation rates, mangrove soil surfaces are projected to rise at rates exceeding SLR resulting in mangrove forests expanding seaward in response to the growth of the suitable habitat. In areas with modest sedimentation, mangrove soil surfaces will rise at a rate equal to SLR, resulting in mangrove forests maintaining their current location and extents. Finally, in coastal areas with low sedimentation, mangrove surfaces are expected to rise at rates lower than SLR resulting in the inundation of the forests. However, in areas with suitable inland habitat (topography and substrate), some of the mangrove ecosystems threatened by flooding will be expected to migrate landward[50]. Mangrove ecosystems that migrate and expand under SLR will be important for supporting the livelihoods of people in the surrounding areas, but will require careful management to ensure they are well established (See Annex 2.D for further details on the threats to mangroves).

[47] Stanturf, J. A. *et al.* 2013. Climate changed vulnerability in Liberia. USAID.
[48] Mangroves generally accrete horizontally in response to increased water depth. However, without adequate space to accrete mangrove ecosystems can become over-inundated, resulting in ecosystem degradation or collapse.
[49] In coastal waterways, sedimentation rates refer to the amount of material (organic and mineral) deposited by the action of water over a given interval of time.
[50] Lovelock, C. E., Krauss, K. W., Osland, M. J., Reef, R., & Ball, M. C. (2016). Tropical Tree Physiology (G. Goldstein & L. S. Santiago (eds.); Vol. 6). Springer International Publishing. https://doi.org/10.1007/978-3-319-27422-5

An increase in average temperatures due to climate change is also expected to affect the ecological function of mangrove forests along Liberia's coast. Global climate simulations project that temperatures will rise between 3°C and 6°C throughout West Africa by the end of the 21st century, depending on the emissions scenario. The rise in temperature will affect mangroves by*, inter alia*: i) changing the composition of mangrove forest species; ii) changing phenological patterns; iii) increasing mangrove productivity where the temperature does not exceed an upper threshold; and iv) expanding mangrove ranges to higher latitudes where the range is limited by temperature, but not limited by other factors[51,52,53]. While temperature increases alone are likely to lead to faster growth, reproduction, photosynthesis and respiration, the physiological response of mangrove forests is expected to reach a critical temperature threshold at which productivity plateaus and declines if exceeded[54,55]. The locations where the tallest mangroves are found, globally, are in the equatorial regions of South America and West AfricaThese hotspots are located in the most remote, cloudy, wet and hot estuarine environments in the world[56]. The optimum leaf temperature for photosynthesis in mangrove vegetation is between 29°C and 32°C, with photosynthesis in mangrove plants ceasing when temperatures reach 38–40°C. However, elevated CO_2 concentrations could have an effect on the temperature response of photosynthesis in mangroves,thereby possibly mitigating growth inhibitions resulting from high-temperature anomalies[57,58]. Temperature projections (Section 3.1.2) indicate that the number of days where temperature is greater than or equal to 30°C will increase significantly under future climate scenarios. Mangroves in Monrovia are, therefore, likely to be in a delicate balance between optimum photsynthesis temperature and temperatures where photosynthesis ceases. Additionally, mangroves being exposed to theramally polluted water — where temperatures are between 36°C and 38°C — for significant periods of time have been shown to have a survival rate of zero[59]. A significant increase in the occurrence of extremely hot days is therefore likely to be detrimental to mangrove ecosystem function.

Climate change is also expected to affect mangrove forest ecosystems through increased annual rainfall and frequency of heavy rainfall events. Rising annual rainfall will positively affect mangroves by, *inter alia*: i) decreasing coastal salinity; ii) increasing mangrove vegetation growth rates and biodiversity; and iii) expanding mangrove areas through colonisation of previously unvegetated areas on landward fringes[60]. Conversely, extreme rainfall and flooding events linked to climate change will negatively affect the health and position of mangroves by altering sediment elevation and soil toxicity. These changes will co-occur with the rise in CO_2 concentration, temperature and sea level, the compounded effect of which will lead to higher stresses on mangrove ecosystems.

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[51] Asbridge, E., Lucas, R., Accad, A., & Dowling, R. (2015). Mangrove response to environmental changes predicted under varying climates: Case studies from Australia. Current Forestry Reports, 1(3), 178–194. https://doi.org/10.1007/s40725-015-0018-4

[52] Ellison J.C. (2000) How South Pacific Mangroves May Respond to Predicted Climate Change and Sea-level Rise. In: Gillespie A., Burns W.C.G. (eds) Climate Change in the South Pacific: Impacts and Responses in Australia, New Zealand, and Small Island States. Advances in Global Change Research, vol 2. Springer, Dordrecht. https://doi.org/10.1007/0-306-47981-8_16

[53] Wilson R. 2017. Impacts of climate change on mangrove ecosystems in the coastal and marine environments of Caribbean Small Island Developing States. Caribbean Marine Climate Change Report Card : Science Review 2017 : 60-82.

[54] Alongi DM. 2015. The impact of climate change on mangrove forests. *Current Climate Change Reports* 1 : 30-39.

[55] Ward, R. D., Friess, D. A., Day, R. H., & Mackenzie, R. A. (2016). Impacts of climate change on mangrove ecosystems: a region by region overview. Ecosystem Health and Sustainability, 2(4). https://doi.org/10.1002/ehs2.1211

[5656] Simard, M., Fatoyinbo, L., Smetanka, C. et al. Mangrove canopy height globally related to precipitation, temperature and cyclone frequency. Nature Geosci 12, 40–45 (2019). https://doi.org/10.1038/s41561-018-0279-1

[57] Mafi-Gholam D and Zenner E. 2018. A review of climate change impacts on mangrove ecosystems. *International Journal of Environmental Monitoring and Protection* 5(2) : 18-23.

[58] Reef R, Slot M, Motro U, Motro M, Motro Y, Adame MF, Garcia M, Aranda J, Lovelock CE, Winter K. The effects of CO2 and nutrient fertilisation on the growth and temperature response of the mangrove Avicennia germinans. Photosynth Res. 2016 Aug;129(2):159-70. doi: 10.1007/s11120-016-0278-2. Epub 2016 Jun 3. PMID: 27259536.

[59] Srivastava, P.K., Mehta, A., Gupta, M. et al. Assessing impact of climate change on Mundra mangrove forest ecosystem, Gulf of Kutch, western coast of India: a synergistic evaluation using remote sensing. Theor Appl Climatol 120, 685–700 (2015). https://doi.org/10.1007/s00704-014-1206-z

[60] Ibid.

The impacts of climate change on mangroves are dependant on how global change drivers interact, in a local context. Examples of the resulting effect of the interactions are included in Table 4 below. Furthermore, one of the biggest factors in how mangroves are impacted by climate change is deforestation and urban expansion. Mangroves can cope with climate change drivers such as sea level rise by expanding inland, however if this is prevented then the vulnerability of mangroves to climate change can be significantly increased[61]. Ultimately, the impacts of climate change on mangroves are complex and the result of how a spectrum of factors interact with each other.

Table 4. Examples of the interactions between global change drivers and the ecologicial consequences they can have, after Osland et. al[62].

Global change drivers	**Ecological effect**
↓ precipitation + ↓ sea level + ↑ temperature	Mortality
↓ precipitation + ↑ temperature	Altered biotic interactions
↑ atmospheric carbon dioxide + ↑ sea level	Elevation change
↑ atmospheric carbon dioxide + ↑ temperature	Expansion
↓ freshwater input + ↑ sea level + ↑ temperature	Expansion
↓ freshwater input + ↓ precipitation + ↑ temperature	Mortality
↑ nutrient + ↑ atmospheric carbon dioxide	Altered biotic interactions
↑ nutrient + ↑ sea level + ↓ freshwater input	Altered productivity
↑ sea level + ↑ precipitation + ↑ freshwater input	Transgression
↑ sea level + ↑ tropical cyclone intensity	Transgression
↑ temperature + ↑ tropical cyclone intensity	Range limit expansion
↑ low-lying coastal development + ↑ sea level	Coastal squeeze
↑ invasive non-native species + ↑ sea level	Delayed transgression
↑ tropical cyclone intensity + ↑ sea level	Structural change, Regime shift
↑ land use change + ↑ sea level + ↓ freshwater input	Habitat loss

4.3.1. Mesurado Wetland and mangrove ecosystems

The Mesurado Wetland (06° 18'N 10° 45'W) is located in Monrovia and the surrounding Montserrado County (Figure 41). The wetland is a highly urbanised system, with built-up areas surrounding it. Close to the wetland are the communities of West Point, Crown Hill, Tope Village, Vamom and Nipay Town.

[61] Cavanaugh, K. C., Kellner, J. R., Forde, A. J., Gruner, D. S., Parker, J. D., Rodriguez, W., & Feller, I. C. (2014). Poleward expansion of mangroves is a threshold response to decreased frequency of extreme cold events. Proceedings of the National Academy of Sciences of the United States of America, 111(2), 723–727. https://doi.org/10.1073/pnas.1315800111

[62] Osland, M.J., Feher, L.C., López-Portillo, J., Day, R.H., Suman, D.O., Guzmán Menéndez, José.Manuel., Rivera-Monroy, V.H., Mangrove forests in a rapidly changing world: Global change impacts and conservation opportunities along the Gulf of Mexico coast, Estuarine, Coastal and Shelf Science (2018), doi: https://doi.org/10.1016/j.ecss.2018.09.006.

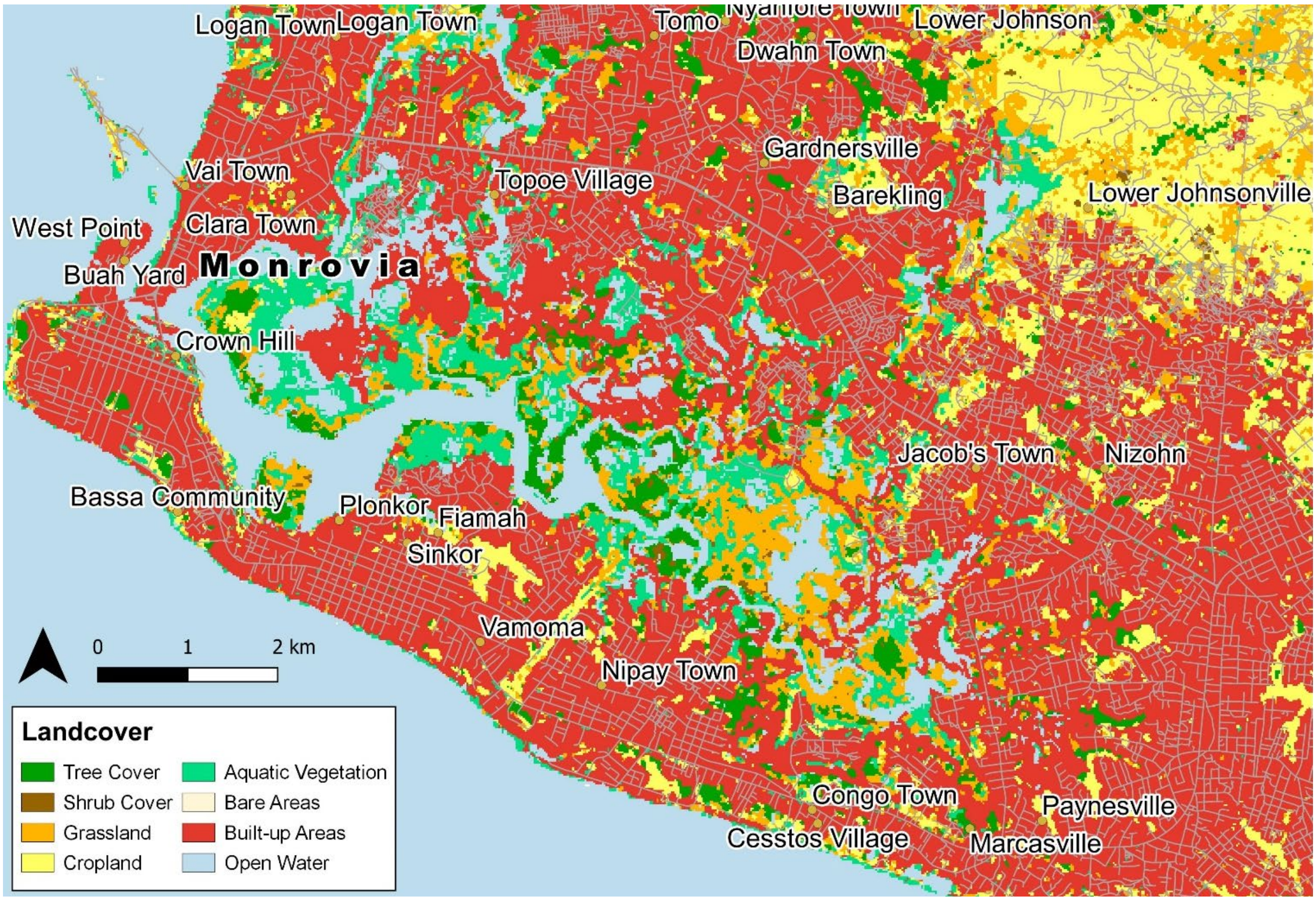

Figure 41. ESA 2016 landcover map of the Mesurado Wetland and the surrounding communities[63].

Mangrove forests are the dominant vegetation type in the Mesurado Wetland, covering more than 99% (~6,750 ha) of the wetland area[64]. The forests contain important mangrove tree species such as French petit (*Rhizophora harrisonii),* red mangrove *(R. mangle)* and black mangrove (*Avicennia africana)* that are threatened by intensive charcoal burning and fuelwood collection. The red mangrove tree (*R. mangle*), which represent more than 80% of the forest area, is the most common tree species in the mangrove forests of the Mesurado Wetland. These forests provide a favourable habitat and feeding ground for several species of birds including the African spoonbill (*Platalea alba*), common pratincole (*Glareola nuchaltis*) and curlew (*Numenius arquata*). They also host the vulnerable African dwarf crocodile (*Osteolaemus tetraspis*), the Nile crocodile (*Crocodylus niloticus*), the critically endangered African sharp-nosed crocodile (*Mecistops* sp.), and the endangered Upper Guinea red colobus monkey (*Procolobus badius*), as well as many other ecologically important species. As a result, the Mesurado mangrove forests are considered to be of high conservation value and have been designated as one of five wetlands in the country of global significance under the Ramsar Convention[65].

In addition to being of high conservation value, mangrove forest ecosystems in the Mesurado Wetland provide surrounding communities with essential ecosystem services such as: i)

[63] Data source: European Space Agency Sentinel-2A Prototype Land Cover 20 Meter Map of Africa 2016. [Online]. Available: http://2016africalandcover20m.esrin.esa.int/

[64] Kiazolu OG. 2019. *Assessment of level of public knowledge, attitudes, and perception towards mangrove forest conservation in Mesurado Wetland in Liberia*. Unpublished Master of Arts thesis, University of Nairobi, Nairobi.

[65] The Convention on Wetlands, known as the Ramsar Convention, is an intergovernmental environmental treaty established in 1971 by UNESCO, which came into force in 1975.

spawning grounds and nurseries for commercially valuable fish and shellfish species; ii) firewood for fuel, charcoal production and fish smoking; and iii) fertile soils for agricultural land. Approximately 1.12 million people living in Monrovia benefit directly or indirectly from the ecosystem services provided by mangrove forests in the Mesurado Wetland and from the associated waterways which are used for transportation, commercial and non-commercial fishing, and sand mining for construction[66].

Despite their substantial socio-economic importance, mangrove forests in the Mesurado Wetland are among the most threatened ecosystems in Liberia[67]. The ecological integrity of the forests and the ecosystem services they provide are threatened by, among others: i) unplanned clearing for housing and infrastructure development by surrounding communities; ii) uncontrolled and unsustainable harvesting of firewood for fuel, charcoal production and fish smoking by communities resident within the forests and surrounding areas; iii) unsustainable sand mining; iv) illegal felling of mangrove trees for building poles and timber production; v) unregulated fishing; vi) uncontrolled waste disposal, particularly of city garbage and sewage from residents within the mangroves and neighbouring homes; and vii) pollution from nearby industrial plants, including an oil refinery and paint factories[68,69]. As a result of these root causes, mangrove ecosystems in the Mesurado Wetland are severely degraded. Most of the mangrove degradation has occurred in areas where human settlements border directly on the wetlands, as well as on the banks of the Mesurado River and its smaller channels (Figure 42). Details of anthropogenic threats to mangrove forest ecosystems and mangrove-dependent livelihood activities in the Mesurado Wetland are provided in Annex 2.D.

[66] Republic of Liberia 2016a. Improve sustainability of mangrove forests and coastal mangrove areas in Liberia through protection, planning and livelihood creation – as a building block towards Liberia's marine and coastal protected areas. Global Environmental Facility (GEF) Project Document. Monrovia: Environmental Protection Agency and Conservation International

[67] Republic of Liberia (ed). 2006. *First state of the environment report for Liberia - 2006*. Environmental Protection Agency and United Nations Development Programme. Monrovia

[68] Republic of Liberia (ed). 2010b. *The master plan study on urban facilities restoration and improvement in Monrovia in the Republic of Liberia. Environmental impact survey on the project for reconstruction of Somalia Drive in the Republic of Liberia*. Ministry of Public Works. Monrovia.

[69]Kiazolu OG. 2019. *Assessment of level of public knowledge, attitudes, and perception towards mangrove forest conservation in Mesurado Wetland in Liberia*. Unpublished Master of Arts thesis, University of Nairobi, Nairobi.

