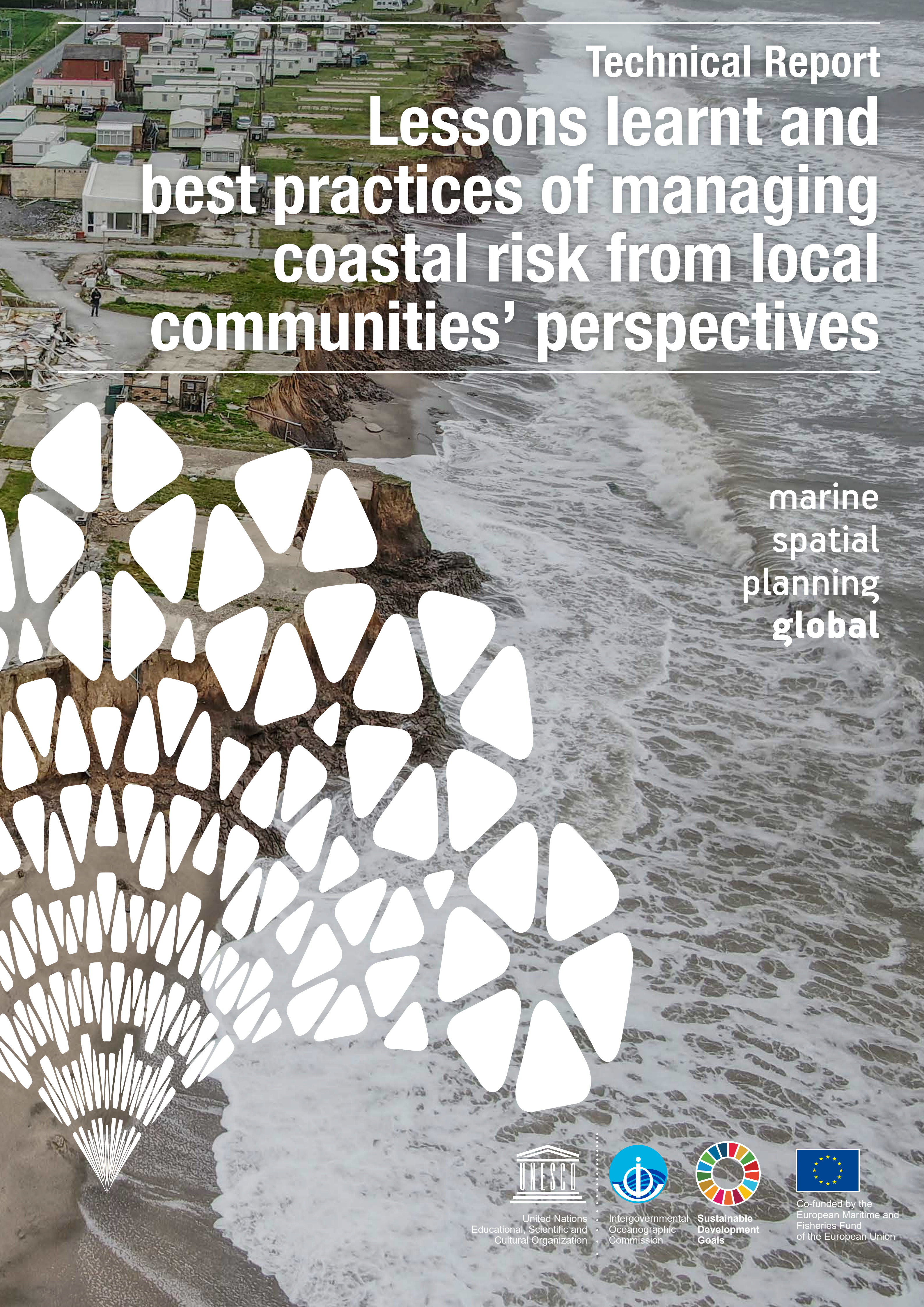

Technical Report

Lessons learnt and best practices of managing coastal risk from local communities' perspectives

marine spatial planning **global**

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Sustainable Development Goals

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Acknowledgements

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1. Introduction

The paradox between sedentary humans and dynamic shores

The coast forms a dynamic, interface zone where the land and sea realms meet and is characterised by some of the world's most sensitive ecosystems, such as mangroves, wetlands, coral reefs, dunes and beaches. Unlike watersheds, coastal areas have no natural, clear nor precise boundaries. They are subjected continuously to the natural processes of weathering, coastal erosion, coastal flooding and sea-level rise. The impacts of these processes and events vary from one coastal zone to another depending on the geology and geomorphology of the coast and its exposure to natural processes.

As the interface between land and sea, coastal areas perform many essential functions like natural protection against storms, regulation of water exchange between land and sea, regulation of the chemical composition of sediments and water, storage and recycling of nutrients and maintenance of biological and genetic diversity. From socio-economic perspectives, coastal zones are important settlement areas which play a critical role in the wealth creation of many nations as they offer access to fisheries and commerce, proximity to rich agricultural lowlands, aesthetic landscapes as well as cultural and recreational opportunities.