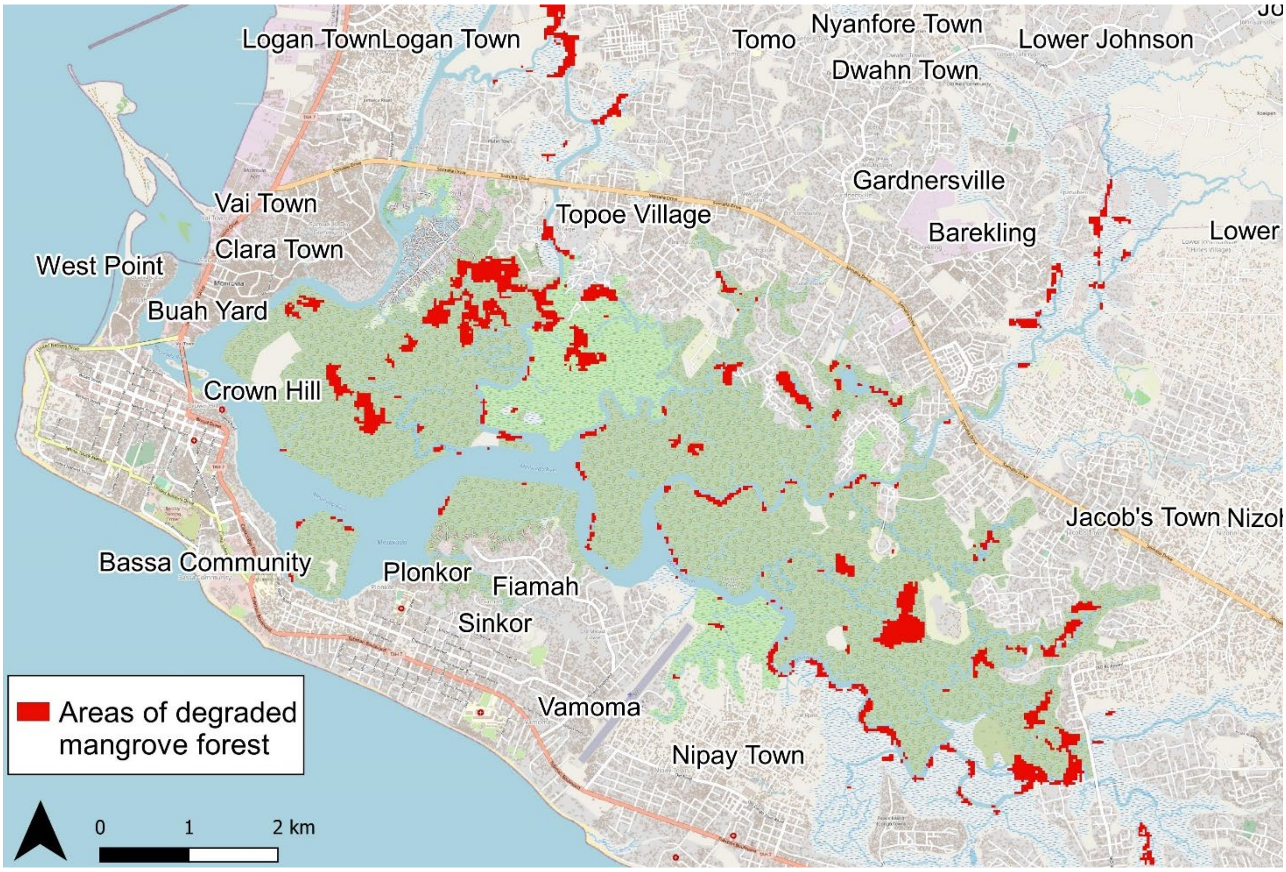

Figure 42. A map indicating areas of degraded mangrove forests in the Mesurado Wetland. These areas were historically part of the mangrove extent, but the 2016 GMW dataset indicates that they have been completely transformed.

Sea-level rise (SLR) caused by climate change is expected to result in higher water levels in the Mesurado Wetland over the next few decades. Consequently, climate change will exacerbate the impact of the root causes of mangrove degradation mentioned above by inundating or ‘drowning’ mangrove forests. In many parts of the world, mangrove forests are expected to adapt to sea-level rise by migrating upslope or inland, i.e. horizontal migration. However, in Monrovia, mangrove forests are almost surrounded — and being encroached upon — by the city and will not be able to adapt to SLR through horizontal migration[70]. Therefore, unless appropriate action is taken to protect the mangroves in the Mesurado Wetland, climate change-related SLR will exacerbate pressure on the ecosystem and result in a reduction in the area suitable for mangrove habitat.

Mangrove inundation in the Mesurado Wetland is however projected to occur over an extended period as high rates of sedimentation in the forests are expected to ameliorate the effects of climate change-induced sea-level rise[71]. The Mesurado estuary — in which the mangrove forests of the Mesurado Wetland occur — has a low water outflow rate and receives substantial sediment input from upstream. As a result, mangrove soil surfaces are projected to rise in tandem with climate change-related SLR, resulting in the forests maintaining their locations and

[70] Annex 2.C: Engineering Sub-assessment. Monrovia: United Nations Development Programme and Liberia Environmental Protection Agency.
[71] Ibid.

extent into the foreseeable future. These mangrove forests will therefore still support communities dependent on them but any reductions in pressure on these systems will be crucial to ensure resource harvesting remains sustainable so that the mangroves are preserved. Measurements using the Surface-Elevation Table-Marker Horizon method in 2006 and 2011 demonstrated that mangrove surfaces were rising at similar rates to SLR at several sites across the wetland[72]. Mangrove forest in the Mesurado Wetland, therefore, have the potential to enhance the resilience to climate change of vulnerable communities in the Monrovia area into the medium and long-term future by continuing to provide them with essential ecosystem services if they are protected and conserved.

5. Policy and institutional frameworks for climate change adaptation and coastal management

5.1. Policy frameworks related to climate-resilient development

Article 9, Chapter II of the 1986 Constitution of Liberia encourages bilateral and regional co-operation between Liberia and other nations — as well as the formation and maintenance of regional organisations aimed at the cultural, social, political and economic development of the peoples of Africa and other nations of the world. Liberia is also party to several multi-lateral environmental agreements, including: i) the United Nations Framework Convention on Climate Change (UNFCCC); ii) the Kyoto Protocol; and iii) the United Nations Convention on Biological Diversity (UNCBD).

The National Adaptation Programme of Action (NAPA), developed in 2008, complements Liberia's strategies for sustainable development. The NAPA targets better access to basic services, improved energy efficiency and forest conservation. Activities prioritised in the NAPA include: i) the diversification of crops to enhance resilience; ii) rebuilding the national hydro-meteorological monitoring system; and iii) projects to reduce the vulnerability of urban coastal areas to erosion, floods and siltation. In addition to the NAPA, the national strategies and plans detailed below are directly related to climate change.

Agenda for Transformation (2015)
This is a medium-term development strategy for Liberia detailing the government's commitment to lift Liberians out of poverty. It is a continuation of the Liberia Poverty Reduction Strategy, which spanned 2008–2011.

National Environmental Policy (2002)
This policy focuses on the sustainable management of the environment and natural resources. It was approved on 26 November 2002 and serves as a legal instrument that provides a broad framework for the implementation of national environmental objectives and plans. The National Environmental Policy aims at ensuring sound environmental and natural resource management and attempts to prevent any unsustainable and damaging exploitation of these resources. Additionally, the policy seeks to integrate environmental considerations in sectoral, structural, regional and socio-economic planning at all levels.

The Environment Protection and Management Law of Liberia (2002)
The Environment Protection and Management Law was adopted on 26 November 2002 in addition to the National Environmental Policy to ensure the sustainable use of Liberia's natural

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[72] CDR International. 2019. Consultancy services for engineering and safeguards assessment of proposed interventions in the coastal areas of the Monrovia Metropolitan Area (MMA) in Liberia. Annex 2.C: Engineering Sub-assessment. Monrovia: United Nations Development Programme and Liberia Environmental Protection Agency.

resources. It promotes the use of natural resources in pursuance of social and economic development without undermining the resilience and regenerative capacity of ecosystems.

National Reconstruction and Development Plan (2002–2007)
This was Liberia's five-year development plan for medium-term economic growth and socio-political development and served as a precursor to the 2008–2011 National Poverty Reduction Strategy.

Initial National Communication to the UN Framework Convention on Climate Change (2013)
This report to the UNFCCC covered thematic areas, including: i) national greenhouse gas inventories; ii) projected climate change impacts; iii) vulnerability and adaptation assessments; and iv) a greenhouse gas mitigation assessments. The report focuses primarily on four economic sectors, namely energy, forestry, agriculture and waste. It also lists potential projects to build Liberia's climate resilience and strengthen its national efforts to address climate change.

National Policy and Response Strategy on Climate Change (2018)
This strategy was developed to provide guidance to national response measures in addressing climate change. The strategy outlines policies for adaptation and mitigation in sectors such as coastal areas, agriculture and settlements. Guidance is also given on how to integrate climate change threats into development planning processes at different levels for effective coordination of efforts.

National Development Policy/Strategy (draft)
This document presents a roadmap with priorities for mainstreaming the UN Agenda 2030 and the African Union (AU) Agenda 2063 into Liberia's development plans, guided by the principles of the New Deal. Implementation of the roadmap took place over a period of 16 months, ending at the handover of the Liberian Administration in January 2018, after the general elections in October 2017. The roadmap outlines the critical steps for: i) integrating the Agenda for Transformation (AfT-II) into national policies; ii) strengthening the country's readiness for implementing the 2030 Agenda and the AU Agenda 2063; and iii) ensuring the sustainability of gains made as a result of the roadmap through the major security and political transitions underway in Liberia.

Climate Change Gender Action Plan for the Government of Liberia (2012)
This plan seeks to ensure that gender equality is mainstreamed into Liberia's climate change policies, programmes and interventions — so that both men and women have equal opportunities to implement and benefit from mitigation and adaptation initiatives in combatting climate change. It also ensures alignment with the 'Liberia Rising 2030' priorities.

National Disaster Management Policy (2012)
This policy focuses on establishing a national disaster risk management (DRM) system to both effectively manage disaster responses and pro-actively develop disaster preparedness and risk prevention/reduction. All administrative levels of the country (national, county, district and community) and all sectors are included in the policy. In addition, the Disaster Risk Management Act establishing a new DRM institution has been approved by the Liberia parliament. The new institution — the National Disaster Management Agency — is an autonomous organisation and will replace the National Disaster Relief Commission (NDRC). Its mandate is much broader than NDRC and it focuses on the entire scope of disaster risk reduction, including: i) coordination; ii) knowledge management; iii) risk identification; iv) preparedness and response; and v) risk reduction.

Water Supply and Sanitation Policy (2009)

The vision of the policy is to use “clean water supply and safe sanitation as a vehicle for reducing the water supply and sanitation-related disease burden, increasing productivity, promoting human welfare and setting the nation on a path towards long-term sustainable growth, development, and poverty reduction”.

Framework for an effective Early Warning System
The early warning system (EWS) project is one of three priority climate change adaptation projects. It has been prepared by the Government of Liberia through its NAPA (under the UNFCCC) and submitted to the Global Environment Facility (GEF). The EWS will enable Liberia to provide weather and climate information and services for the health, agriculture, transport, energy and water resources sectors. The project relies on collaboration across ministries, agencies and organisations to ensure its successful implementation. A GEF Least Developed Countries Fund (LDCF) grant of US$ 6.7 million was awarded for the project with in-kind co-financing from the Government of Liberia, and US$ 200,000 from UNDP. The EWS project was expected to last until 2017 and achieve: i) increased capacity of hydro-meteorological services and associated networks — to monitor and predict extreme climate-related hazards and climate trends; ii) efficient and effective use of tailored climate, environmental and socio-economic data — to produce appropriate information which can be communicated to government entities and communities to enable informed decision-making; and iii) increased awareness of the major risks associated with climate change in government, private sector and local communities, and use of available information when formulating development policies and strategies.

5.2. National level institutions relevant for coastal management

There are ten national government institutions with mandates related to climate change and/or decision making in coastal management in Liberia. These and other relevant bodies are described below.

The **Ministry of Mines and Energy** (MME), previously the Ministry of Lands, Mines and Energy, is the line ministry responsible for the management of coastal areas.
The **Environmental Protection Agency** (EPA) was created in 2005 and is responsible for: i) raising awareness on environmental matters; ii) coordinating and strengthening the activities of environmental organisations; iii) developing national environmental policies and laws; and iv) enforcing environmental protection laws. The EPA is responsible for leading the implementation of Liberia’s NAPA and serves as the Designated National Authority (DNA) for the Clean Development Mechanism (CDM) of the UNFCCC. A National Environmental Policy Council, headed by the MME, oversees policy formulation at the EPA and sets priorities for national goals and objectives for the protection of the environment. The EPA also has a Board of Directors which includes the Minister of Finance and Development Planning.
The **National Fisheries and Aquaculture Authority** is responsible for overseeing the fisheries sector, including coordinating primary, secondary and tertiary sector stakeholders and developing the institutional and legislative framework for fisheries management.
The **Ministry of Public Works** (MPW) is responsible for the planning, management and coordination of public infrastructure works in Liberia, including coastal infrastructure.
The **National Disaster Management Agency** (NDMA) seeks to develop legal and institutional frameworks and implement innovative approaches for reducing vulnerability and disaster risk in Liberia. This includes increasing resilience of coastal communities in the face of extreme climate events and coastal flooding.
The **Liberian Hydrological Service** (LHS) was established in 1972 and is responsible for monitoring and protecting Liberia’s water resources. Specifically, the LHS collects, analyses, manages and disseminates hydrological data to support the country’s water and sanitation sector.
The **Liberian Meteorological Service** (LMS), placed under the Ministry of Transport.

The **Liberian Maritime Authority** (LMA) is responsible for designing policies and strategies relating to the functioning and development of the maritime sector as well as enforcing laws and executing appropriate plans and programmes.
The **Ministry of Finance and Development Planning** (MFDP) has the mandate to formulate and administer strategies relating to economic development as well as fiscal, monetary and tax policies for the promotion of sound and efficient management of financial resources.
The **National Port Authority** (NPA) is responsible for the oversight and development of the four ports in Liberia, of which Monrovia is the largest. The NPA works closely with both the public and private sectors to leverage the ports to support economic development in the country.

In addition to these ten institutions, the National Environmental Policy Council, National Climate Change Steering Committee (NCCSC) and National Climate Change Secretariat (NCCS) are involved in the development and implementation of environment and climate change-related policies. The Liberia Forestry Development Authority (FDA) is a state corporation established by an Act of Legislature in 1976, with the mandate to sustainably conserve and manage all forest resources for the benefit of present and future Liberian generations. The Forestry Law of 2006 directed the FDA to establish a Protected Forest Areas Network encompassing at least 30% of the country's forests. While the FDA is charged with setting up a protected areas network, train and equip staff for deployment to those areas, monitor and patrol protected areas and prosecute violations, their scope also expands to forest conservation, community awareness surrounding protected areas and agroforestry. This includes the sustainable use of mangroves that lie outside of the protected areas network.

5.3. Institutions at local level relevant for coastal management

5.3.1. Institutions at municipal level

The **Monrovia City Corporation** (MCC) is the agency responsible for planning and management of municipal services in the City of Monrovia. The MCC manages several communities along the coast. The **Paynesville City Corporation (PCC)** manages the Paynesville area, a city larger — in terms of surface area — than the City of Monrovia, expanding eastward along the Robertsfield Highway. The PCC also covers several communities that lie along the coast.

5.3.2. Community-based organisations

Community organisations relevant to coastal management in the Monrovia Metropolitan Area (MMA) include: i) the National Women's Commission of Liberia; ii) the National Training of Trainers Institute in Paynesville; and iii) the New African Research and Development Agency (NARDA). The NARDA network includes more than 30 active, full-member non-governmental organisations (NGOs) and 30 affiliated, rural Community-Based Organisations (CBOs). It provides coordination, consultancy, assessment services, leadership training, community engagement, financial management, proposal development, project implementation and reporting skills.

5.3.3. Non-governmental organisations (NGOs)

- The **Save My Future Foundation (SAMFU)** is a local NGO working to promote partnerships with environmental organisations, the Liberian government and local communities to ensure the sustainable management of Liberia's natural resources. SAMFU has an Endangered Marine Species Conservation Program that seeks to build awareness and promote the protection of turtles in coastal communities.

- **Conservation International (CI)** is an international NGO that works on the protection and sustainable use of rainforests and coastal mangrove forests in Liberia. CI works closely with indigenous and local populations through a conservancy agreement model.

5.3.4. Private sector organisations

The **Liberian Bank for Development and Investment (LBDI)** was created by an Act of the National Legislature in 1961, under the joint initiative of major international financial institutions that purchased equity in the Bank. It commenced operations in 1965 as the Liberian Bank for Industrial Development and Investment. Under an amendment in 1974, the name was changed to the Liberian Bank for Development and Investment (LBDI). A further amendment in 1988 enabled the Bank to engage in commercial banking activities, to complement its development objectives.

6. Previous and current coastal protection and adaptation responses, best practices and lessons learned

6.1. Previous and current coastal protection and adaptation responses

There are very few examples of previous and current coastal protection work in Liberia. Some of the available representative examples are described in this section.

6.1.1. An overview of past and on-going projects aimed at improving coastal management

The management of coastal zones in Liberia is highly fragmented among many institutions — ministries, agencies, private sector and environmental civil society organisations. These institutions, in many cases, operate independently with limited coordination to others that have similar interventions and interests in coastal zones. Some of these institutions include, *inter alia:* the Ministry of Lands, Mines and Energy, Environmental Protection Agency (EPA), National Port Authority, Ministry of Agriculture, Ministry of Defence, Ministry of Public Works, Ministry of Internal Affairs, Forestry Development Authority and Liberia Maritime Authority. Therefore, there is a need for an integrated approach to the management of the coast. This need led to the formation of the ICZM Task Force hosted within the Ministry of Land, Mines and Energy. However, the ICZM Task Force has been operating mostly as an *ad hoc* intervention force in cases of flooding and other climatic hazards. The core functions of ICZM — planning and management of the coastal area — have not been covered by this Task Force. Besides building the hard structure rock armour protection of 500m on the Buchanan coast, the Buchanan coastal protection project (Figure 43) attempted to form an ICZM Unit which would replace and upgrade the work of the Task Force with coastal management and planning scope. This intervention had limited scope as both project and funds ended. There is a desire from the Government of Liberia (GoL) to develop an ICZM Policy followed by the formation of an independent ICZM body. However, without international support Liberia is unlikely to succeed in establishing such an inter-sectoral agency.

Figure 43. Buchanan coastal defence project.

6.1.2. Efforts for the improvement and upgrading of coastal protection works

In New Kru Town, the United Nations Development Programme (UNDP) and the GoL completed the first phase of a 100-meter New Kru Town coastal defence project in March 2015 (Figure 44). The project was implemented by the Centre for Environment and Development in Africa (CEDA), a local non-governmental organisation in Liberia, with funding of US$ 50,000 from the Global Environment Facility (GEF) Small Grants Programme. The project consisted in pilot gabion groynes and a revetment on 100 meters of coastline.

Figure 44. Invitees touring pilot project site on the Popo Beach in New Kru Town.