On a global level, coastal zones comprise 20% of the Earth's surface, yet they host approximately 50% of human population within 200 km of the sea (Ngoran and XiongZhi, 2015). Nearly 600 million people live in coastal areas that are less than 10 m above sea-level, and it is expected to increase by 50% over the next 25 years (McGranahan, Balk and Anderson, 2007). This rapid urbanisation – coupled with the fast-growing economy of coastal areas, their changing land use and land cover, the deterioration of ecosystems and runoff from upland land uses – is making coastal zones vulnerable to pollution, habitat degradation, overfishing, invasive alien species, severe weather events and coastal hazards, such as storms, coastal flooding and coastal erosion (Creel, 2003).

As the globe's temperature rises more than it would naturally (Solomon *et al.*, 2007), other climate changes have already started to generate additional pressures and adverse consequences on coastal environments due to climate and sea-level related hazards. All coastal zones are, to some extent, under threat of accelerated sea-level rise (SLR) and climate change; however, the effects are not uniform as they vary considerably regionally and over a range of temporal scales (IPCC, 2007). Even in highly-developed nations, unequal distribution of wealth along the coastal areas is leading to significant differences in social vulnerability (Martinich *et al.*, 2013) but societal understanding of the distributional and equity implications of SLR impacts and adaptation actions remains limited. In many developing countries, the exposure of low-lying coastal urban and rural areas and of their populations to coastal flooding, storm surge, inadequate sanitation facilities and limited access to essential resources is all too common. When combined with the exposure to physical threats, such as those emerging or aggravated by climate change (IPCC, 2012), this phenomenon is more pronounced in densely-populated coastal areas where the high population growth rate places increasing stress on the coastal ecosystems (World Bank, 2017).

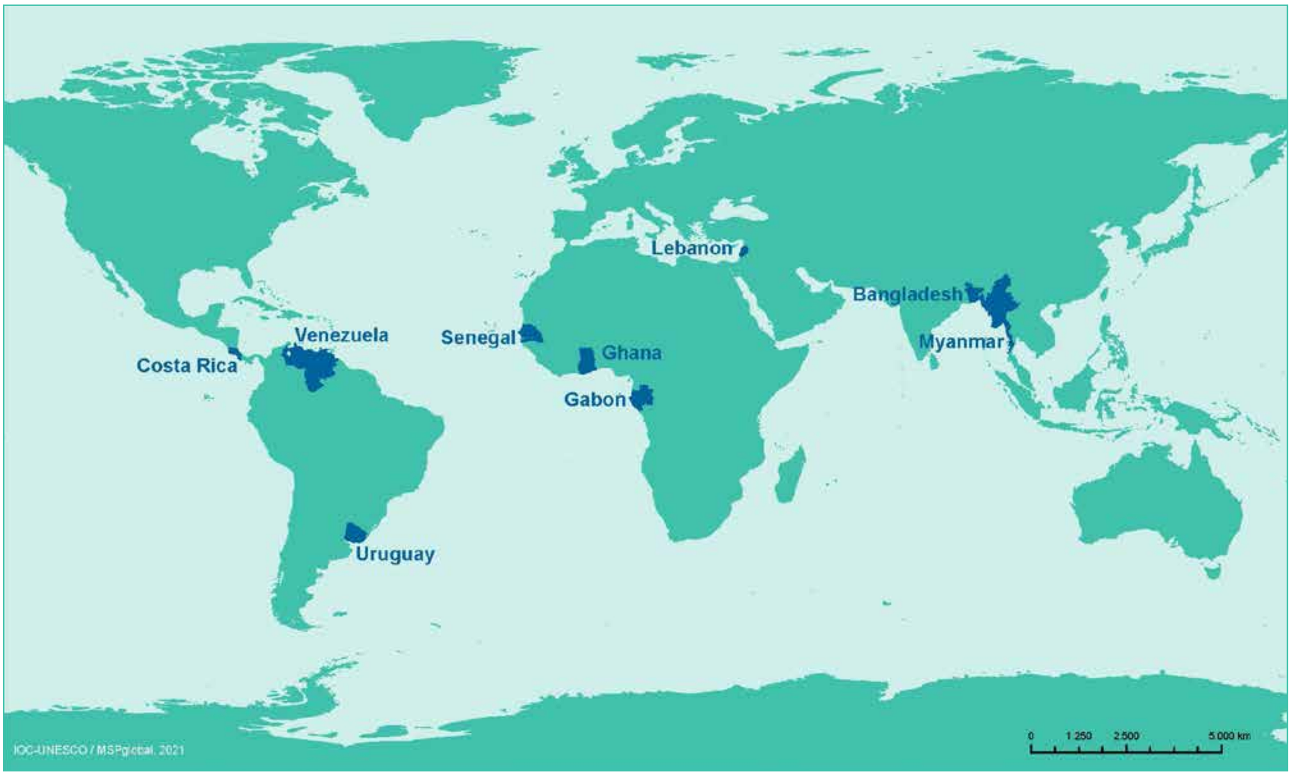
Given the growing challenges expected in coastal areas from accelerated sea-level rise, climate change and urbanisation, there is an urgent need for multidisciplinary long-term interventions and sustainable management to prepare for and minimise the growing risk with the ultimate aim of preserving human life and improving economic prospects, security, peace and stability (IPCC, 2012). Comprehending and preparing for the risk that these changes bring globally requires understanding issues as well as maintaining strong links with actors and stakeholders in determining the location and extent of current and future exposure. In this way, more appropriate and locally acceptable strategies and decisions can be made that address specific local problems, while recognising broader or more distant implications for national and international consequences (Dawson *et al.*, 2009). Indeed, successful adaptation measures to reduce coastal risk have simultaneously addressed fundamental issues related to both the enhancement of local collective actions and the creation of approaches at national and international scales that complement, support and legitimise such local actions.

What you will find in this publication

The objective here is to present how various hazards affecting coastal areas impact the local communities in selected countries, and how these matters are being managed by national, regional and local governmental institutions. This analysis was conducted for nine countries, namely Bangladesh, Costa Rica, Gabon, Ghana, Lebanon, Myanmar, Senegal, Uruguay and Venezuela. The information is organised in nine national chapters with a similar structure: first, a general presentation of the country and its coastal zone; secondly, an overview of the main natural hazards affecting their coasts; then, the management of such hazards is described at national and local level; this is followed by a description of concrete adaptation measures; and, to conclude, some final remarks to reinforce key ideas or set guidelines for future governance in the country.

From the perspective of the local communities, this publication also intends to present lessons learnt and good practices emerging from the national experiences with natural hazards affecting the coastal zone. This work is part of the activities led by the MSPglobal Initiative of the Intergovernmental Oceanographic Commission (IOC) of UNESCO and European Commission, and is supported by the Government of Sweden. It relates to the projects *2020 Regional and global development actions in support of Ocean Literacy for all* and the *Joint Roadmap on marine spatial planning process worldwide in the context of the UN Decade of Ocean Science for Sustainable Development*.

To carry out the work, IOC-UNESCO gathered a group of international consultants from various backgrounds related to marine sciences to review previous and ongoing national public strategies, plans and actions dealing with coastal



Location map of the nine countries addressed in this publication.
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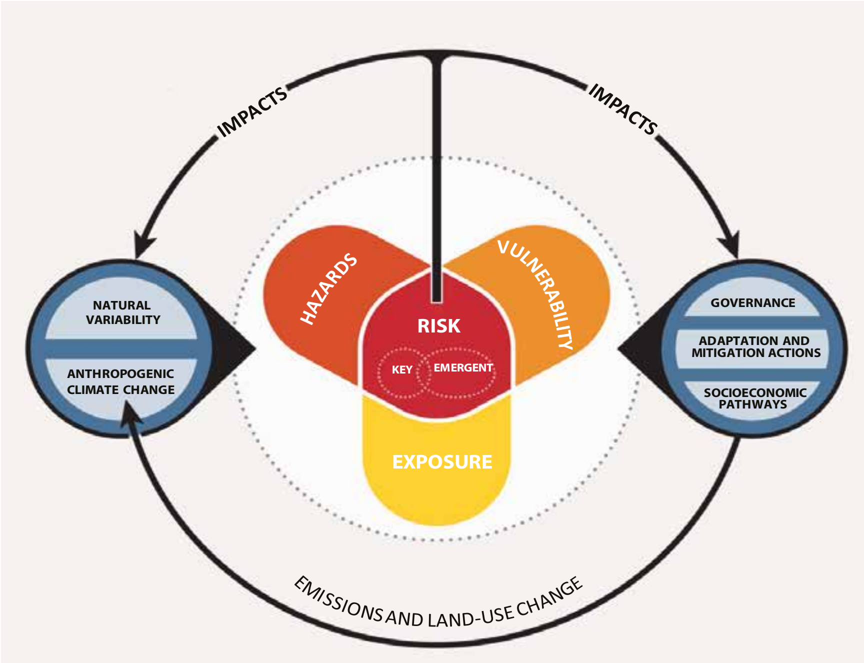
zone management, coastal risk management and conservation of coastal areas. Scientific publications and technical reports addressing coastal hazards and the vulnerability of coastal communities were also considered in this review, as well as publications by diverse bodies of the United Nations. Finally, the international consultants of each analysed country also obtained and examined the perceptions of scientists, civil society actors, municipality managers and technicians, and representatives of coastal communities through a series of interviews aimed at providing additional information drawn from the bibliographic analysis. These stakeholders were requested to assess current and future risks, identify key priorities requiring intervention and highlight potential recommendations based on their experience in their respective sectors and institutions.



Risk results from the intersection of hazard, exposure, vulnerability.
© IPCC (2014)

A bit of context

In this publication, there are four key concepts: hazard, exposure, vulnerability and risk. Hazard is any manifestation of a potential phenomenon (natural or anthropogenic) that puts at stake the human, economic or environmental assets. A hazard reflects the probability of human loss, habitat destruction, destruction of population centres or loss of natural resources, in the short or long term (IPCC, 2014). The most identified natural hazards in the countries covered in this publication include sea-level rise, coastal flooding, coastal erosion, impact of severe storms, rainfall flooding, saline intrusion and salinisation of coastal lands and aquifers, drought, pollution, degradation of natural coastal ecosystems and destruction of habitats, decrease of biodiversity and spread of invasive alien species, and scarcity of living resources.

Exposure deals with the location, attributes and value of assets that are important to communities (people, buildings, factories, farmland, etc.) and that could be affected by a hazard. It is directly linked to the presence of people, livelihoods, species or ecosystems, environmental functions, services, resources, infrastructure or economic, social or cultural assets in places and settings that could be adversely affected (UNESCO/IOC, 2020).