With financial and technical support of UNDP and the GEF/Least Developed Countries Fund (LDCF), the "Enhancing Resilience of Vulnerable Coastal Areas to Climate Change Risks in Liberia" project was launched in 2011 for the construction of a breakwater system, consisting of rock armour and gabions, as shown in Figure 43) in Buchanan, Grand Bassa County (Walvis Bay, Robert Street and Port of Buchanan). The project sought to reclaim coastal lands in Buchannan, protect coastal infrastructure from erosion and limit the threats to human settlements and livelihoods from coastal erosion. Presently, 500 of the 600 meters of the coastal project have been constructed, with the construction of the remaining 100 meters due to start soon. While in the Robertsport pilot site, the project is implementing measures to reforest mangroves and reduce mangrove deforestation — by promoting solar dryers for the fishery communities, constructing energy efficient ovens for fish smoking, and promoting alternative livelihoods for those engaged in mangrove harvesting — in order to strengthen its role as buffer zones against the flooding of the coastal communities.

In the three counties of Grand Cape Mount, Grand Bassa and Montserrado, the project has already been carrying out some preparatory works for the implementation of coastal protection measures, such as : i) organising local consultations and planning processes to ensure the project approach is participatory; ii) communities raising awareness and establishing rules on the best practices to protect the coastal areas against the main human-related drivers of coastal vulnerability to climate change, such as sand mining, inappropriate settlements in the coastal areas, mangrove depletion and community mobilisation for the maintenance of the coastal protection measures; iii) training of local entrepreneurs and communities on gabion and revetment construction; and iv) undertaking a feasibility study and detailed design of gabions and revetment.

6.1.3. Interventions in disaster risk management

The impacts of climate change are affecting several coastal communities in Liberia. One of the most affected communities is the West Point Community. Coastal erosion has destroyed several homes in the community making hundreds of inhabitants homeless. This has required the attention of the GoL and relocation of some of the most affected families in the VOA Community in Brewerville has begun (Table 4). The current structures are made from wooden frames covered with corrugated zinc sheets and locally made mats placed inside the walls. VOA Community is the former home of Sierra Leone refugees, some of whom have integrated into the Liberian society.

Table 5. Number of West Point community already relocated into temporary housing in VOA area (source: Mr. Demol More Chairman, Disaster Victims Association (DVA) Liberia).

VOA location breakdown – number of people moved to the location by October 2016		Moved from:	Date moved:
Women	75	West Point	25 May–23 July 2016
Children	96	West Point	25 May– 23 July 2016
Men	21	West Point	25 May–23 July 2016
Total	192		

As seen so far, the GoL has pursued only *ad hoc* measures for the couple of hundred critically endangered people of West Point. However, there are thousands more whose lives and properties are under immediate danger and need to be relocated (Table 5).

Table 6. Number of people in urgent need of relocation.

Coastal erosion disaster victims in urgent need of relocation from West Point area (as of 8 September 2016)		Data datum range:
Women	2,401	Data collected for period 17 November 2013 – 8 September 2016

Children	3,397	(source: Mr. Demol More, Chairman, DVA Liberia, Township of West Point)
Men	1,007	
Total West Point	6,805	
Coastal erosion disaster victims in urgent need of relocation from New Kru Town area		Data datum range:
Women	5,000	As of data received by 29 September 2016. (source: Mr. S. Tugbe Worjloh, Vice Governor, New Kru Town) REMARK: According to official data of National Disaster Management Agency, the population of New Kru Town is slightly above 75,000 people. However, according to data received from the Vice Governor of the area, Mr. S. Tugbe Worjloh, the total population is close to 175,000 people. Even though the discrepancies in data are significant, they are probably realistic as the last census took place 2008. Similar discrepancies in data were already observed for West Point area — where official data suggests there are around 40,000 people, while local community representatives, the Monrovia City Corporation, and government ministries agree that the real number is already above 85,000 people).
Children	(included into women/men count)	
Men	5,000	
Total	10,000	
Coastal erosion disaster victims in urgent need of relocation from JFK Hospital area		Data datum range:
Women	15,000	Total number of endangered communities in need for the climate resilient shelter represents slum housing area that runs from 19th Street to 24th Street. This estimate was based on a headcount conducted in the advent of the Ebola viral situation in 2015. Out of given total number, 674 persons (387 males, 287 females) represent those members of the community whose houses have already been partially or totally demolished by coastal erosion.
Children	(included into women/men count)	
Men	15,000	
Total	30,000	
		The area also has one primary school, ACFI, which has been affected by the continued coastal erosion. The community currently has seven primary schools (not affected by the erosion yet), including one public school. There is also one public clinic in the area, People's United Community Clinic. In addition, the entire affected slum housing area is shouldering the JFK Hospital — the number one referral hospital in the entire country. The JFK Hospital is currently at risk of being damaged within a few years if the current rate of coastal erosion is not halted. The value of JFK Hospital and its national importance coupled with the risk to the slum community justifies the need for the anticipated interventions of engineering and ecosystem-based adaptation (EbA) solutions in the area.

In order to fully manage the situation, the GoL has founded the National Disaster Management Agency (NDMA) for the purpose of implementing the National Disaster Management Policy, coordinating the national disaster management system, incorporating state and non-state actors at national, county, district and chiefdom levels, as well as handling disaster-related matters to ensure reduced vulnerabilities to natural- and human-induced hazards. In the time of this study's preparation, the NDMA Act was approved and ratified by both houses and is currently awaiting signature from the president.

6.1.4. Previous and current projects addressing mangrove conservation

Relevant past and ongoing projects that address mangrove conservation in Liberia include:

The Liberia Maritime Authority-run project 'Reclaiming Liberia's beaches and waterways, 2011-2014[73]. This project — which was funded at ~US$1.5 million/year — was aimed at raising the awareness of local communities in Liberia about the importance of coastal and mangrove ecosystems. In addition, the project provided employment through beach clean-ups and supported small community developments such as latrines.

The UNDP GEF-financed pilot project 'Enhancing resilience of Liberia Montserrado vulnerable coastal areas to climate change risks in Liberia, 2017–2018.[74] This project piloted a series of strategies for reducing vulnerability and building the resilience of local communities and socio-economic sectors to the threats of climate change in Liberia's coastal Montserrado County. The project included the rehabilitation of degraded mangroves and training local communities in integrated coastal management. Through this project, the UNDP supported coastal communities in Montserrado County in conserving mangrove vegetation and in constructing energy-efficient ovens for drying fish. The project had a pilot site in Robertsport which focused on more efficient fish smoking to reduce the timber demand from nearby mangrove forests. The promotion of solar dryers and construction of energy-efficient ovens for drying fish have been the primary management interventions.

The GEF project entitled 'Improve sustainability of mangrove forests and coastal mangrove areas in Liberia through protection, planning and livelihood creation — as a building blocks towards Liberia's marine and coastal protected areas, 2017–2019.[75] The aim of this project was to secure protection for mangrove forest areas in Liberia by providing integrated land-use policies and tools for mainstreaming biodiversity conservation in these areas.

The Conservation International and Environmental Protection Agency-run project 'Conservation and sustainable use of Liberia's coastal natural capital, 2019–2024.' The aim of this project is to improve the conservation and sustainable use of Liberia's coastal natural capital by mainstreaming the value of ecosystems into the country's development trajectory.

The numerous management plans that have been put in place to maintain the ecological character of the Lake Piso Wetland since 2006[76]. Several management plans were prepared during a field mission organised by Bird International in collaboration with other organisations such as the Farmers Associated to Conserve the Environment (FACE) and the United Nations Environment Programme (UNEP) in 2006[77]. The baseline management plans also include the restoration plan for mangroves as outlined in the five-year plan (2005–2009) of the Coastal and Marine Ecosystem Plan of Action.

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[73] Republic of Liberia 2014a. Improve sustainability of mangrove forests and coastal mangrove areas in Liberia through protection, planning and livelihood creation – as a building block towards Liberia's marine and coastal protected areas. Global Envirnment Facility (GEF) Request For CEO Approval. Monrovia: Environmental Protection Agency and Conservation International

[74] Republic of Liberia (ed). 2014b. *Strengthening Liberia's capability to provide climate information and services to enhance climate resilient development and adaptation to climate change.* Environmental Protection Agency and United Nations Development Programme. Monrovia.

[75] Republic of Liberia 2016a. Improve sustainability of mangrove forests and coastal mangrove areas in Liberia through protection, planning and livelihood creation – as a building block towards Liberia's marine and coastal protected areas. Global Environmental Facility (GEF) Project Document. Monrovia: Environmental Protection Agency and Conservation International

[76] Republic of Liberia (ed). 2007. *Information Sheet on Ramsar Wetlands(RIS): Lake Piso*. Environmental Protection Agency. Monrovia.

[77] Ibid.

The ongoing investments by the Liberian government in mangroves and coastal areas. The Liberian government invests significantly in the management and conservation of mangrove and coastal regions of the country through funding the activities of government agencies such as the Forestry Development Authority (FDA), Environmental Protection Agency (EPA) and Maritime Authority. The agencies' activities in mangrove and coastal areas are mainly directed at building awareness, improving livelihoods, monitoring intervention efforts, and planning sustainable ecosystem management planning. The FDA is the custodian of protected areas and provides employees to manage mangrove protected areas in Liberia. The EPA hosts several education and awareness-raising events related to conserving coastal regions and their biodiversity. These include hosting National Wetlands Day, Biodiversity Day, World Environment Day and Ozone/Climate Change Day. The total investment in these activities annually is ~US$ 75,000[78]. There is also ongoing collaboration between the EPA and the FDA in developing sustainable methods for using mangrove resources.

More details on these projects are provided in Annex 2.D.

6.1.5. Previous and current support for alternative livelihoods

There are few alternative livelihood programmes that have been implemented in urban Liberia. Most alternative livelihood programmes have been focused in rural forest communities to dissuade people from unsustainable use of forests. Most of these programs have had very limited success because the livelihood options presented to communities by these programmes cannot compete with incomes gained from illegal logging, the bush meat trade or diamond and gold mining in the parks and forest reserves. This is due to the fact that the livelihoods offered are based on an assessment of what communities want to do rather than any kind of value chain analysis to identify products and services that show the greatest potential for increasing household income, and what elements along the value chain act as barriers to alternative livelihood development[79]. Despite the challenges associated with life in informal coastal settlements, the urban poor depend coastal ecosystems for their shelter, livelihoods, and communities.

In 2014, the Finn Church Aid (FCA) provided support for an agricultural programme with the purpose of increasing food production and developing agriculture into a more productive source of livelihood. Poor families were assisted in producing eggs for both local and national markets. The urban agriculture project also strove to mould agriculture into an alternative source of income in the informal settlements of the country's capital Monrovia. FCA provided training for cultivating and selling fast-growing vegetables, with the aim of helping the poorest population improve their standards of living.

Since 2008, the Bangladesh Rural Advancement Committee (BRAC) launched its operations in Liberia and has been working in several counties including Montserrado and Margibi County with programmes in microfinance, agriculture, poultry and livestock, health, as well as Empowerment and Livelihoods of Adolescents programmes. BRAC Liberia established its microfinance company in 2009 to provide micro-loans and small enterprise loans for the marginalised. The objectives of the programme are to increase access to microfinance services to marginalised families, initiate sustainable micro-enterprises and strengthen the institutional structures for effective management of the microcredit systems.

[78] Republic of Liberia 2014a. Improve sustainability of mangrove forests and coastal mangrove areas in Liberia through protection, planning and livelihood creation – as a building block towards Liberia's marine and coastal protected areas. Global Envirnment Facility (GEF) Request For CEO Approval. Monrovia: Environmental Protection Agency and Conservation International
[79] DAI. 2008. Liberia Environmental Threats and Opportunities Assessment.

The Ministry of Gender, Children, and Social Protection (MGCSP) is implementing over 5 livelihood projects including:

- Economic Empowerment of Adolescent Girls and Young Women (EPAG) programme;
- Vulnerable Girls School programme;
- Rural Women Economic Empowerment programme;
- Social Cash Transfer programme for extremely poor and labour-constrained households; and
- Peace Building Fund project.

In 2014, the MGCSP with support from the Swedish International Development Cooperation Agency (SIDA) through the World Bank, trained 1,000 adolescent girls under its EPAG project. Out of all beneficiaries, 420 are currently in Greater Monrovia, 155 in Kakata, with the remaining 425 in Grand Bassa County. Since its inception, the EPAG project has supported the upskilling of 3,500 young women.

A proposed GEF LDCF-funded project entitled 'Enhancing the resilience of vulnerable coastal communities in Sinoe County of Liberia' will introduce opportunities that will enable the diversification of livelihoods among coastal communities vulnerable to climate change, with particular focus on women and youth. This will be achieved by, *inter alia*: i) identifying and implementing sustainable livelihood value chains for coastal communities; and ii) facilitating access to micro-finance loans to enable the establishment of businesses. This project will build on the GCF project for which this feasibility study is prepared and will include activites for knowledge-sharing and Integrated Coatal Zone Management (ICZM).

6.1.6. <u>Previous and current support for adaptation planning</u>

In 2016, the GoL with the support of UNDP received GCF's approval for the Readiness proposal entitled 'Advance the NAPs process for medium term investment planning in climate sensitive sectors (i.e. agriculture, energy, waste management, forestry and health) and coastal areas in Liberia' (US$ ~2,263,000). The activities in this proposal focus on four outputs: i) Strengthening institutional frameworks and coordination for implementation of the NAPs process; ii) Expansion of the knowledge base for scaling up adaptation; iii) Building capacity for mainstreaming climate change adaptation into planning, and budgeting processes and systems; and iv) Formulation of financing mechanisms for scaling up adaptation (including public, private, national and international).

In 2016, the GEF approved a 6 years project to develop the capacity of the GoL to meet its global environmental obligations (US$ 3,050,000). One component of this project is the development of an integrated environmental knowledge management system (EKMS) to collect, collate and disseminate information relating to environmental priorities, with an emphasis on climate change.

In 2020, the World Bank International Development Association approved the project: Liberia First Inclusive Growth Development Policy Operation (US$ 40,000,000). The proposed project is the first in a programmatic series of three single-tranche operations designed to support the GoL as it implements a structural reform program focused on productivity-driven private-sector-led growth, improved public-sector transparency, and greater economic and social inclusion.

Moreover, a proposal entitled, "Enhancing Climate Information Systems for resilient development in Liberia (Liberia CIS)", is under development for submission through the GCF's Simplified Approval Process. The aim of the project is to strengthen Liberia's multi-hazard impact-based forecasting and early warning systems (MH-IBF-EWS). The project will focus on improving meteorological and hydrological system management, through effective monitoring, forecasting and early warning for sector- and location-specific response planning and disaster management in Liberia. Furthermore, the project targets Last Mile CIS coverage. Activities will target upgrading infrastructure, developing institutional capacity and establishing effective Last Mile interventions for improving the understanding of climate change impacts amongst vulnerable communities.

The proposed GEF LDCF-funded project entitled ‘Enhancing the resilience of vulnerable coastal communities in Sinoe County of Liberia’ will use innovative technologies to improve coastal adaptation planning, response and communication mechanisms by expanding the understanding of coastal ecosystem services and their value to communities and stakeholders. Among the proposed interventions include: i) establishing knowledge hubs to collect and disseminate information on sea and river defence management; ii) strengthening coastal flood and erosion early-warning and risk management systems to support management and monitoring of coastal ecosystems; and iii) developing context-specific coastal community action plans which encourage the adoption of adaptative livelihoods and practices.

6.2. Best practices and lessons learned

6.2.1. Sustainable alternative livelihoods options

Several sustainable livelihood programmes implemented in Liberia have had limited success. The livelihood options presented to communities through these programmes have mostly not been able to provide sufficient income to communities to incentivise them to stop beach sand mining, illegal logging and trading meat from protected marine life — including turtles and dolphins. Options for sustainable alternative livelihood activities should be developed, including, for example: i) renewable charcoal and wood production; ii) fish drying; iii) sand production; iv) tourism and ecotourism; v) renewable energy production; and vi) information and computer technology. Previous production and sustainable livelihoods — like farming, carpentry, masonry and mechanics — should also be re-introduced.

6.2.2. Environmental education and awareness regarding mangrove ecosystems

Although Liberia has a coastline that is dominated by mangrove forests, there is a significant lack of knowledge regarding the ecological and socio-economic importance of the ecosystems in the country[80]. In particular, there is limited understanding of the critical role mangroves play in providing ecosystem services to local communities such as the maintenance of healthy fish stocks, coastal line protection, habitat provision, carbon sequestration and provision of storm shelters. As a result, the importance of mangrove forest conservation is yet to be fully appreciated by most of the local communities living along Liberia's coastline. For example, a recent survey conducted in the Mesurado mangroves in Monrovia has revealed that just over half of the residents were aware of the critical ecological function of mangroves[81].

To effectively manage and conserve mangrove forests, local communities living in and around these forests need to understand the ecological and economic value of the ecosystems. There is, therefore, a need to implement intensive mangrove forest conservation education that will enlighten local communities on the sustainable management and conservation of these natural resources.

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[80] Tuagben DS. 2012. The vulnerability of the coast of Liberia to marine oil spills: Implications for biodiversity and renewable natural resource utilization. MSc, University of Cape Town, Cape Town.
[81] Kiazolu OG. 2019. Assessment of level of public knowledge, attitudes and perception towards mangrove forest conservation in Mesurado Wetland in Liberia. MA, University of Narobi, Nairobi.

6.2.3. Policy development and implementation

Although there is not yet a coherent coastal management framework that defines the roles and responsibilities of stakeholders or organises the development of activities and settlements in the coastal zone, the GoL is in the process of developing relevant appropriate polices to protect the environment and combat climate change (see Section 5). The GoL is committed to protecting the environment for its present and future citizens through existing and planned policies. However, the complexity of the Liberian context — specifically high degrees of poverty and limited public environmental awareness — constrains the effective implementation of existing and upcoming environmental and climate policies.

6.2.4. Infrastructure for coastal protection

The sandy coastal areas of Liberia are particularly vulnerable to wave action, currents, tides, and sea-level rise, because they are mostly directly exposed to the Atlantic Ocean. Even small disturbances to the system equilibria can lead to increased rates of coastal erosion. Coastal vegetation still naturally occurs in some of these areas, acting as an effective and cost-efficient form of coastal protection. However, restoring coastal vegetation is not a feasible option for coastal protection in all areas of the coastline, because the vegetation cannot withstand the extreme force of wave action. In these areas — particularly where the coast is inhabited by high density populations — hard infrastructure is required to prevent rapid coastal erosion. Areas where natural beach vegetation has been removed and houses built close to the shoreline are particularly vulnerable, as are areas where sand is being mined in large quantities. The development and implementation of a comprehensive ICZM plan is an important step in protecting these coastlines in the long term.

6.2.5. Importance of an integrated approach to address coastal vulnerability

The experience of previous projects has shown that coastal vulnerability is complex with links to diverse challenges including livelihoods, settlements and infrastructure. Addressing this vulnerability requires engagement across many sectors in order to focus on both root causes and immediate challenges. For example, the need to address coastal erosion requires not only physical measures to protect the coastline, but also collaboration with communities living in the area. Settlements, livelihoods and the ecosystem services they depend on affect the capacity of communities and institutions to cope with and adapt to coastal erosion in the long term. If these challenges are not addressed through an integrated approach, single project outputs are unlikely to be sustainable, as no other element will be developed to support them after project closure.

6.2.6. Building capacity for monitoring, forecasting and communicating coastal dynamics for sustainable management of natural resources

The Liberian Meteorological Service (LMS) has limited capacity to monitor, forecast, archive, analyse and communicate information on coastal dynamics, water resources and climate. This includes forecasting the impact of extreme weather events and disasters. In addition, a lack of historical meteorological, oceanographic and biodiversity data constrains the capacity of the LMS to deliver reliable weather forecasts and climate projects and also limits the capacity of the GoL to make evidence-based decisions. Although the GEF/LDCF project “Strengthening

Liberia's capability to provide climate information and services to enhance climate-resilient development and adaptation to climate change" has been implemented to address this barrier, it concentrated on inland areas of Liberia and not on the coastal belt, where weather, climatic and oceanographic information are crucial. Improving the technical and institutional capacity of the LMS to collect, analyse and disseminate these data and operate these monitoring systems is necessary for improving the effectiveness of long-term development planning and the delivery of timely warnings to vulnerable sectors — including agriculture, fisheries and forestry — and vulnerable communities.

The AfDB/GCF project entitled, "Enhancing Climate Information Systems for resilient development in Liberia (Liberia CIS)", focuses on strengthening climate monitoring systems for increased climate resilience in Liberia. Direct beneficiaries for this project include rural farmers and settlements along the coastline of the country. Moreover, one of the focus areas of the project is Last Mile climate information system (CIS) coverage country-wide and 100% of the total population are considered to be indirect beneficiaries which will see a decrease in coastal communities' vulnerability to coastal erosion. The proposed project for which this feasibility study serves will utilize information generated by the monitoring systems improved under the AfDB/GCF project to enhance ICZM interventions.

6.2.7. Importance of a participatory or community-based approach

Previous projects that have been successful have consistently involved organisers and stakeholders and have focused on: i) reaching a common understanding with and within the target community; ii) analysing the community's resource uses and needs; iii) communicating the precise objectives of the project at the outset; and v) creating capacity-building and skill development initiatives. Stakeholder engagement and participatory approaches should not be limited to the design phase of a project. Ongoing and iterative engagement with stakeholders at all relevant levels is a critical aspect of supporting a project to achieve its objective. This sense of local ownership is particularly important for the long-term sustainability of project interventions. Additionally, demonstrating direct and quantifiable benefits to beneficiary communities in the early phases of project implementation is an important factor contributing to their success. One way of doing this is to support the development of alternative livelihood opportunities for improving both resilience to and knowledge of climate change.

6.2.8. Importance of gender sensitivity and gender mainstreaming

Men and women in Liberia use mangroves differently and have unique perspectives about why mangroves are important and how they should be protected[82]. In general, men do the majority of the fishing while women are responsible for smoking the fish. Noting these gendered differences is central to addressing the different drivers of mangrove loss and the principal beneficiaries of mangrove conservation[83]. Based on the critical differences in the use of mangrove and coastal resources by women and men in Liberia, a gendered perspective on mangrove conservation will be adopted by the proposed project.

[82] Republic of Liberia 2016a. Improve sustainability of mangrove forests and coastal mangrove areas in Liberia through protection, planning and livelihood creation – as a building block towards Liberia's marine and coastal protected areas. Global Environmental Facility (GEF) Project Document. Monrovia: Environmental Protection Agency and Conservation International
[83] Ibid.

Women in Liberia often sit on decision-making bodies but tend to be offered nominal positions with minimal decision-making power or influence[84]. Therefore, despite women's statistical representation, their political and public voice remains underrepresented. Furthermore, marginalised groups, such as women and youth, are not sufficiently involved in public meetings concerning the management of mangroves and marine resources and are therefore unable to fully participate in the project. In the local context in Liberia, it may be culturally taboo for women to disagree with their male counterparts openly. As a result, efforts to increase gender equality in decision making regarding coastal resources by mixing men and women in public forums is unlikely to create the enabling environment for women's participation, because the presence of men may serve as a limiting factor to female participation.

Projects that seek to ensure the equitable representation and participation in decision making by both men and women should establish separate project decision-making bodies for men and women at target project sites[85]. In addition to establishing a central project decision-making body in target project sites, the proposed project should create separate project decision-making bodies for men and women that will report directly to the main project management decision-making body[86]. Finally, every effort should be made to ensure that women's representation in mixed project management decision-making bodies is not limited to nominal positions[87].

6.2.9. Effective knowledge management to support adaptive management and contribute to upscaling and replication

Incorporating effective and efficient knowledge management strategies into climate change adaptation projects is critical for supporting knowledge sharing and climate-resilient development at local, national and international scales. Knowledge management — when executed correctly — facilitates the rapid implementation of adaptive management strategies during project implementation. It also contributes to building a repository of knowledge on best practices and lessons learned for adaptation interventions. This is an important consideration because access to information on the success of locally implemented adaptation strategies is often limited, which inhibits their widespread implementation in similar geographical, climatic, cultural and socio-economic conditions. Embedding accessible knowledge management platforms into projects enables climate change adaptation information — including all protocols developed by the project as well as the best practices and lessons learned collected through the project's monitoring and evaluation processes — to be housed for access by project stakeholders and other user groups. Such a platform also provides users with specific knowledge products that will guide policy- and decision-makers to implement sustainable adaptive management practices. To ensure that knowledge management strategies are efficient, it is important to ensure that knowledge-sharing platforms are: i) locally appropriate; ii) easily accessible; iii) sustainable beyond the lifespan of the project; iv) diverse, employing several forms of media and dissemination strategies; and v) linked to — or are nested within — a larger framework of knowledge management initiatives.

7. Needs, gaps and barriers for scaling-up coastal adaptation

[84] Republic of Liberia (ed). 2016b. *Improve sustainability of mangrove forests and coastal mangrove areas in Liberia through protection, planning and livelihood creation – as a building block towards Liberia's marine and coastal protected areas. Gender mainstreaming Strategy and Action Plan*. Environmental Protection Agency and Conservation International Monrovia.
[85] Ibid.
[86] Ibid.
[87] Ibid.

Liberia and the Monrovia Metropolitan Area (MMA) have a number of critical needs to scale up coastal adaptation. These can be divided into several broad categories including the need for: i) institutional strengthening; ii) human capacity development; iii) infrastructural/hard structural development; and iv) adaptation planning.

Institutional strengthening requires further development of institutional arrangements, clear division of responsibilities as well as development of new institutions. Human capacity development is required across many sectors. There is a lack of engineers required for coastal management, lack of educators to help the development of engineers, as well as a lack of interest for higher education among the population due to lack of finances for schooling in the average Liberian family. The Liberian Meteorological Service has been established, but it lacks the qualified personnel and equipment required to be able to perform the duties outlined in its establishment act. The National Disaster Management Agency (NDMA) is similarly limited.

Infrastructural development is also required to scale up coastal adaptation. The rainy season in the MMA area is characterised by particularly high amounts of precipitation, stormy cloud outbursts and flooding with up to a meter, or even higher, of water in many areas of the MMA — often coinciding with the location of informal settlements and the most vulnerable communities. The effectiveness of the sewerage/drainage system is very low for several reasons including: i) lack of maintenance; ii) population growth and overuse; and iii) limited financial capacity to extend or maintain road infrastructure. The low-lying coastal road network, which makes up most of the roads in the MMA, is in similar condition as only the most urgent maintenance is undertaken. Additionally, even after maintenance has been completed, roads are soon damaged because of the combination of rainfall, poor construction and overuse.

The situation with potable water and sanitation is similarly poor. Although there are several public wells with water pumps and several wells in each informal settlement, water is not satisfactorily sanitary due to pollution from the ground — faeces, household wastewater and no wastewater treatment to process them. Additionally, there are very few sanitation facilities in some of the least developed informal settlements, which results in widespread open defecation. Much of the MMA area is also under influence of the Mesurado River, which is considered as the most polluted body of fresh water in Liberia — 30–40% of domestic waste from communities living around the lagoon is thrown or flushed into the river, along with industrial waste. These conditions create additional barriers to the protection and management of mangrove ecosystems as they require additional recovery periods or interventions to offset the risks that increase with the expansion of informal settlements into these ecosystems.

Additional gaps and barriers relating to coastal management and climate change adaptation are described below.

7.1. Integrated coastal management approaches

Integrated and comprehensive coastal management approaches have not been undertaken much in recent projects and programmes (neither from government nor from donor sites). As seen in the Section 6 above, previous projects have mostly addressed site-specific challenges and offered site-specific solutions. The UNDP-funded coastal project 'Enhancing Resilience of Vulnerable Coastal Areas to Climate Change Risks in Liberia' included soft components related to livelihood support — such as offering solar fish driers, energy efficient stoves and providing help to fishing communities in terms of tools and equipment. This integrated approach needs to mainstreamed into future projects. The need for immediate action — which often means hard interventions, in order to save lives and assets — cannot be ignored, but needs to go hand-in-hand with long-term ecosystem-based adaptation (EbA) interventions and enhancement of communities' capabilities to adapt to climate change by increasing climate resilience. Only through this mainstreaming can mangrove ecosystems be effectively protected and managed in a sustainable manner for the long-term benefit of communities reliant on them.

7.2. Gaps in coverage of coastal protection works (EbA solutions as well as hard structures)

Currently, as confirmed by the field scoping, much of the coastal areas in the MMA require protection from coastal erosion in order to protect communities (JFK Hospital area, West Point, New Kru Town), assets and infrastructure (JFK Hospital itself, Freeport industrial area, Hotel Africa area, Providence Island) or ecosystems (Mesurado wetland, natural characteristics of coastal beaches and estuaries). Few coastal protection measures have been implemented on any part of the MMA coastline. In the Hotel Africa area, some evidence remains of beach rock armour revetment which was implemented a decade ago. Little remains in New Kru Town coastal area of a pilot project implementing gabion armour on the beach. Both projects and structures have already failed due to lack of funding to finish the work and for maintenance.

7.3. Gaps in forecasting of sand movement dynamics

No local or national institution currently has the capacity to actively monitor and measure any marine-related data, including currents, wave movements and sand dynamics. Existing data are mostly products of scientific research from foreign experts and are often not up-to-date. More recent studies performed for other purposes (i.e. port development) as well as some hydrodynamic and marine sediments data is likely to be known to private companies — such as shipping companies, port authorities, ore mining companies — but are not shared with public institutions. The monitoring of sand movement is also crucial for land-use planning as it will inform which communities are vulnerable to displacement as SLR and other climate change effects negatively impact the living conditions of these communities. In order to effectively strategise the migration of people displaced by climate change impacts, particularly those reliant on natural resources for their livelihoods, the capacity for forecasting needs to be improved.

7.4. Gaps in infrastructure design and land-use planning that intensify vulnerability

The design of the basic infrastructure[88] in Liberia was done primarily in the last century and pre-civil war era. Limited maintenance and increasing population have placed this infrastructure under significant strain. Partly because of Liberia's long civil wars, urban land-use planning and zoning regulations at the national or county level are limited in Liberia. Rapid urbanisation in Monrovia characterised by increased informal settlements contributes to constrained land-use planning in the city. Activities such as unsanctioned urban sprawl and unplanned beach sand-mining have resulted in destruction of mangrove forest in the Mesurado Wetland. This rapid expansion into wetland areas reduces the amount of natural resources available to people previously living in the region while simultaneous increasing the number of people reliant on the wetland area, creating a compounding pressure on the wetland. Furthermore, people displaced by SLR and shoreline loss tend to resettle near the natural resources they are dependent on.

[88] in this study basic infrastructure is considered to be sewerage/drainage, water and sanitation, power/electricity and roads

7.5. Gaps in technology and technical capacity for collecting, analysing and using biophysical data

To keep coastal communities, economies and ecosystems healthy requires monitoring and assessing how these areas are changing, including: i) amounts of contaminants in the water; ii) sea-level rise (SLR); and iii) surveys of coastline and coastal sea floor, ocean physical, chemical and biological observations, which help coastal communities make the best decisions for themselves and the environment. Tools such as satellites, thermometers and tide gauges, are required to collect observations. However, not all collected observations are in the same format, meaning they cannot be easily used together. There are also gaps in the information that is collected. Development, erosion and other forces can alter the face of the MMA coastal landscape. These changes have implications for Mesurado Wetland conservation, development and planning, and so for the effective preservation of these ecosystems this capacity needs to be developed. A range of tools to monitor changes in the shape of the coast is required. For example, Light Detection and Ranging (LIDAR) technology can often be used to determine changes in coastal elevations or sea-level — in which case it then becomes a sea-level gauge. Satellite imagery and aerial photography are tools that can be used by the coastal management and national geodetic survey offices to survey and create maps of shoreline as well as track land cover change over time, including deforestation.

SLR and flood-related hazards already have severe impacts on the MMA. Coastal communities need to be taken into account when analysing and planning for these threats. Long-term historical trends of locally measured sea-level and tide stations are required for adaptation planning and design of adaptation measures. Training is also required for a number of public institutions involved in coastal management to build technical capacity, in order to understand the causes of inundation, identify local vulnerabilities and communicate risks.

7.6. Gaps in institutional service provision coverage and capacity

Limited institutional capacity at national and local levels constrains the development of climate-smart, integrated and locally-appropriate coastal management solutions. Specific challenges relate to coordination and clear definition of roles. For example, the Liberian Meteorological Service, responsible for collecting and monitoring weather and climate data, is placed under Ministry of Transport and therefore has a limited ability to collaborate with other institutions working on environmental management and scientific services. Coordination and role definition in disaster management have been improved by the establishment of the National Disaster Management Agency (NDMA) under the responsibility of the Ministry of Internal Affairs.

7.7. Gaps in coordination between sectors and ministries

Independent sectoral planning and execution of service delivery often result in ministries being unaware of actions taken by other sectors/ministries. Similarly, there is limited communication between ministries regarding project proposal preparation and project implementation. Specifically, there is no single agency responsible for integrated coastal management in Liberia, but at least ten government institutions are involved in different aspects of coastal management (see Section 5). Supporting line ministries, NDMA and the Environmental Protection Agency are involved in disaster risk management and climate change adaptation. Strengthening the capacity of these agencies for coordinating and collaborating with stakeholders is expected to help to bridge this gap.

7.8. Gaps in financing to overcome and repair repeated damage to infrastructure from cycles of disasters

Financing from the national budget is insufficient for recovering from and proactively preventing destruction due to coastal erosion. The low gross domestic product (GDP) and large development needs (see Section 2) of the Liberian population means that the Government of Liberia has limited ability to invest in medium- to long-term measures. Donor funding has been used for humanitarian causes but has thus far been insufficient to build resilience to climate change. There has also been limited development of private investments and public-private-partnership (PPP) investments into climate change adaptation. This is partially because the investment risks are high.

8. Proposed project sites

Proposed project sites are devided as follow: i) the coastal section of West Point for hard coastal protection activities under Output 1; and ii) the 4 focus areas of Topoe village, Fiamah, Jacob's Town and West Point for mangrove degradation related activities under Output 3. For coastal protection infrastructure, 5 coastal sections have been initially assessed (Hotel Africa, New Kru Town, West Point, American Embassy and JFK Hospital) and West Point has been identified as most at risk. For mangrove degradation related activities, the Mesurado Wetland has been assessed to identify mangrove degradation hotspots (see Annex 2.D) and the communities of Topoe village, Fiamah, Jacob's Town and West Point were selected.

8.1. Site selection process for coastal protection

The site selection process under this feasibility study included a two-step process to address a combination of information gaps and financial shortfalls. Under this process, sites were identified by assessing them against a set of criteria including areas that: i) are at high-risk from coastal erosion, sea-level rise (SLR) and other dynamic ocean processes associated with climate change; ii) are populated by low income households and/or vulnerable people or groups with a low adaptive capacity and are at risk of climate change impacts; and iii) contain high natural or ecosystem value (including provisioning of ecosystem services) located within the vulnerable zone.

Based on this initial assessment in 2017, three areas — covering the majority of the MMA coastline — as well as the Mesurado Wetland, were identified as requiring the implementation of soft and/or hard interventions to: i) respond to accelerated coastal erosion and SLR; ii) increase resilience and adaptive capacity of vulnerable coastal communities; and iii) improve knowledge on sustainable management of natural resources and reduce anthropogenic pressure on critical ecosystems. The three areas identified according to the initial criteria were subsequently subdivided into five coastal sections for further studies to determine specific localised climate change impacts and adaptation requirements (Figure 45).