Vulnerability is the degree to which a system can cope or not cope with the adverse effects of natural hazards. It reflects the system's predisposition to be adversely affected (UNESCO/IOC, 2020). Vulnerability depends on the nature, magnitude and rate of natural hazards to which the system (human or natural) is exposed. It also depends on the sensitivity and adaptive capacity of the system (IPCC, 2007). Vulnerability therefore refers to the fragility of an ecological-social-economic-political system in the face of a given hazard.

Risk results from the intersection of hazard, vulnerability and exposure. Risk concerns the potential for consequences where something of value is at stake and where the outcome is uncertain. Risk is often represented as the probability of occurrence of hazardous events multiplied by the impacts if these events occur. The term risk is often used to refer to the potential – when the outcome is uncertain – of adverse consequences on lives, livelihoods, health, ecosystems and species, economic, social and cultural assets, services (including environmental) and infrastructure (UNESCO/IOC, 2020). Coastal risk refers to the vulnerability to which citizens and natural ecosystems, located in areas close to the sea, are exposed to certain events of natural origin or human activities. The concept of risk herein adopted deals with the losses or damages mainly due to natural hazards that affect coastal areas. In some cases, human actions that can also be responsible for important losses and damages are also addressed.

Natural hazards often cause disasters that pose serious threats to local communities. Pre-existing factors include a fragile social system (with marginalised urban settlements and an overall high ratio of displaced people), a fragile economic system (namely with long-term recession and a radical increase in poverty rates), and a fragile environment including sensitive coastal habitats and many degraded ecosystems. Vulnerability to coastal hazards increases with low-lying coastal areas while the high concentration of activities on the coast reduces the adaptive capacity of coastal communities (IFRC, 2020; Mattila, 2019).

Assessing the vulnerability of coastal areas and the communities living in them is an essential step in identifying the impacts of natural hazards and the sustainable management of coastal areas (Yates-Michelin and Bulteau, 2011). Coastal risk is evaluated on a multidisciplinary scale, involving professionals from different areas such as science, technology, sustainable development and governance. Coastal risk management depends on directing and managing available information about problems, causes and effects to ultimately minimise losses. The effectiveness of such management will depend on programmes and plans created with solid bases. Such effectiveness is expected to be achieved with the actions and results of best practices, according to the social and ecological context of each region or area to be addressed. The success of any programme for the management of coastal hazards and disasters, in any part of the planet, will depend on the existing capacity to prepare, prevent, mitigate and respond to natural hazards: the capacity to adapt to a changing ocean and climate; the financial capacity to implement expensive soft and hard engineering solutions and interventions and their maintenance; the extent to which new policies and measures follow an ecosystem-based approach; and, finally, the level of education, awareness and participation of the population.

The extent of the research conducted in each country on the impacts and response mechanisms related to natural hazards together with the complexity and functionality of institutional setups can bring many challenges to coastal risk evaluation and management. This publication therefore aims to provide a summary on the current situations and challenges with respect to managing coastal risk in a selection of countries and explore best practices applied in the context of local communities. Partially based on direct communications with a wide range of stakeholders with diverse levels of knowledge, expertise and interests, this publication may occasionally showcase different narratives. As a result, this publication alone may not reflect the complete picture of the complex societal challenges around coastal management nor provide location-specific full assessments. Depending on the literature available and existing local knowledge, this publication offers a glance into the major challenges that coastal community face and the viable opportunities around them.

2. The case of Bangladesh

A group of people carry a boat by hand after the disappearance of the Kutubdia port, in Bangladesh, due to rising sea-levels due to climate change.

Author: Sanjoy Roy

2.1 Bangladesh and its coastal zone

2.1.1 General aspects of the Bangladesh coast

Around 70% of the global coastal population, who are seriously affected by many coastal hazards, live in Asia, including Bangladesh, according to Asia News (2019). Approximately 37 million people (approximately 25% of the country's population) live in the coastal region of Bangladesh, which has a shoreline of 710 km long comprising one-third of the country's land area (32%), (Ahmed, 2019; BBS, 2011). This densely populated coastal region has made the country one of the world's top 15 risk hotspots and is likely to exacerbate the situation further by 2050, with population estimates of 60 million (World Bank, 2009). Furthermore, the highly dynamic hydro-meteorological phenomena along with the current century climate change have directly been influencing the intensity and frequency of different extreme events in coastal Bangladesh.

Like the global scenario, not all the parts of coastal Bangladesh are equally susceptible. The central and western parts of the coastal region are more vulnerable compared to the eastern coastal region. Saline intrusion, tidal flooding, and storm surge affect the western coastal region severely (Karim and Mimura, 2008). The central region experiences a tremendous erosion-accretion process where the loss and emergence of islands are common scenarios. This region also faces the most devastating tropical cyclone and storm