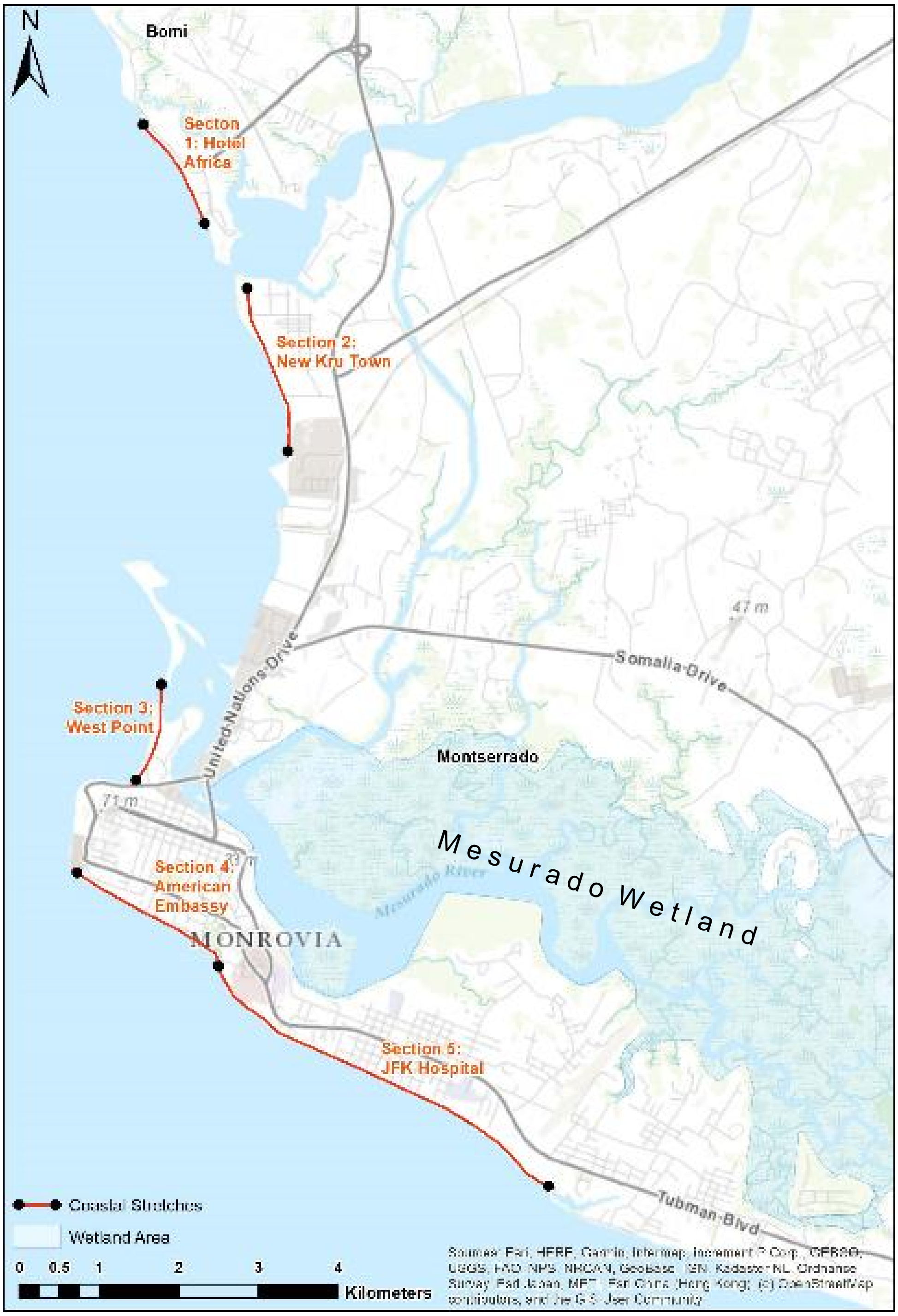

Figure 45. Map of Monrovia's coastline depicting five vulnerable coastal sections assessed under the Feasibility Study. The Mesurado River and Wetland is shown in the centre of the map.

Extensive near shore hydrological and wave modelling was undertaken for the five prioritised sections to determine the proportional contribution of climate change to current and predicted coastal retreat. Concurrently, socio-economic and demographic investigations were undertaken to quantify the vulnerability of populations within each of these sections. Overall, all five sections were defined as housing vulnerable people[89] who are at risk of climate change impacts and

[89] Further information on vulnerable people within coastal communities in the MMA is provided in Annex 6: ESAR.

require the implementation soft adaptation interventions, including: i) diversification and climate-proofing of livelihoods; ii) awareness raising on the impacts of climate change and potential adaptive strategies; and iii) capacity building at local and institutional levels.

Modelling of the near-shore hydrology and wave dynamics identified that coastal erosion poses a significant threat to several sections the MMA's coastline even under non-climate change conditions (Figure 46). Based on these assessments only two of the five coastal sections — namely New Kru Town (Section 2) and West Point (Section 3) — demonstrated additional climate change impacts severe enough to justify a request for climate funds to cover the cost of implementing protective infrastructure.

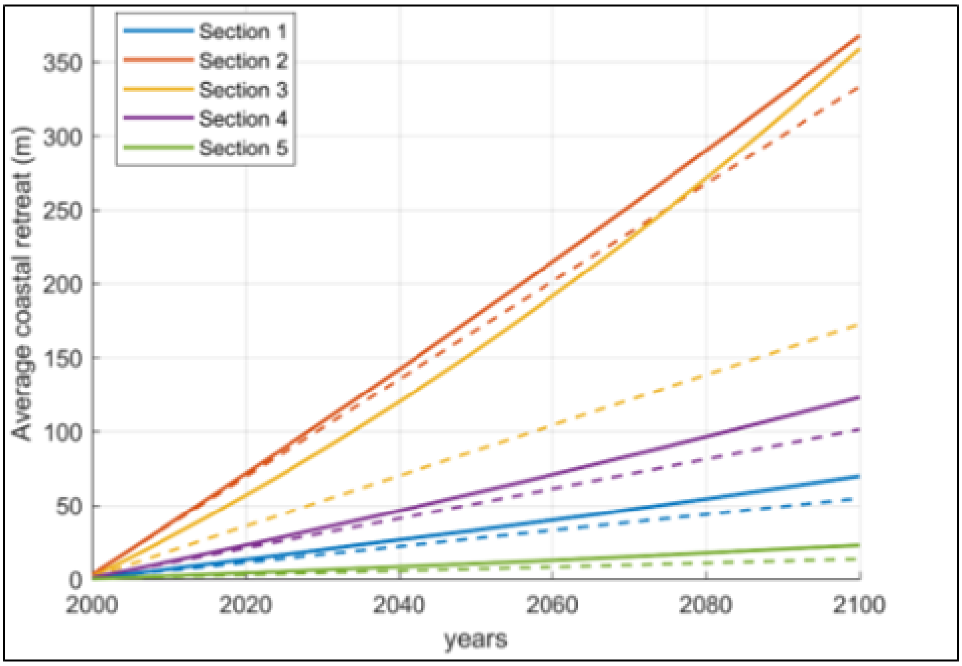

Figure 46. Average coastal retreat between 2000 and 2100 for five coastal areas in Monrovia under RCP8.5 (continuous lines) and without climate change (dashed lines).

8.2. Site selection process for focus areas in the Mesurado Wetland

Extractive practices by local communities within and around the Mesurado Wetland are the primary drivers of degradation and mangrove loss (Section 3.1 of Annex 2.D: Mangrove Sub-assessment). The spatial degradation trends and hotspots identified under Section 4 are consequently the logical focus areas for project interventions. The sections below show the spatial location of focus areas for proposed project interventions under Outputs 1 and 3 of the Funding Proposal (Figure 47). Further details of each focus area can be found under Section 7.3 of Annex 2.D: Mangrove Sub-assessment.

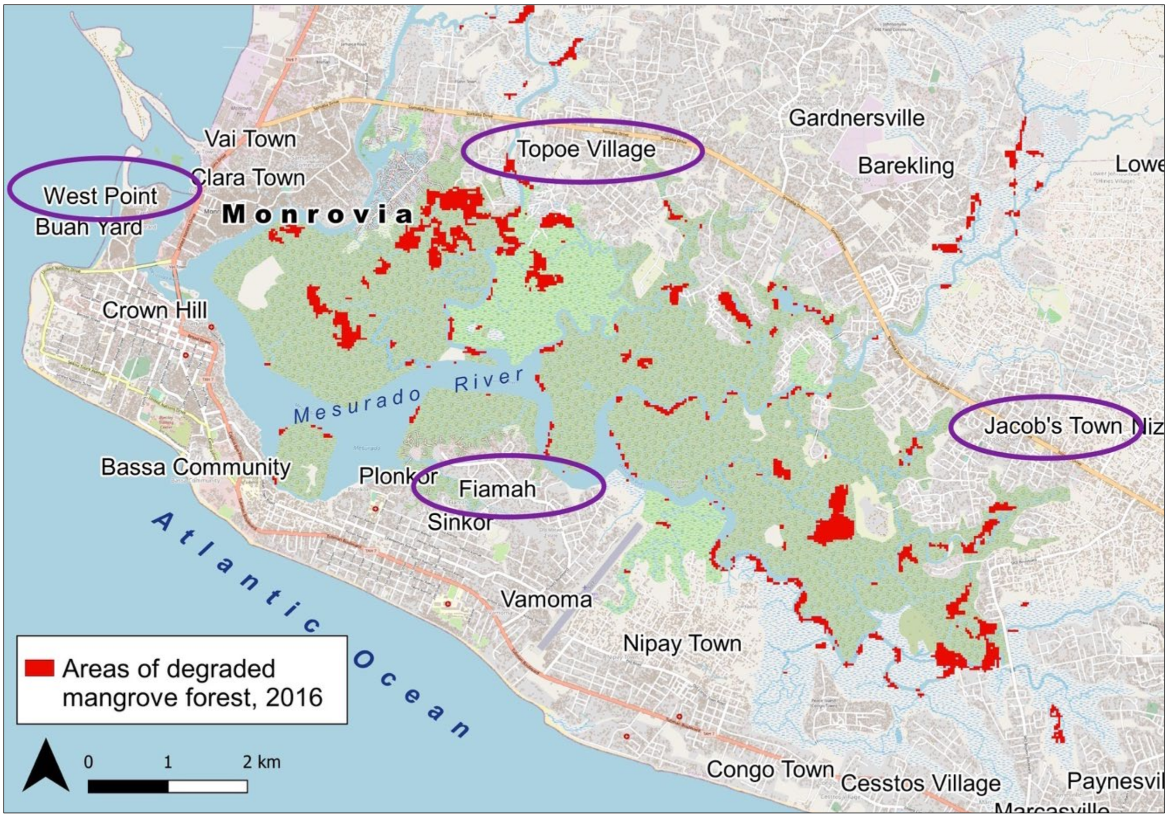

Figure 47. Focus areas in the Mesurado Wetland mangrove degradation hotspots.

8.3. Site descriptions for focus areas in the Mesurado Wetland

Table 6 provides information on the 4 focus areas for mangrove degradation related activities. Further details on these communities is provided in Annex 2.D.

Table 7. Focus areas in the Mesurado Wetland mangrove degradation hotspots.

Community	Estimated inhabitants	Land ownership status	Infrastructure	Structures
Jacob Town	20,000	Undeclared, illegal, unprotected	- Electricity available: Yes - Garbage location: Disorganized deposit - Road types: Dirt paths - Transportation: Bus, motorbike, taxi	Estimated permanent structures :978 Estimated temporary structures: 283
Fiamah	5,654	Declared, legal, protected	- Electricity available: Yes - Garbage location: Common area inside settlement - Road types: Dirt paths - Transportation: Bus, taxi	Estimated number of structures: 1,150

Community	Estimated inhabitants	Land ownership status	Infrastructure	Structures
Topoe Village	4,000	Undeclared, illegal, unprotected	- Electricity available: No - Garbage location: Common area inside settlement - Road types: Dirt paths - Transportation: Bus, Motorbike, taxi	Estimated number of structures: 307
West Point	60,000 to 85,000	Undeclared, illegal, unprotected	- Electricity available: No - Garbage location: Common area inside settlement - Road types: Dirt paths and tarred roads - Transportation: Bus, Motorbike, taxi	N/A

8.4. Site descriptions for coastal protection

Brief descriptions of the five coastal sections considered for hard coastal protection are provided below, with additional information on coastal erosion available in the technical feasibility documents provided as an addendum to this Feasibility Study (Annex 2.B: Vulnerability Sub-assessment and Annex 2.C: Engineering Sub-assessment). Further information on social dynamics, livelihood practices and adaptive capacity within these areas is also available in Annex 6: ESAR.

Section 1: Hotel Africa
The Hotel Africa section is the northernmost area of the MMA assessed under this study. It has a coastline of ~2,200 m and is named after the Hotel Africa Complex, which was constructed in 1979 and has minor historical and cultural importance. The area has a total population of ~6,000 people[90] — at least ~4,000 of whom are exposed to the impacts of coastal erosion and SLR. Besides its historical and cultural value, the area has some limited economic and touristic potential but is assessed as having a low ecological value as most of the original coastal ecosystem has been severely degraded by anthropogenic activities. It is estimated that climate change induced coastal erosion will contribute to an additional 20 m (29%) towards coastal retreat above a no climate change scenario, with the total extent of coastal retreat projected to exceed 70 m by 2100 (Figure 48).

[90] The total population is based on demographic surveys conducted in 2008. Although there is no more recent information on population growth for this area, it is estimated that the total population is greater than reported.


Figure 48. Aerial photo of Hotel Africa area with mouth of St. Paul River at the far stretch. The existing rock revetments established with private funding are visible in the foreground of the photograph.

Section 2: New Kru Town

The New Kru Town section is a low-income, densely populated residential area located on the north end of Bushrod Island with a coastline of ~2,400 m (Figure 49). It has a total population of ~75,000 people[91] — at least ~16,000 of whom are exposed to the impacts of coastal erosion and SLR. New Kru Town was established as a resettlement project for residents of Old Kru Town after World War II when Old Kru Town area was developed into a breakwater for the new Freeport area. Located on the corner of the Atlantic Ocean and the Saint Paul River estuary, fishing is an important source of income for local residents. It has moderate economic importance currently and proximity to the Free Port and Free Economic Zone means that it is likely to become more economically important in the future. A significant number of beachfront dwellings in this section are at risk of coastal erosion and several dozen existing shoreline dwellings have already collapsed or been swept away. The overall ecological value of the section is assessed as being low, because of the long period of human occupation and densely populated settlements. In this section of coastline, it is estimated that climate change-induced coastal erosion will contribute an additional 35 m (10%) towards coastal retreat above a no climate change scenario, with the total extent of coastal retreat projected to exceed 370 m by 2100. However, acknowledging the rapid rate of coastal retreat along this stretch of coastline, New Kru Town has benefited from the establishment of a rock armour intervention under a GEF-LDCF funded project, namely the '*Enhancing Resilience of Liberia Montserrado County Vulnerable Coastal Areas to Climate Change Risks II'* project.

[91] This is the population according to the 2008 census, however the governor of the area reports that the population is higher and current estimates place the population between ~85,000 and ~170,000.


Figure 49. Coastal erosion on shores of New Kru Town. (Photograph taken by V. Kalinski).

Section 3: West Point
The West Point section is located on a sand bar formed by interaction of Mesurado River and the Atlantic Ocean with a coastline of ~1,500 m. It is a densely populated informal settlement with a total population ~29,000 people[92] — ~10,800 of whom are exposed to the impacts of coastal erosion and SLR. There are several community-based organisations (CBOs) operating within the community, including youth groups, women's groups, elderly groups and the West Point Commission — which is the local governing body. The dominant ethnic group in the settlement is the Kru, but other tribes that can be found within the community include the Lorma, Vai, Greebo, Kissi, Kpelle and Mende. It is among the poorest areas in the MMA and is highly vulnerable to coastal erosion as well as seasonal flooding. Sanitation and hygiene conditions are extremely poor and basic infrastructure is virtually non-existent, which exacerbated the well-documented Ebola outbreak in 2014. The land on which the community is located is owned by the government and the residents occupy the land under a Squatters Rights License, giving them limited rights of occupation. Intense and prolonged occupation by people has placed immense pressure on the local vegetation and biodiversity, which has resulted in the area being assessed as having a low ecological value.

The extreme baseline vulnerability of the West Point settlement has been previously acknowledged by the GoL, who attempted a community relocation plan in the 1970s. This plan was unsuccessful and resulted in the majority of the community moving back to West Point within the same year. In this section, it is estimated that climate change-induced coastal erosion will contribute an additional 195 m (108%) towards coastal retreat above a no climate change scenario, with the total extent of coastal retreat projected to exceed 350 m by 2100.

Section 4 and 5: American Embassy to Bernard Beach

[92] This is the population according to the 2008 census; however, community leaders estimate the population to currently exceed ~85,000.

Sections 4 and 5 were assessed independently under the technical feasibility assessments (Annex 2.B: Vulnerability Sub-assessment and Annex 2.C: Engineering Sub-assessment) but are being combined under this description because of their geographic proximity. The combined sections — referred to as the Atlantic Seaboard section — is a highly urbanised area with a coastline of ~7,300 m. The population along this stretch of coastline is estimated to be exceed 80,000 people — with ~19,000 people being exposed to the impacts of coastal erosion and SLR. The section includes numerous businesses and hotels as well as institutions, such as the JFK hospital, Barclay Training Centre (BTC), foreign embassies and government buildings. The section has experienced severe degradation and all the coastal vegetation has been removed through anthropogenic activities. The existing beach is devoid of vegetation but plays an important recreational role for local communities (Figure 50). It is estimated that climate change-induced coastal erosion will contribute an additional 22 m (21%) for section 4 and 9 m (64%) for section 5 towards overall coastal retreat by 2100 above a no climate change scenario. Total coastal erosion for sections 4 and 5 is projected to amount to 70 m and 25 m by 2100 respectively.

Figure 50. Stretch of barren beach behind BTC area. The area used to be covered with coconut trees and other beach vegetation. Remains of the beach grass and other vegetation can be seen in the distance. Extreme storm waves can reach up to the road and the BTC[93].

9. Potential coastal protection solutions

As detailed in Sections 3 and 4 above, climate change is likely to substantially increase the rate of coastal erosion on parts of the Monrovian coast. Measures to reduce the impact of climate change on the coast and reduce the rate of coastal erosion are therefore a critical component of climate change adaptation in the MMA. Specifically, these measures are required to: i) protect settlements and assets; ii) safeguard coastal livelihoods; iii) protect cultural and heritage sites; and iv) protect fragile ecosystems. In this section, a range of potential coastal protection measures are assessed for each of the sites identified in Section 8.

[93] Photo: V. Kalinski.

9.1. Approaches to coastal protection

Three general approaches to coastline protection were considered, each with several advantages and disadvantages and appropriate to different contexts. These approaches are, using: i) engineering ‘hard’ coastal defence structures; ii) ‘soft’ natural or social interventions; and iii) a combination of both. **Hard engineering interventions** are often the most effective option, particularly when development close to the coast is necessary (for example for ports). These structures are also effective immediately upon completion of the construction, which is not true of all ‘soft’ interventions. However, in general, a hard engineering approach tends to: i) be expensive; ii) have a limited lifespan, depending on the type of structure, quality of design and durability of materials used; iii) be visually unattractive; and iv) in some cases require frequent maintenance. In addition, coastal defence structures can have a negative impact and increase erosion in other places along the coast.