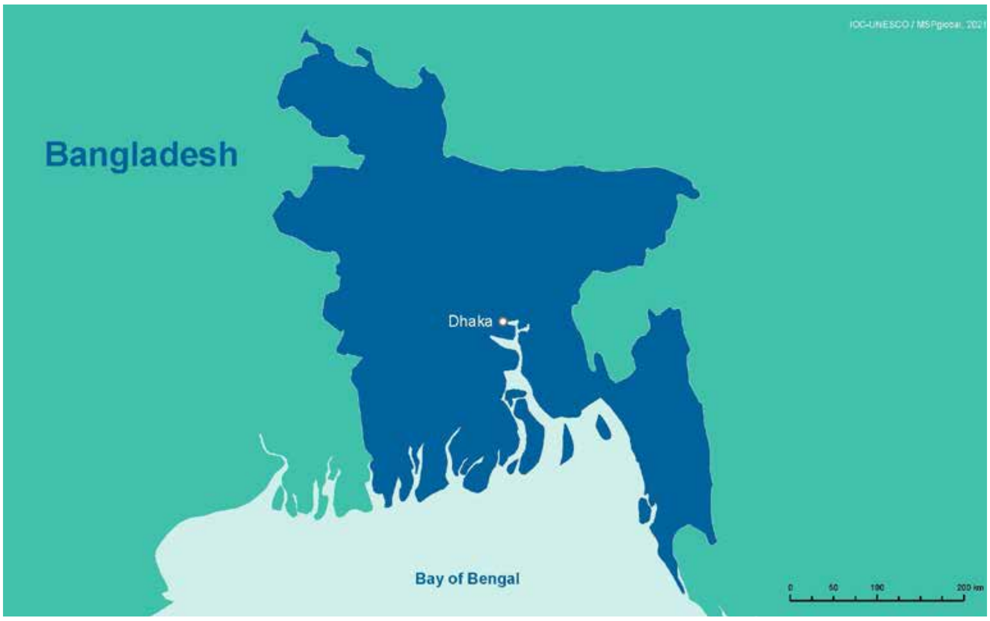


Figure 2.1 Location map of Bangladesh.
© UNESCO-IOC.

surge, almost every year causing hundreds of casualties (Ali, 1999; Karim and Mimura, 2008). For example, more than 49% of global cyclone-induced death occurred in the coastal region of this country (Bhuiyan and Dutta, 2012). Around six million coastal people have been exposed to increased salinity in the soil and water and to the resulting decline in agricultural production (Krupnik *et al.*, 2017), and this is predicted to be more than doubled (13.6 million people) by 2050 (Khan *et al.*, 2011). During normal coastal flooding conditions, 18% of the area of this country gets inundated whereas during extreme flood 55% of the area goes underwater, which is going to worsen in the future climate change induced sea-level rise scenario.

Prediction reveals that a one-meter rise of sea level will inundate around 1,000 km^2 of coastal land (Islam *et al.*, 2015; Sarwar, 2013), and this will create a permanent inundation in 18% of the land of the country. Besides coastal flooding and saline intrusion, it is also projected that all the other hazards in the coastal area of Bangladesh will increase in terms of intensity and frequency due to climate change (Bhuiyan and Dutta, 2012). According to the Ministry of Flood and Disaster Management of Bangladesh (MoFDM, 2009), climate change is not only increasing community vulnerability by changing the normal nature of temperature, rainfall, and sea-level, but also by exerting stress on water availability, agriculture, and coastal ecosystems.

In addition to the natural settings, the low-grade socio-economic conditions of the coastal inhabitants are also responsible for increasing their susceptibility to numerous coastal hazards. High population density, poverty, poor infrastructural condition, inadequate implementation of adaptation and mitigation measures, etc. are rendering to this vulnerability and risks. The disaster response and management system of Bangladesh is widely appreciated around the globe. However, given the scale and complexities of the disasters, the risk reduction and adaptation efforts are still insufficient. Given the centralized government structure, the national level guidelines are often not reflected in the local level projects in the coastal zone. The coastal zone policies also somewhat ignore the human-induced hazards and their management, which may result in grave consequences soon.

Local people using a riverside road affected by erosion in the Meghna delta, Bangladesh.
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2.1.2 Geographical and administrative settings

With 47,200 km^2 area (MoEF, 2007), the coastal zone of Bangladesh is located between 23°29'32.46" – 20°35'14.00"N latitudes and 88°42'1.45" – 92°20'29.86"E longitudes (Figure 2.1). This region is hydrologically and geomorphologically characterized by the Ganges-Brahmaputra-Meghna (GBM) river system, one of the largest river systems in the world (Ahmad, 2019), formed by the active sedimentation in the recent geological time scale. The western and eastern limits of the region are bounded by the territories of India and Myanmar, respectively. Towards the south, the coastal region has formed a 710 km long coastline from the southwestern end of Sundarbans mangrove forest, in the southwest, to Saint Martin's Island, in the southeast. The entire coastal region has a flat topography with low elevation (≤ 5 m, Islam *et al.,* 2006), except the tertiary hill tracts located in the eastern coast.

According to the coastal zone policy of the country (CZPO, 2005), the coastal region comprises 19 coastal districts covering 147 *upazilas* (administrative regions), accounting for 32% of the entire land territory of the country (CZPo, 2005). Around 38 million people live there, representing 25% of the country population (BBS, 2011). Based on the geomorphological characteristics, the entire coastal region of the country is divided into three distinctive zones as western coast, central coast and eastern coast which covers 27,150 km^2, 12,040 km^2 and 8,010 km^2 areas, respectively (Pramanik, 1988). The eastern coast is defined by the Feni river estuary, which is characterized by both coastal plain and hills of tertiary origin. This region has a 145 km long sandy beach, the longest beach of the country, with two major tourists' destinations (Cox's Bazar and Patenga). The central coast covers the entire Meghna river estuary which extends from the Feni river estuary to western bank of the Tentulia river. This region is the active deltaic part of the country, which is highly dynamic in terms of hydro-morphological fluxes (Brammer, 2014). Annually, 6 million m^{3}s^{-1} of water flow with 2,179 million tons of sediment being discharged into the Bay of Bengal through the lower Meghna river of this estuary (Curry and Moore, 1971). Erosion and accretion owing to the continuous shifting of riverbanks and shoreline are common phenomena here. Due to dynamic hydro-morphological behaviour of this active deltaic region, numerous *char lands* (coastal islands) emerge and disappear in this estuary. The western coastal region is commonly known as the Ganges delta – a semi-active delta in coastal Bangladesh – which lies between the western bank of the Tentulia river, to the east, and the Hariabhanga river (Bangladesh-India border), to the west. Due to the artificially decreased water flow in the Ganges river, this region receives comparatively lower sediment discharge, and thereby erosion/accretion processes in this delta are much lower compared to the other parts of the coast. Additionally, the presence of the mangrove forest has enhanced the land stability in this region (Sarwar, 2005).