Soft engineering solutions include ecosystem-based or natural interventions as well as some engineering works, like beach nourishment. These measures tend to be less expensive and are more likely to have ecological benefits, but can be limited in their effectiveness in certain contexts. For example, planting vegetation to stabilise coastal dunes is unlikely to be effective if the rate of coastal erosion is very high. In such case trees’ roots are likely to be eroded before the trees establish and start to perform their intended coastal protection function.

Well-designed **combined solutions** can achieve the benefits of both hard and soft approaches. For example, off-shore breakwaters can decrease the energy of waves before they hit the shoreline and reduce the rate of erosion to allow enough time for establishment of protective vegetation that would have been planted on the shore. Off-shore breakwaters and beach nourishment are also often combined. A combined approach is likely to have a longer lifespan than hard infrastructure but is expected to be expensive and ensuring synergy between the hard and soft interventions is likely to be complex.

9.2. Analysis of coastal defence options

The proposed coastal projection interventions have been selected based on stakeholder consultations, options analyses and technical feasibility assessments. An overview of the process is given below, followed by details of the options analysis, which is described in further detail in Annex 2B: Vulnerability Sub-assessment.

A multi-criteria analysis (MCA) workshop was held on 30 January 2019. At this workshop, initial intervention options (soft/hard/combination of hard and soft interventions) identified by the technical consultants were presented to project stakeholders (representatives from communities within critical coastal hotspots, relevant government ministries and agencies, NGOs, and development agencies). These stakeholders were split into three groups to rank the initial intervention options based on clearly defined criteria. The groups were defined based on the three critical hotspots: the St. Paul area (Hotel Africa and New Kru Town); the Mesurado area (West Point: the focal area for intervention); and the Atlantic area. The aim of the structures/interventions as they relate to climate change adaptation, as well as the advantages and disadvantages of the intervention options, were thoroughly explained to stakeholders to guide their decisions. Based on the MCA exercise, the stakeholders’ preferred intervention options were captured by the technical consultants and used to refine the set of intervention options.

Through further technical assessments and the MCA workshop, two feasible intervention options for the Mesurado Area (West Point) were identified and assessed by the technical consultants: a rock revetment; and a groyne with beach nourishment. At the request of the Government of Liberia, a meeting was scheduled for 30 May 2019 to discuss the Vulnerability and Engineering Sub-assessments produced by the technical consultants. This meeting included relevant government entities, UNDP and the technical consultants for the project and was hosted by the EPA. In this meeting, a presentation was made by the project team covering the climate rationale for the critical hotspots with emphasis on West Point, and the advantages and disadvantages of the aforementioned two intervention options for West Point, including the costs associated with both options. A decision was then made by relevant government stakeholders, stating their preference for the rock revetment over the groyne with beach nourishment option. Prior to the Validation Workshop, West Point community representatives were informed of the two intervention options, the government's preferred solution and the reasoning behind it. They validated the government's preference and agreed that the rock revetment option was preferable. The Vulnerability and Engineering Sub-assessments were shared with the government upon completion and again on 27 May 2019, along with the invitation to the consultation described above and a breakdown of the key matters for discussion and decision at the meeting. This process is described in the Vulnerability Sub-assessment (Annex 2.B) and Figure 6-1 on page 88 of the Vulnerability Sub-assessment (Annex 2.B) summarises the selection criteria for coastal protection interventions.

A summary of the initial options analysis is provided in Table 7. Based on this analysis, four feasible options for coastal protection were identified: i) rubble mound groynes to block longshore sediment transport; ii) breakwaters to force wave-breaking; iii) revetments to stabilise the shoreline; and iv) retreat and leave the coastline vulnerable.

Table 8. Analysis of the advantages, disadvantages and feasibility of a range of coastal protection measures in the Monrovia Metropolitan Area.

Strategy	Measure	Advantages	Disadvantages	Feasibility
Direct defence				
Managed retreat – people and assets move out of vulnerable area	• No physical interventions • Implementing a set-back line (safety zoning) • Realignment of urban planning and settlements	• Natural processes are not interrupted • No maintenance • Relatively inexpensive	• Additional land, settlements and assets will be lost • Loss of coastal livelihoods • Difficult to implement	Yes, though does not address the direct impact
Adaptation of assets/ buildings	• Buildings on piles • Reinforcing coastal buildings • Strengthening shoreline roads	• Natural processes are not interrupted	• Very difficult to achieve in highly urbanised areas with dense buildings • Very expensive to retrofit adapted structural interventions	Not financially feasible
Sediment nourishment	Several possible methods, including: • Beach nourishment • Sand engines • Perched beach • Sand groynes	• No downdrift erosion • Flexible and able to respond to changing conditions • Costs spread over long period of time	• Long-term maintenance required	Technically feasible, but it has been acknowledged that the long-term maintenance is unlikely to occur.
Block longshore sediment transport	Several possible methods, including: • Timber groynes • Rubble mound groynes	• Decreases required nourishment frequency and required maintenance • Low costs compared to breakwater	• Causes downdrift erosion • Does not mitigate cross-shore erosion	Yes, rubble mound groynes are feasible
Dissipate wave energy (Ecosystem-based)	Restoration of: • Mangrove forest • Coral reef • Oyster reef • Salt marshes	• Numerous ecological benefits • Improved food security • Opportunities for livelihood diversification	• Require continuous protection and maintenance • Require large areas	Mangroves are not wave facing and therefore not effective. Other options have been assessed as ineffective

Strategy	Measure	Advantages	Disadvantages	Feasibility
	• Seagrass beds		• Reliability dependent on environmental conditions and anthropogenic impacts	because of intense wave energy.
Force wave breaking	• Emerged breakwater • Reef breakwater	• Reduces long- and cross-shore transport • Decreases required nourishment frequency and required maintenance • Potential ecological benefits	• Causes downdrift erosion • High cost (both options) • Changes to currents and inconvenience to fishers.	Yes
Stabilising the shoreline	• Revetment • Vertical seawall	• Minimal long-term maintenance	• Causes downdrift erosion • Causes additional erosion in front of the structure, beach will disappear	Yes
Indirect defence				
Improved coastal management	• Sustainable fisheries management • Protected marine and mangrove areas • Effective pollution control and waste management • Sustainable sand extraction	• Improved management of nature and natural resources • Substantial ecological benefits • Improved food security • Opportunities for livelihood diversification	• No direct protection against coastal hazards	Yes, although this approach does not address the direct impact of SLR and coastal erosion
Improved governance	• Development and capacity building of national and metropolitan regulatory institutions to improve regulations and enforcement • Development of land use allocations and plans • Updating land tenure system • Strengthening community-level management to control	• Improved management of natural resources • Better and more sustainable management of coastal areas and communities • Increased resilience of coastal communities	• No direct protection against coastal hazards	Yes, although this approach does not address the direct impact of SLR and coastal erosion

Strategy	Measure	Advantages	Disadvantages	Feasibility
	land use and illegal settlement • Public awareness campaigns to increase understanding of climate change vulnerability			

These four options are assessed for each of the coastal sections identified. Details of the assessment are given below.

Coastal section 1: Hotel Africa

Recommended intervention: managed retreat

The baseline Vulnerability Sub-assessment (see Annex 2.B) suggests the Hotel Africa section of coastline has is moderately vulnerable to coastal erosion. Specifically:

- tangible direct & indirect damages are expected to be small;
- damage to intangible considerations such as health and recreation is expected to be moderate;
- damage to the livelihoods of coastal communities is expected to be small; and
- damage to leisure and real estate opportunities is expected to be large.

This section of coastline is projected to retreat 50–80 m by 2100 (Figure 51) and to erode evenly along the shoreline (Figure 52). Considering this section in isolation, the development of a breakwater is recommended as the most appropriate coastal defence. This would reduce the wave erosive potential and maintain the beach for leisure and real-estate opportunities. However, the current vulnerability of Section 1 is assessed to be moderate overall, and the lowest of the five coastal sections assessed. This is due to the lower exposure of assets and communities, with the largest impact being the effect of coastal erosion on the potential leisure industry. In the context of the larger project this section is at the least risk and considering the large cost implications of the break water, it is unlikely that any of the feasible developments will be justified. It is therefore proposed that a managed retreat pathway should be the focus of adaptive measures for Section 1.

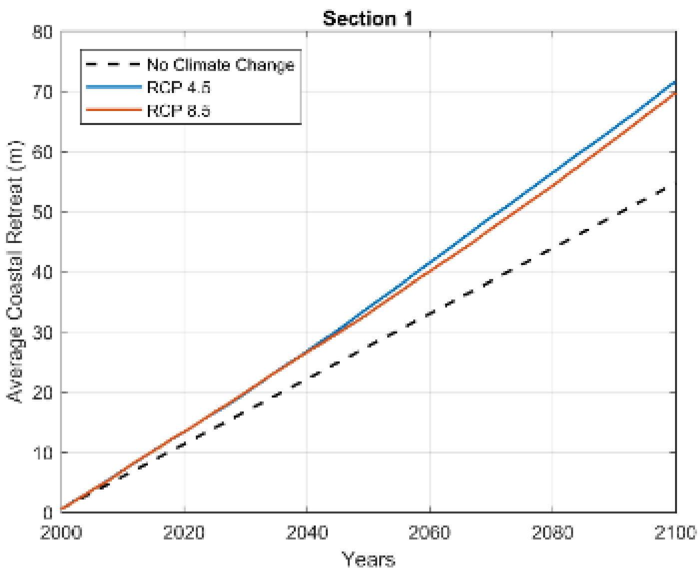

Figure 51. Magnitude of projected coastal retreat at Section 1: Hotel Africa due to sediment deficit and the Bruun effect up to 2100, under a no climate change scenario and RCP 4.5 and RCP 8.5.

Coastal Section 1

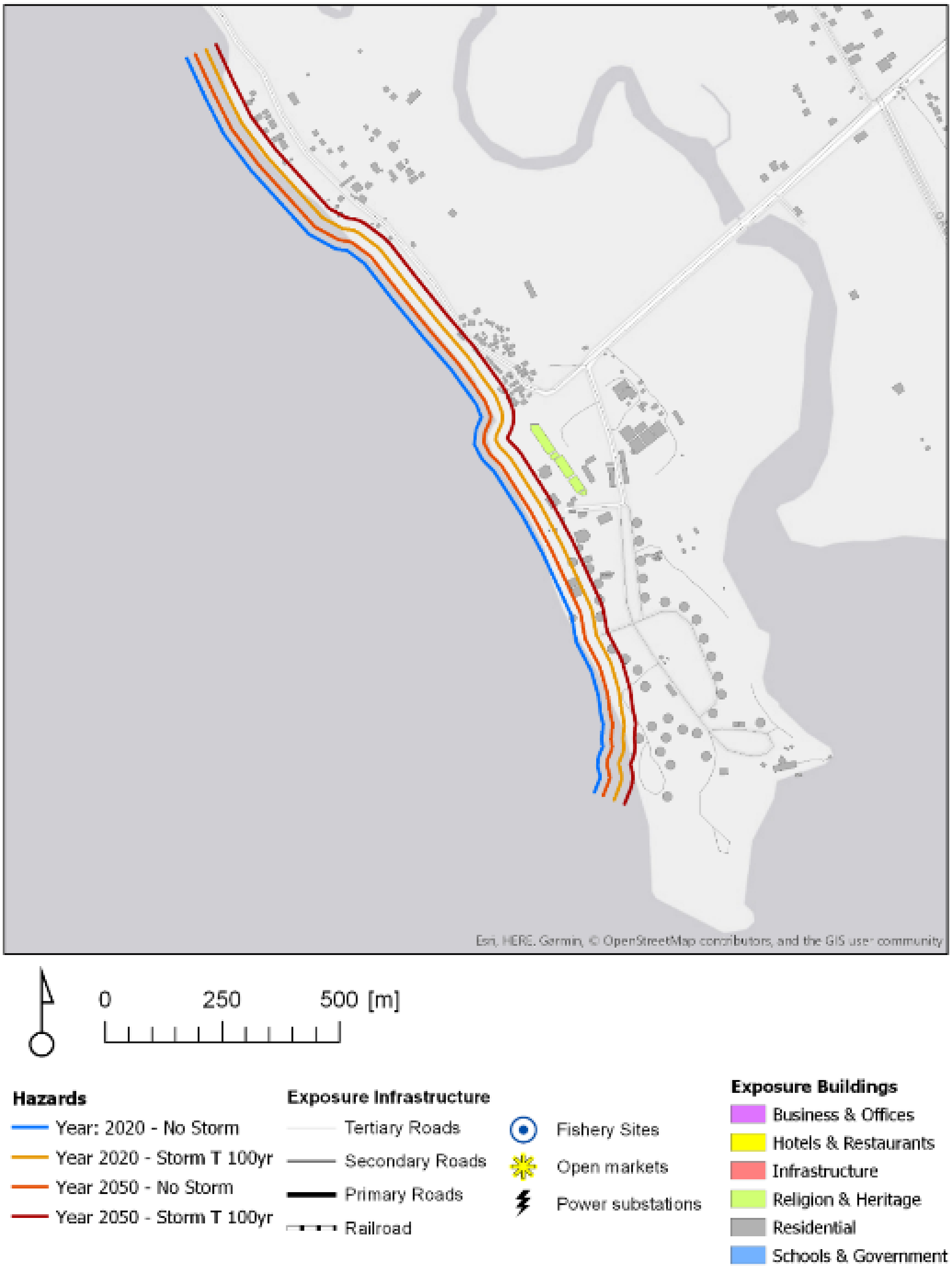

Figure 52. Map of projected coastal retreat at Section 1: Hotel Africa in 2020 and 2050 with and without 100-year storms.

Coastal section 2: New Kru Town

Recommended intervention: upgrading rock armour wall

The baseline vulnerability assessment (see Section 8) suggests the New Kru Town section of coastline is highly vulnerable to coastal erosion. The tangible direct and indirect damages, intangible damages to health and recreation, damage to coastal livelihoods and damage to leisure and real estate opportunities are all expected to be large.

This section of coastline is projected to retreat 300–400 m by 2100 (Figure 53), which is an order of magnitude more than Section 1. The northern part of this section is projected to erode faster than the remainder of the section. A rock armoured wall has been constructed as a coastal protection measure for this section and, considering the section in isolation it is recommended that this rock armoured wall be strengthened to increase its lifespan. The beach in front of the existing rock armoured wall is constantly utilised and provides access to the sea for the fishing communities living in the area. Neither the existing wall nor an upgraded wall will protect this beach against erosion and beach nourishment would be necessary to ensure its continued existence. However, it is unlikely that the operations and maintenance required for beach nourishment would be undertaken.

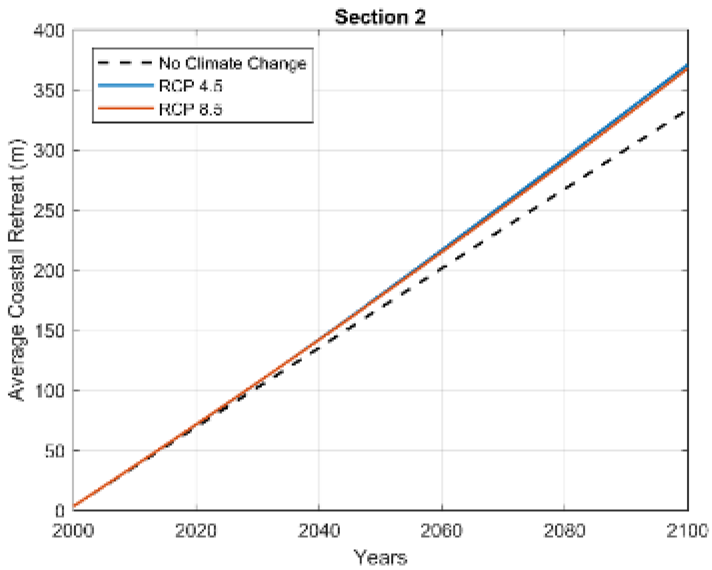

Figure 53. Projected coastal retreat at Section 2: New Kru Town due to sediment deficit and the Bruun effect up to 2100, under a no climate change scenario and RCP 4.5 and RCP 8.5.

This section is highly vulnerable and has the largest number of affected persons to all the assessed factors. While the damage exposure is high, these projected damages are as a result of natural systems and processes rather than being associated with climate change (Figure 54). Adaptation is therefore essential and should be robust to defend the community. Considering the existence of the present rock armoured wall, upgrading this installation would be the most efficient coastal protection solution.

Coastal Section 2

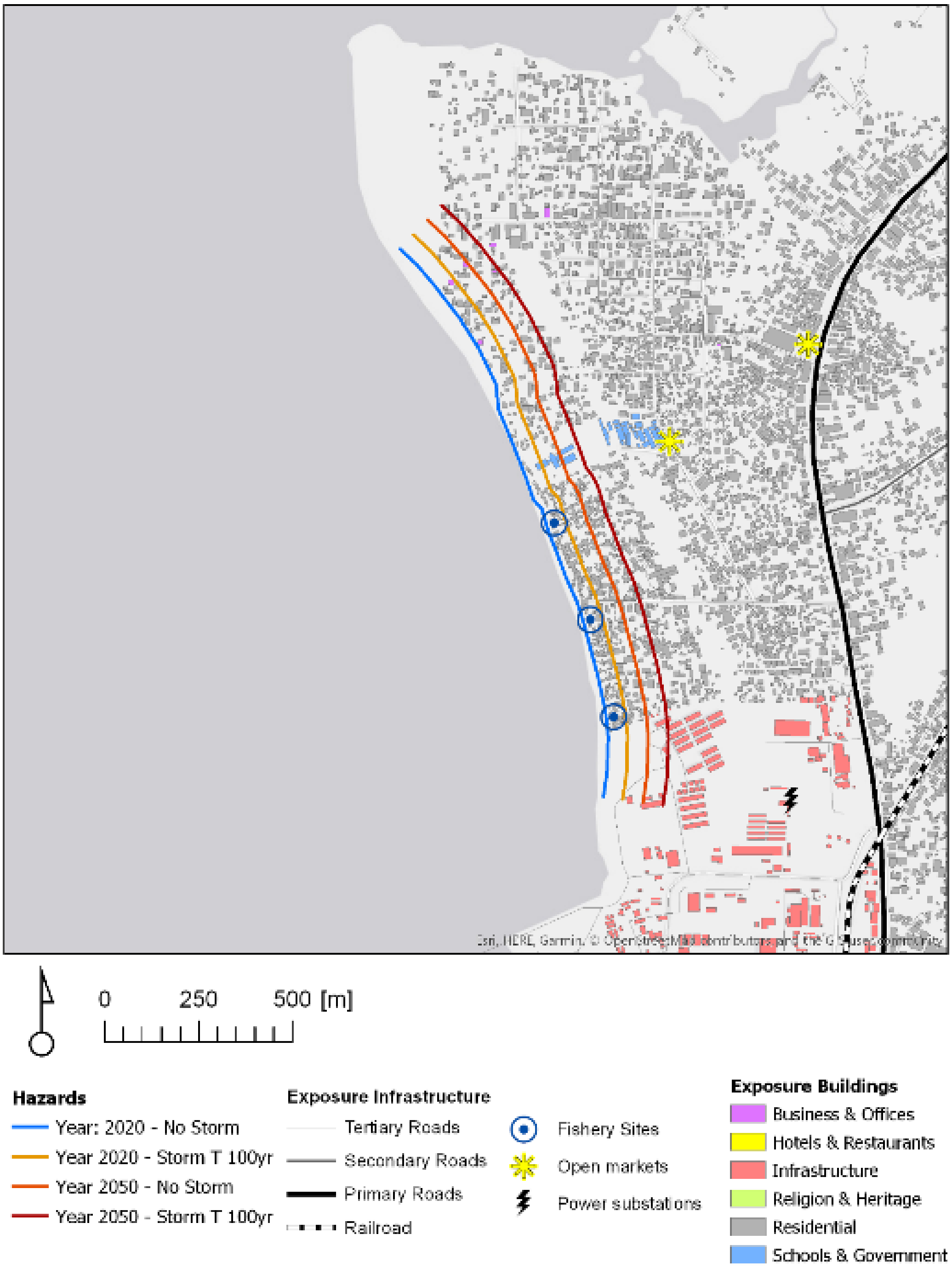

Figure 54. Map of projected coastal retreat at Section 2: New Kru Town in 2020 and 2050 with and without 100-year storms.