Depending on the exposure to the Bay of Bengal, the coastal region of Bangladesh can be further divided into exposed (23,935 km^2) and interior (23,265 km^2) coasts (Ahmed, 2019). Among the 19 coastal districts, 12 that are exposed to the bay and therefore are categorized as exposed coasts. The remaining landward seven districts are defined as interior coast. Due to the unique geographical setting, high population density, flat terrain, and low altitudes, the coastal region of the country is exposed to multiple natural and anthropogenic hazards such as cyclones, tidal surge, sea-level rise, coastal erosion, saline intrusion, pollution, biodiversity loss, etc.

2.1.3 Hydro-morphological condition

The coastal region of Bangladesh is highly dynamic owing to the high freshwater discharge through numerous rivers and strong oceanographic phenomena such as waves, tides, and currents. There are hundreds of rivers including tributaries and distributaries of the Ganges-Padma, Meghna, and Chattogram hilly rivers that pass through the coastal districts of the country. These rivers carry enormous freshwater (160,000.0 m^{3}s^{-1}) with huge sediment load from the upstream and finally discharge into the Bay of Bengal, most of which are released through the numerous channels of Meghna estuary (FAO, 2016; Roy and Mahmood, 2016). In the Ganges delta, in the western coastal region of the country, freshwater input reduced significantly in the last decades due to the construction of the Farakka barrage across the Ganges river in India, in 1975. After the establishment of the barrage, freshwater inflow during the dry season in the Ganges delta of Bangladesh has reduced by 51% compared to the per-Farakka construction period (Saha *et al.,* 2018). Therefore, the erosion/accretion dynamics in the western deltaic system are very low compared to the other parts of the coast. Moreover, the presence of the Sundarbans mangrove forest has provided stability to this portion of the coast.

Being an active deltaic part with recent formation, the central coast has been going through tremendous morphological changes (Brammer, 2014). The high freshwater and sediment discharge through the Lower Meghna river and other active channels to the Bay of Bengal have been resulting in a tremendous erosion/accretion scenario in the Meghna delta. For instance, a thirty-year Landsat image-based study estimated a 52.5 km^2 per year of land erosion between 1985 and 2015 in the coastal region of the country, with most of the erosion occurring in the adjacent mainland and numerous islands of the Meghna estuary (Ahmed *et al.,* 2018). However, numerous island formation is also noticed in this region due to sediment deposition. Low hydro-morphological dynamism is observed in the eastern coastal region, except in the Sandwip island of Chattogram (Hoque *et al.,* 2019a).

2.1.4 Climate

In Bangladesh prevails a subtropical monsoon climate characterized by high summer temperatures, high humidity and heavy rainfall. Seasonal precipitation has a wide variety. Relatively small temperature ranges are observed across the country. Though Bangladesh has six seasons in a year, three main seasons are distinctive and dominant.

- Hot and humid summer season: This season extends from March to June. It is characterized by high temperature (32°-37 °C) and moderate humidity (≈ 53% relative humidity). The daily maximum temperature fluctuation is less than 12 °C. April and May are considered as the hottest months of the year (BMD, 2013). The Nor 'wester, a thunderstorm event commonly known as Kalbaishaki in Bangladesh, blows from the northwest with hail and violent wind gusts in this season, which causes severe damage to human properties.

- Humid monsoon season: This season prevails from June to early October, with the temperature becoming lower (25°-32 °C) than the summer season while humidity increases. This southwest monsoon brings heavy rainfall to the country. Approximately 80% of annual rainfall (≈ 2,000 mm) occurs in this season (Roy *et al.,* 2020). The southern coastal region receives abundant rainfall during this monsoon compared to the northern part of the country.

- Winter season: The winter season persists from October to early March. Both temperature and humidity start to decrease in October and exhibit the lowest values in December and January. January is considered as the coldest month of the year with the temperature going down to 10 °C. During winter, daily temperature fluctuation remains below 18 °C (UNEP). A bit warmer temperature persists in the coastal area during this season compared to the northern part of the country. In the last few decades, several catastrophic tropical cyclones originated in the Bay of Bengal made landfall in coastal Bangladesh during the early winter season, especially between October and November, which caused extreme casualties and damage of properties (Hoque *et al.,* 2019b).