Coastal section 3: West Point

Recommended intervention: constructing revetment with green promenade

According to the baseline vulnerability assessment (see Section 8), the coastline at West Point highly vulnerable to coastal erosion. The tangible direct and indirect damages, intangible damages to health and recreation, damage to coastal livelihoods and are all expected to be large, while damage to leisure and real estate opportunities is likely to be moderate.

Coastal erosion projections vary substantially, from 150 m in a scenario without climate change to more than 250 m under RCP 8.5 (Figure 55). Much of the West Point peninsula is likely to disappear by 2050 in the absence of coastal protection measures (Figure 56), threatening the dwellings of ~10,800 people. Some informal adaptation measures currently exist, as the West Point community has attempted to prevent ongoing erosion, but these have had limited success.

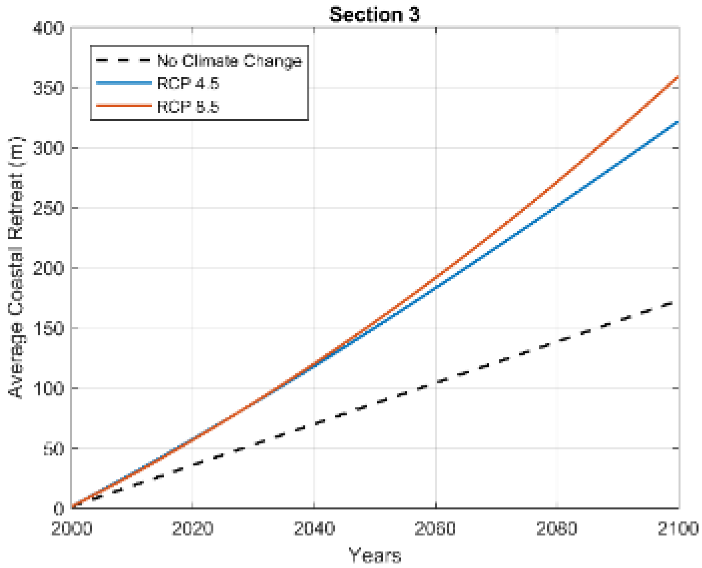

Figure 55. Projected coastal retreat at Section 3: West Point due to sediment deficit and the Bruun effect up to 2100, under a no climate change scenario and RCP 4.5 and RCP 8.5.

The existence of the mouth of the Mesurado Estuary to the north of West Point is an important consideration for assessing coastal protection measures. For example, constructing rubble mound groynes would cut off sediment supply to the estuary mouth and therefore accelerate its erosion. Furthermore, for the beach to remain stable with groynes in place, sediment nourishment would be required. A revetment would also limit sediment supply to the estuary, but to a lesser extent than groynes. Measures to dissipate wave energy would not be sufficiently effective to protect this part of the coastline. For these reasons, constructing a revetment is recommended as the most effective coastal defence measure for West Point.

The informal nature and high density of the West Point settlement indicates its vulnerability in all assessed factors other than leisure and real estate opportunities which have limited development potential. Furthermore, the climate change additionality is highest of all sites at 110%. For these reasons (detailed further in Section 8), this section should be the highest priority for intervention. In the context of this project, cost implications of a breakwater are likely to make this option unfeasible and the construction of a revetment is recommended.

Coastal Section 3

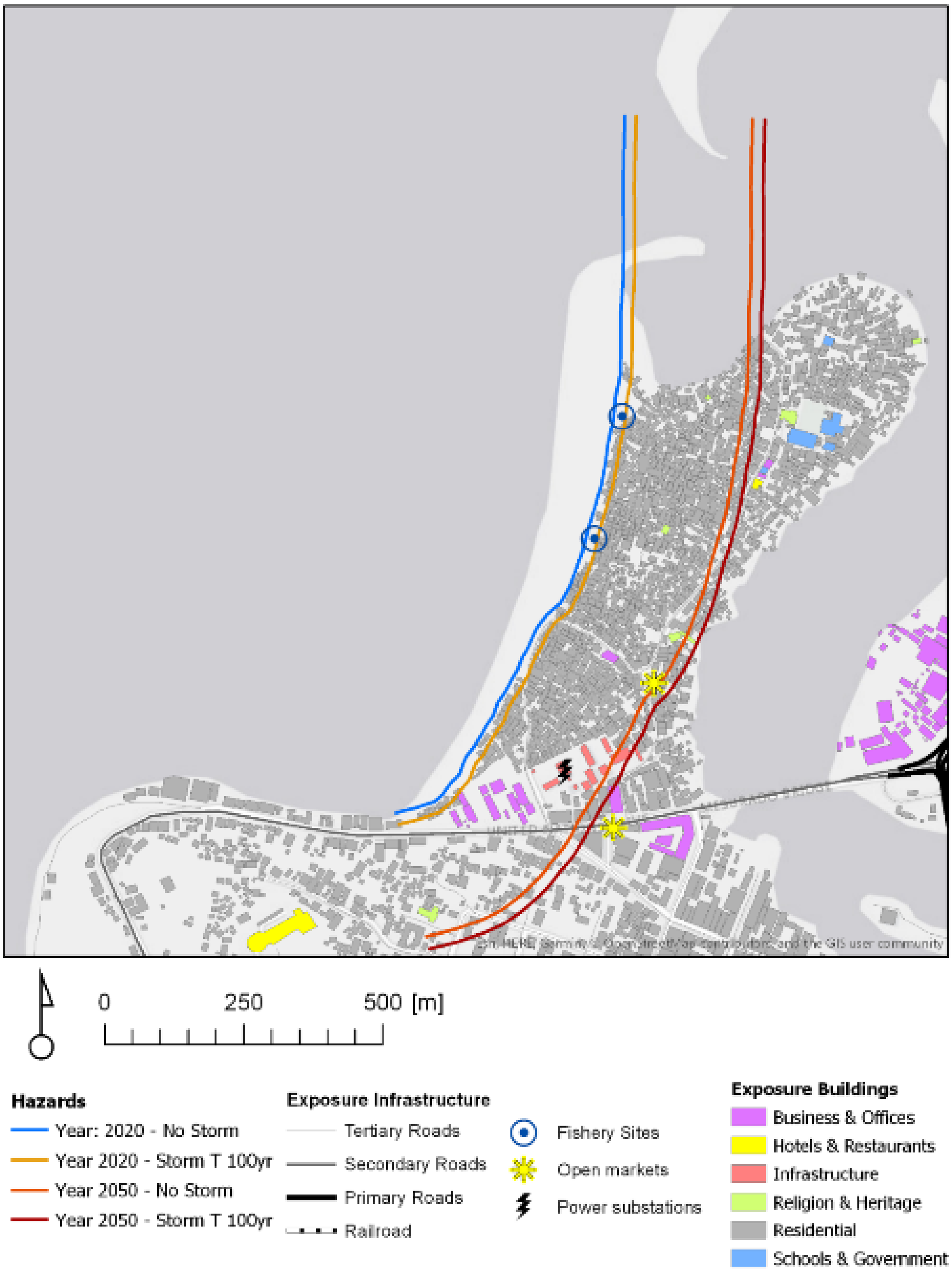

Figure 56. Map of projected coastal retreat at Section 3: West Point in 2020 and 2050 with and without 100-year storms.

Coastal section 4: American Embassy

Recommended intervention: Beach nourishment
The vulnerability assessment suggests that this section of the coastline is also highly vulnerable to coastal erosion. Specifically:

- tangible direct & indirect damages are expected to be large;
- damage to intangible considerations such as health and recreation is expected to be moderate;
- damage to the livelihoods of coastal communities is expected to be small; and
- damage to leisure and real estate opportunities is expected to be large.

This section of coastline is projected to retreat by 100–130 m by 2100 (Figure 57) and to be eroded evenly along the length of the section (Figure 58). The area would benefit from the development of a groyne as a coastal protection measure, with beach nourishment to ensure it remains stable. A revetment was deemed to be ineffective due to the high wave energy and a breakwater — while effective — would be a very expensive due to the steepness of the shoreface. Beach nourishment even without a groyne is likely to defend the section against SLR, although this would require additional maintenance.

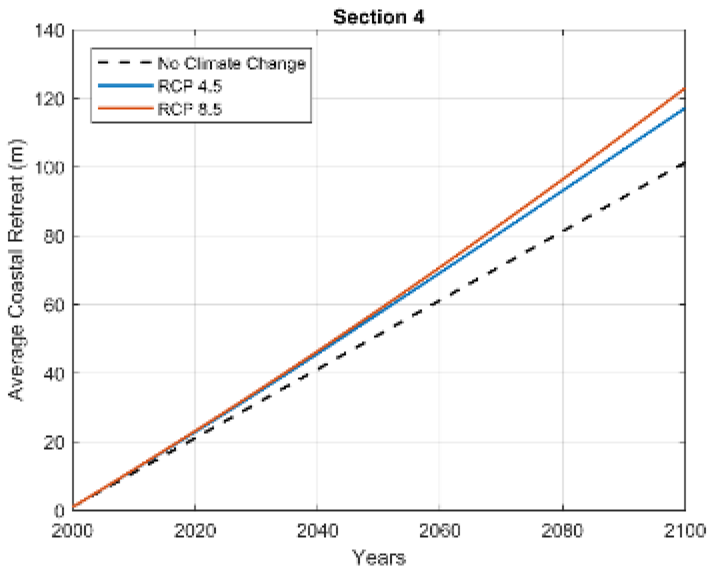

Figure 57. Projected coastal retreat at Section 4: American Embassy due to sediment deficit and the Bruun effect up to 2100, under a no climate change scenario and RCP 4.5 and RCP 8.5.

The direct tangible assets and leisure and real-estate opportunities are particularly vulnerable in this area. However, the requirement of beach nourishment means that the measures discussed above cannot be recommended unless there is a commitment to ongoing operation and maintenance.

Coastal Section 4

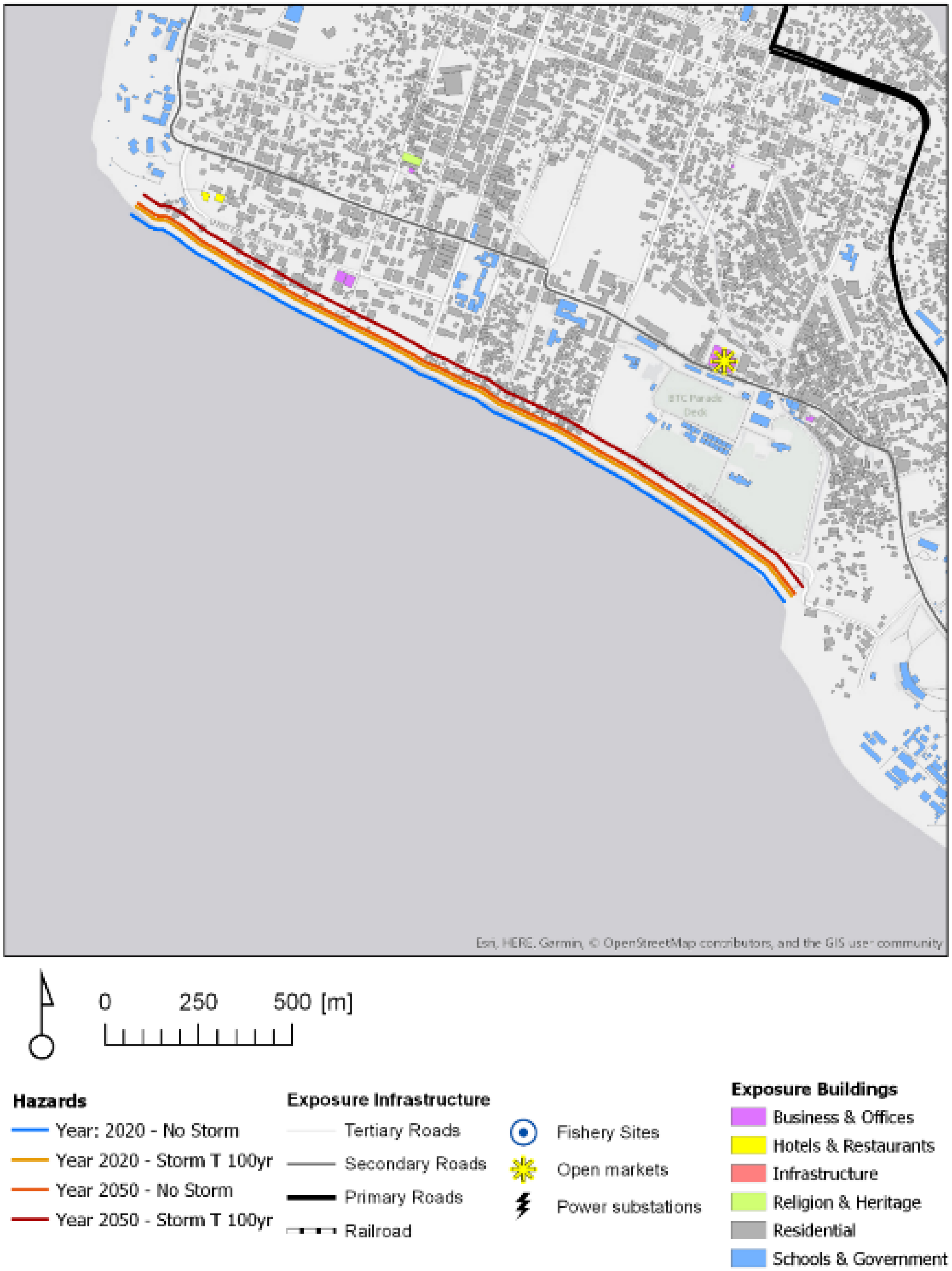

Figure 58. Map of projected coastal retreat at Section 4: American Embassy in 2020 and 2050 with and without 100-year storms.

Coastal section 5: JFK Hospital

Recommended intervention: managed retreat

The vulnerability assessment suggests that the vulnerability of this section of the coastline coastal erosion is relatively low. Specifically:

- tangible direct & indirect damages are expected to be small;
- damage to intangible considerations such as health and recreation is expected to be small;
- damage to the livelihoods of coastal communities is expected to be moderate; and
- damage to leisure and real estate opportunities is expected to be moderate.

The projected magnitude of coastal retreat in for Section 5 in 2100 ranges from ~14 m without climate change to ~40 m under RCP 4.5 (Figure 59). These values are an order of magnitude lower than projections for Sections 2,3 and 4. This section is not as vulnerable to coastal erosion as other parts of the Monrovian coastline, but has several important social assets (Figure 60). It is likely to benefit from the development of a breakwater or a groyne with beach nourishment. However, the significant costs of these interventions mean and lower priority in terms of vulnerability means that their development under the project will not be justified. Development in this section may be possible under a managed retreat option.

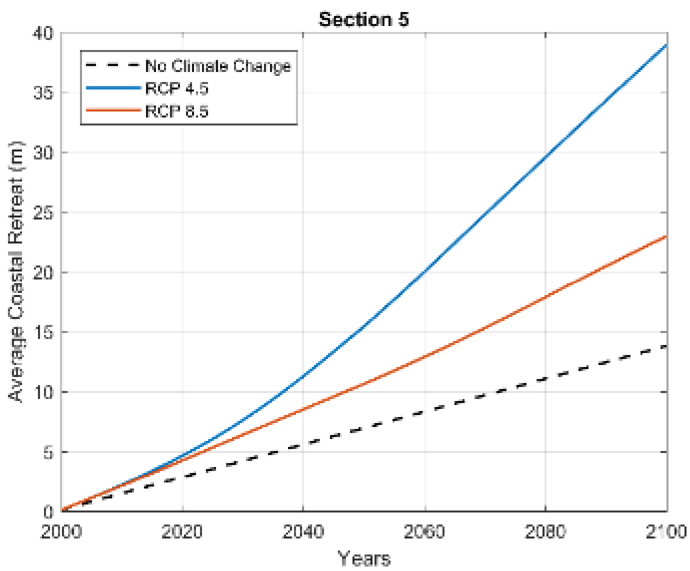

Figure 59. Projected coastal retreat at Section 5: JFK Hospital due to sediment deficit and the Bruun effect up to 2100, under a no climate change scenario and RCP 4.5 and RCP 8.5.