Vehicles try to drive through a flooded street in Dhaka, Bangladesh.
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2.1.5 Ecological importance

In coastal Bangladesh, there are a few fresh and saline water ecosystems with global conservation value. The freshwater ecosystems include the natural wetlands, lake, and rivers, which supports a wide variety of floral and faunal biodiversity. The world's largest halophytic mangrove forest ecosystem, commonly known as the Sundarbans, is in the southwest corner of the coastal region. It is a Ramsar site covering 6,017 km^2 along the Khulna, Satkhira, and Bagerhat districts and was named after the *Sundari (Heritiera fomes),* the most abundant tree species in the forest. There are three wildlife sanctuaries in the south of Sundarbans that were established under the Bangladesh Wildlife Preservation Act of 1974, cover 1,397 km^2 area, and are UNESCO World Heritage Sites since 1997.

Due to its variety of globally endangered and endemic species, such as the Royal Bengal Tiger (*Panthera tigris*), River Terrapin (*Batagur baska*), Ganges dolphin (*Platanista gangetica*), and Irrawaddy dolphin (*Orcaella brevirostris*), the Sundarbans mangrove forest is internationally important (UNESCO, 2020). It also provides habitat for ample of flora and fauna species such as 30 species of mangroves, 693 species of wildlife including 210 species of fishes, 59 species of reptiles, 8 species of amphibians, 14 species of crabs, 49 species of mammals, 43 species of molluscs, and 315 species of waterfowl (UNESCO, 2020). A coral ecosystem is located around the island of Saint Martin, the country's only coral island, where about 36 species of living coral have been reported (Hossain and Islam, 2006). Numerous coastal rivers and estuaries sustain distinctive habitats and provide an ecological base for the fishery resources of coastal Bangladesh (BOBLME, 2011). Furthermore, in southern Bangladesh, the country's coastal islands such as Sonadia, Nijhum Dwip, Char Kukrimukri, etc. are known as biodiversity hotspots.

Royal Bengal Tiger in the Sundarbans mangrove forest, Bangladesh.
© Thinker360/Shutterstock.com

2.1.6 Socio-economic status

According to the BBS (2011), the coastal zone of Bangladesh holds 39 million population with an average population density of 2,662.80 per km^2. Among the 19 coastal districts, exposed coastal region under 12 districts account for 13.17 million population with an average population density 4,386.21 per km^2. In this region maximum population density (21,146 per km^2) is observed in Chattogram, which is the largest port city and economic hub of the country. On the other hand, the interior coastal region inhabits 18.6 million population, with an average density of 1,809.46 per km^2. The population of the coastal area is increasing steadily and is projected to grow around 69.8 million by 2050 (Ahmad, 2005).

People collecting drinking water in the aftermath of a cyclone in Shyamnagar, Bangladesh.
© Bayazid Akte /Shutterstock.com

Among the total population in the coastal zone, only 56% of the population is literate, with the literacy rates of males and females being almost the same (male 57% and female 54%). The total number of households in the region is 10.5 million, where only 11% of households are *pucca* (brick-built). Approximately 52% and 74% of the entire coastal population has electricity and sanitary toilet facilities, respectively, and around 88% population has access to safe drinking water sources (BBS, 2011). The coastal communities are engaged in different economic activities such as crop production, inland aquaculture, fishing, salt cultivation, shrimp and crab farming, forest resource extraction, tourism, and various industries. Among those, agriculture is the dominant economic activity in the coastal area, with around 60% of the people involved. In recent decades, the dependency on the agricultural sector, especially crop production, has decreased by 18% compared to 1970 because of the shifting towards more profitable economic sectors, such as shrimp farming, industries, and sea-salt production (Mazid, 2014). In addition, 13%, 11%, and 8.9% of coastal people are dependent on fisheries and aquaculture, forest resource extraction, and different industries, respectively (BBS, 2011; BOBLME, 2011). However, in the coastal region, the proportion of the population living below the absolute poverty line is marginally higher than the country poverty line, whereas the annual Gross Domestic Product is like the national averages.

2.2 Coastal hazards in Bangladesh

As one of the world's most coastal hazards-prone countries, Bangladesh's littoral is vulnerable to numerous natural and human-induced phenomena. Among these, tropical cyclones, storm surge, coastal flooding, sea-level rise, shoreline retreat, coastal erosion, saline intrusion, pollution, and climate change are highly responsible for raising the vulnerability of the society in coastal Bangladesh (Hoque *et al.,* 2016). In addition, the lower socio-economic status, high population density, and greater reliance on coastal services have increased the vulnerability of the coastal community to the above-mentioned threats, most often resulting in the loss of life and property. For instance, 49% of global deaths induced by cyclones occurs in coastal Bangladesh (Bhuiyan and Dutta, 2012). Due to the cyclone activity and associated storm surges, around 718,000 deaths occurred in the coastal region of the country over the last 50 years (Haque *et al.,* 2011). Because of the low elevation of the coastal region, the coastal people have been affected by coastal flooding, almost every year. This phenomenon largely affects the livelihoods in the western and central coastal regions, where the average land elevation is less than 5 m. Constant morphological changes, particularly on the central coast, have also led to landlessness by eroding people's homesteads and agricultural lands. For instance, between 1995 and 2015, an estimated 118.3 km^2 per year of erosion occurred in the coastal region, most of which took place on the south-central coast and the coastal islands (Ahmed *et al.,* 2018).