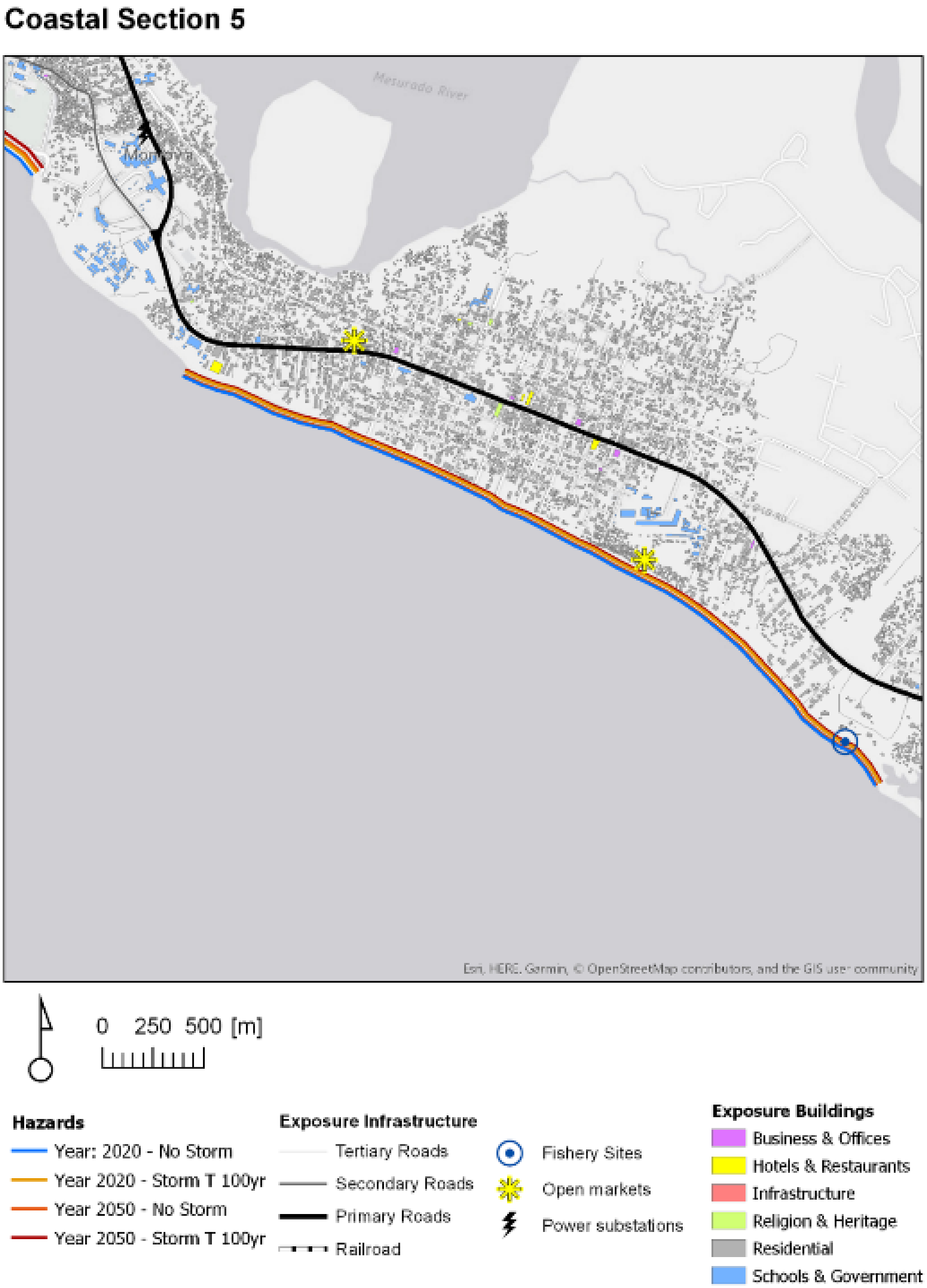

Figure 60. Map of projected coastal retreat at Section 5: JFK Hospital in 2020 and 2050 with and without 100-year storms.

9.3. Soft interventions

The effectiveness of the hard infrastructure interventions in addressing increasing sea-level rise while seeking to safeguard the current livelihoods of local industries will need to be supported through engagement with — and buy-in from — local affected persons, fisherfolk and communities exposed in the mangrove areas. Table 8 gives details of options for soft interventions.

Table 9. Options of indirect strategies and measures for supporting and facilitating coastal protection.

Indirect strategy	Measure
Community awareness and management strengthened	Awareness of the risk to properties and communities needs to be communicated in each of the sections regardless of interventions being undertaken. This can be done through: • public awareness campaigns to increase understanding of existing and future vulnerability; and • community engagement that outlines the benefits of the interventions and the options selected. It will also be critical that information on the link between mangroves and the fishery industry is provided for the affected and beneficiary communities.
Capacity development for Integrated Coastal Zone Management (ICZM)	The coastline of Monrovia is exposed to the effects of erosion, even in the absence of climate change-induced sea-level rise. ICZM plans will need to be established to reduce the exposure of future developments, and where possible, mitigate risks in areas already established. To be most effective, this strategy would include: • establishing an inter-agency ICZM working group with the aim of raising awareness of ICZM issues with community stakeholders and decision makers; and • integrating ICZM principles into development strategies, policies and regulations for land management.
Mangrove protection providing livelihood defence	Mangroves in the MMA are integral to the long-term sustainability of the fishing industry as they provide a spawning ground for fish as well as firewood to fuel cooking and smoking of fish. Effectively safeguarding these areas will therefore not only strengthen defence of the adjacent inland areas against sea-level rise, but also maintain the spawning grounds paramount to the fishing industry. The following points are potentially important strategies for conserving mangroves. • Building community by-in and ownership through engagement highlighting the link between the potential of mangroves to act as a defence against increased sea-level and for the stability of the fishery industry. • Assessing mangrove nourishment needs to match vertical mangrove accretion to sea-level rise. • Preparing sustainable sediment use strategies for nourishment being cognisant of pollution control and waste management. • Formalising community, fishery industry and government responsibilities for conducting nourishment activities, and monitoring intervention effectiveness for both the mangrove and fishery sustainability. • Developing skills required to utilise, maintain and expand the project interventions that improve livelihood resilience while reducing the demand on the mangrove systems. Community buy-in to developing and utilising these skills will be supported by the links highlighted during community engagement.

9.4. Cost estimate

Costs of both the direct and indirect interventions have been estimated. Cost breakdowns of two possible funding scenarios are given below (Table 9). For each of the hard infrastructure interventions, a range of estimated costs is given.

Table 10. Estimates for two funding scenarios, with a breakdown accordingly to coastal defence strategy and section.

Section	Recommended strategy	Cost range estimation (million US$)
Scenario 1		
Section 1 - Hotel Africa	Option 4 – leave vulnerable area	
Section 2 - New Kru Town	Option 3 – revetment	21–32
Section 3 - West point	Option 3 – revetment with green promenade for recreation	14–22
Section 4 - American Embassy	Option 1 – rubble mound ground and beach nourishment	9–15
Section 5 - JFK Hospital	Retreat Option 4 – leave vulnerable area	
Mangrove area	Mangrove protection providing livelihood defence	4.3
All sections	Community awareness and management strengthened	1.7
All sections	Capacity development for Integrated Coastal Zone Management	3.1
Scenario 1: total		US$ 53–78 million
Scenario 2		
Section 1 - Hotel Africa	Option 4 – leave vulnerable area	
Section 2 - New Kru Town	Option 4 – leave vulnerable area	
Section 3 – West point	Option 3– Revetment with green promenade for recreation	14–22
Section 4 - American Embassy	Option 4 – leave vulnerable area	
Section 5 - JFK Hospital	Option 4 – leave vulnerable area	
Mangrove area	Mangrove protection providing livelihood defence	4.3
All sections	Community Awareness and Management Strengthened	1.7
All sections	Capacity development for Integrated Coastal Zone Management	3.1
Scenario 2: total		US$ 23–31 million

9.5. *Conclusion*

This options analysis suggests that the most appropriate coastal defence option for the project to support is the construction of a revetment at West Po int (Section 3), to protect the dwellings of ~10,800 people that are threatened by coastal erosion. This section is one of the most vulnerable to coastal erosion, along with New Kru Town (Section 2). Coastal erosion at West Point can also be more strongly attributed to climate change than along much of the Monrovian coastline, making it more appropriate for a climate change project to contribute to coastal protection measures in this section. In addition, it is recommended that interventions to improve community awareness and build capacity from ICZM are undertaken to support and improve the sustainability and replicability of the hard coastal defence interventions. With limited baseline information available about the condition, composition and functioning of the mangrove ecosystems in the Mesurado Estuary, it is unlikely that physical interventions to protect the mangroves could be undertaken through the project, as the environmental and social risks associated with such measures would be considerable (refer to section 2.3. of Annex 2.D for details). The reliance of vulnerable communities on these mangrove ecosystems compels protection measures to be directed in livelihood adaptations and resilience building rather than restricting these communities from accessing much-needed resources. Detailed recommendations for direct and indirect coastal protection interventions are given in the following section (Section 10).

10. Recommendations for project interventions

10.1. *The way forward*

Developing a comprehensive solution to the climate change impacts and adaptation needs identified through this Feasibility Study requires the implementation of a range of interventions for both the MMA and across Liberia. For example, the need to address accelerated coastal erosion and SLR requires both the implementation of engineering-based solutions for erosion hotspots as well as institutional strengthening, technology transfer, capacity building, awareness-raising and the establishment of a management plan for the Liberian coastal zone. If not addressed through an integrated approach, any single project output would fail to achieve to generate systemic and catalytic change and would fail to be sustainable in the long-term. During the project preparation and scoping phases, extensive background research and consultation with stakeholders has been undertaken along with in-depth site assessments. This approach has been chosen to determine the most appropriate solutions to overcoming the listed barriers and increase the climate resilience of the MMA and contribute to increased resilience across the entire Liberian coastal zone.

10.2. *Specific barriers that need to be addressed by recommended interventions*

Critically, recommended long-term solutions to identified challenges should take into account and overcome identified barriers to ensure that impact pathways will be interrupted by project activities. The barriers previously summarised in this Feasibility Study (Section 7) are further categorised according to three thematic areas to contextualise the inclusion of subsequent recommendations in Table 10.

Table 11. Summary of barriers according to identified thematic areas.

Thematic area	Description of barrier(s)
Institutional barriers	• Lack of a coherent coastal management framework and coastal management plan defining the roles and responsibilities of all relevant stakeholders for development activities and settlements in the coastal zones. • Poor institutional coordination of the coastal management and climate change management responsibilities and initiatives within government institutions. • Limited baseline data to inform long-term planning and management activities (e.g. mangrove forests stock and condition, biodiversity status of coastal and marine areas, climate/hydrometeorological data) • Lack of monitoring equipment to retrieve data, develop a baseline and measure change-of-state, which is necessary to underpin informed decision-making processes.
Capacity- and knowledge-related barriers	• The officers and staff at the national, county and community level do not have the required capacity/expertise for designing and implementing climate resilient initiatives or integrated coastal zone management. • Limitation in access to climate information necessary for the mainstreaming of climate change into the design and the implementation of coastal management policies, strategies and plans • Limited knowledge and capacity related to best practice for coastal management and climate change adaptation • Limited access to appropriate tools and methodologies to assess the vulnerability of different communities and design appropriate adaptation strategies • Limited technical and institutional capacity to undertake monitoring of coastal dynamics and determine the impact chain arising from changes in near-shore currents and wave action.
Financial barriers	• Lack of domestic financial resources restricts the type of interventions that can be implemented, specifically with regard to protective infrastructure. • Weak financial capacity of coastal communities to undertake independent adaptation actions and generate new skills or livelihood practices to increase their resilience to climate change.

To overcome the barriers listed above it is necessary to implement an integrated solution that address all three thematic areas. This solution will achieve the following four outcomes: i) enhance the health and resilience of the natural coastal assets, with a specific focus on ecosystems that provide critical services and underpin livelihoods; ii) protect vulnerable coastal communities through the establishment of hard infrastructure solutions, EbA solutions or alternative strategies; iii) create an enabling environment by establishing plans, updating policies, fostering cross-sectoral collaboration and/or facilitating technology transfer to support improved management of the coastal zone; and iv) build capacity at local and institutional levels through training, awareness-raising and knowledge-sharing to support long-term sustainability and contribute to the upscaling of interventions.

10.3. Recommended interventions

In order to achieve the outcomes listed above, it is recommended that the following interventions are implemented through an integrated approach to increase the climate resilience of vulnerable communities within the MMA and facilitate upscaling of successful interventions across Liberia.

10.3.1. Establish protective infrastructure to safeguard vulnerable communities against accelerated coastal erosion

In the greater MMA, particularly its low-lying coastal communities such as West Point, New Kru town, Bushrod Island, etc., the socioeconomic wellbeing of the population is very sensitive to severe weather and extreme climate events due to their high degree of vulnerability and low adaptive capacity. Very often communities experience loss and damage of property because of climate change impacts such as sea-level rise and floods. With significant numbers of the population in these communities extremely poor and their incomes strongly linked to the activities along the coast, their livelihood has become more and more climate-sensitive. In identifying potential solutions (see Section 9), consideration has been given to the current and future use of the areas e.g. whether areas are used for fishing, swimming, or dwelling. Where hard engineering solutions are proposed, consideration must be given to maintaining access during and after construction. This can be done by incorporating access features, such as steps, ramps, flat surfaces and other access way features into the design.

10.3.2. Develop high-resolution multi-criteria vulnerability maps of the Liberian coastal zone to inform the development of an Integrated Coastal Management Plan and subsequent adaptation activities

A low-resolution vulnerability assessment for Liberia's coast has proved valuable in identifying hotspots for intervention and adaptation activities. However, the resolution of the above-mentioned study is not conducive to inform planning and/or interventions at the site scale. It is therefore important to upscale the outcomes of this study by increasing the resolution of the data inputs and subsequent outputs to ensure adequate detail and proactive planning. Procuring high-resolution spatial data will enable these maps to take into account coastal erosion and the health of mangrove ecosystems, historically and throughout the project implementation, to ensure the vulnerability maps take these critical aspects of coastal zone management into account. Validation of these subsequent outputs will involve relevant committees and stakeholders.

10.3.3. Facilitate the development of an Integrated Coastal Zone Management Plan (ICZMP) for the MMA and strengthen technical and human capacity to implement and upscale the plan across Liberia

The development of an integrated strategy for coastal planning and adaptation measures is of utmost importance to avoid duplication of effort and maladaptive practices. It is recommended that this take the form of an Integrated Coastal Zone Management Plan (ICZMP) for the entire Liberian coastline, with the first phase of this iterative process focusing on the MMA, benefiting ~one million residents of Monrovia through improved coastal planning and management. Following this, the process can be replicated elsewhere in the country. An important success factor in the development and implementation of the ICZMP will be the degree to which cross-sectoral collaboration and cooperation — particularly with and between government line ministries, departments and agencies — can be achieved. Similarly, coastal dynamics forecasting is critical for a wide range of scientific endeavours required in the management of coastal zones in the MMA including: i) modelling of coastal inundation zones; ii) estimating storm and tidal surges; iii) quantifying volumes of sand movement due to erosion and accretion; iv) studying marine currents and surface circulations; and v) identifying vulnerable zones along the coast. Very often this process would require a mix of spatial data generated through remote sensing and traditional surveying techniques. Currently, the GoL has no equipment that fulfil this need, and limited financial resources with which to procure it. To address these challenges, it is recommended that financial and technical assistance be provided to procure remote and in-situ oceanographic sensing equipment as well as the requisite hardware and software to process and analyse data. Additionally, it is recommended that staff from relevant institutions be capacitated to: i) collect, process and analyse data; and ii) install and undertake minor maintenance to maintain the equipment in working order.

10.3.4. Strengthen the adaptive capacity of communities through awareness raising and training on alternative climate resilient livelihoods.

Buy-in to proposed adaptation interventions will be crucial in determining the impact and sustainability of any such activities. To this end, community sensitisation, awareness raising, and knowledge sharing should form part of the strategy to improve adaptative capacity at the community level. The imposition of strategies and initiatives — particularly with respect to new technology or infrastructure — in a top-down fashion should be avoided at all costs. Instead, a bottom-up approach of consultation, engagement and capacity development should prevail, where communities are trained to develop and implement alternative climate-resilient livelihood strategies. Informal trading and small enterprises form the livelihood strategy for the majority of people in the affected area. New and sustainable livelihood options are required in order to reduce the appeal of the destructive activities such as beach mining, illegal coastal logging and bush / protected marine life meat trade. Additionally, considering the disruption to these livelihood strategies resulting from SLR and the need to improve upon the baseline considering the endemic poverty in Liberia, the project shall promote Small, Medium and Micro Enterprise (SME) development by improving access to finance, developing human capital and skills and facilitating access to markets and Information. Linking SMEs to climate resilience interventions will create a feedback loop that facilitates the up-take of the interventions while promoting local development, such as the maintenance of cold storage units and the manufacturing of energy-efficient cookstoves. This enables the communities to benefit on a development level while also enhancing their climate change resilience. SMEs would enhance livelihoods and generate income for the low-income segment of the population and promote social development, social stability, and contribute to the development of the private sector.

10.3.5. Develop co-operative management strategies to safeguard — and ensure the sustainable use of — critical ecosystems such as the Mesurado Wetland

Coastal communities in the MMA are disproportionately reliant on climate-sensitive livelihoods and have limited access to develop or engage alternative livelihood practices. It is therefore necessary to secure the livelihoods of vulnerable communities who rely on climate-sensitive fishing practices through sustainable co-management of important ecosystems such as mangroves. The adaptive capacity of vulnerable communities needs to be strengthened and innovation enabled by supporting local fishery-based livelihoods through sustainable co-management of mangrove areas and providing training to catalyse the uptake of diversified climate-resilient livelihoods. The provision of energy efficient cookstoves well as cold storage units will improve the adaptability of these communities while simultaneously reducing the pressure on the critical ecosystems they are dependent on. Energy-efficient cookstoves will lower the amount of wood that needs to be harvested and cold storage units will further reduce the demand on wood supply by providing an alternative to smoking fish for preservation. These strategies will ensure that the demand placed on mangrove ecosystems that are able to survive and expand under SLR and other changing conditions will enable mangroves to support dependent communities.

10.3.6. Ensure that gender sensitivity is mainstreamed throughout project interventions

Recognising the prevalence of gender inequality in Liberia, project interventions should increase local adaptive capacity by strengthening gender- and climate-sensitive livelihoods. Given that the majority of fishmongers in Monrovia are women and that the loss of the mangroves will disproportionately affect women and exacerbate existing gender inequality, it is important to undertake gender-sensitive stakeholder consultations to identify the dependencies and vulnerabilities of coastal communities, and to disaggregate these vulnerabilities on a gendered basis. Any knowledge products derived from project interventions should be tailored to identified user-groups, designed and disseminated in a gender-sensitive manner.