Climate change has been a major concern in coastal Bangladesh in recent decades because it poses a range of threats that are already evident in the coastal region. Due to a low-lying deltaic region, climate change-induced vulnerability of the coastal community will be more extreme soon (Karim and Mimura, 2008). Around 1,000 km^2 of coastal land and its inhabitants are projected to be severely affected by a 1 m-rise of sea-level in the current century (Islam *et al.,* 2015; Sarwar, 2013). The rising sea-level trend, coupled with reduced freshwater inflow from the upstream river basin, has been intensifying intrusion of salinity in the surface water, soil, and groundwater. However, several anthropogenic causes such as the construction of barrages, salt cultivation, and shrimp farming are also responsible for increasing salinity in the coastal region. According to Mahmuduzzaman *et al.* (2014), the area affected by saline intrusion increased by 27% in the coastal region of the country between 1973 and 2009.

According to the future climate change scenarios, the coastal hazards triggered by the severity and magnitude of climate change are predicted to be significantly higher than the present condition, which could increase the vulnerability of the large coastal community to multiple natural and anthropogenic hazards (Bhuiyan and Dutta, 2012).

2.2.1 Coastal erosion and delta evolution

The coastal area of Bangladesh is a highly dynamic entity that is subjected to varying rates of accretion and erosion in different parts of the coast (Brammer, 2014). A significant portion of this coastal area shares the same landmasses with the Bengal delta, which is acclaimed as the second largest delta in the world (Goodbred *et al.,* 2003; Hori and Saito, 2007), covering a hundred thousand square kilometres of area. This delta fed by the sediments that have been carried from the upstream by the GBM river system (Allison and Kepple, 2001; Sarker *et al.,* 2015; Umitsu, 1993). The dynamism of the river courses along with the tidal influences from the Bay of Bengal is considered as the active factor for shaping the coastal area of the country (Sarker *et al.,* 2015).

Coastal dynamics are usually driven by two kinds of factors in the broad-spectrum: the natural factors (*e.g.,* sea-level rise, variability in sediment supply, excessive rainfall, storm waves, longshore sediment transport, and prevailing southwestern monsoon wind); and the human-induced causes (*e.g.,* removal of subsurface resources, interruption of material in transport, and reduction of sediment supplies to the littoral zone) (Krantz, 1999). The varying rates of erosion and accretion in different parts of the coastal area are attributed to the different factors such as grades of vegetation cover, variation in the discharge of upstream river, beach slope gradient, soil compaction, tidal bores, the extent of human interventions, etc. (Krantz, 1999). For example, the morphological changes observed in the western zone are significantly lower than in the central part of the coast. Warrick and Ahmad (1996) suggest that this lower rate of erosion could be due to the presence of mangrove vegetation of the Sundarbans. On the other hand, the central zone is highly dynamic regarding erosion/accretion and shoreline shifting compared to the other parts of the coastal zone.

The higher rates of accretion and erosion could be the effect of huge sediment and freshwater input through the GBM system, ebb-tide currents, bathymetry, high rate of river water discharges, soft and unconsolidated soils, tropical cyclones, storm surges, etc. (Ali, 1999; Brammer, 2004; Brammer, 2014; Barua, 1997; Hossain, 2012; Mikhailov and Dotsenko, 2007; Parvin *et al.,* 2008; Shamsuddoha and Chowdhury, 2007). The accreted land area in the central coastal zone, particularly in the Meghna estuarine area, has been found as 451 km^2 from 1984 to 2007. Brammer (2014) and Ahmed *et al.,* (2018) identified a net gain of 411 km^2 of land in the central Meghna estuarine coast. Both studies claim similar gains of land for this part. The coastal islands in the aperture of Meghna estuary are extremely dynamic. There is a notable amount of land gain along with land losses in some parts that are reported by many studies. However, the dynamic morphological behaviour in the coastal region of Bangladesh might be characterized by the dynamic nature of the estuary and high rates of water discharge, as well as the anti-clockwise circulation of coastal tides (Sarwar and Woodroffe, 2013).

Whereas the western and central coasts exhibit a significant erosion/accretion scenario, the eastern coastal zone shows a lower dynamism. The flat and unbroken coast (Huq *et al.*, 1999) and northerly transportation of sediments along this zone could be the reason behind this lower rate of accretion and erosion (Barua *et al.*, 1994). Although the eastern zone is less dynamic compared to the other regions, erosion and shoreline changes have still been observed, which could be the cause of the anti-clockwise circulation of tidal current passing through the Sandwip channel (Ahmed *et al.*, 2018) and the excessive amount of rainfall due to the increasing temperature (Krantz, 1999).

Stormy waves hit the world's longest natural sea beach in Cox's Bazar, a popular tourist destination in Bangladesh.
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2.2.2 Coastal flooding

Bangladesh is a lower riparian country; it lies between the Himalayas and the low-lying coast of Bay of Bengal. Seasonal climatic variation, heavy monsoon rainfall, and high exposure to tropical cyclones have made it one of the most flood-prone counties in the world (Brammer, 1990; Hofer and Messerli, 2006; Nicholls, 2006). Due to its low elevation, the coastal region of the country suffers from several types of floods such as fluvial floods, tidal floods, fluvio-tidal floods, and storm surge floods, among which storm surge-induced flood causes severe damage to human properties and loss of human lives and cattle. For instance, the storm surges of 1970 and 1991 were the most disastrous in the history of Bangladesh, causing a death toll over 638,000 in the coastal region of the country (Alam and Dominey-Howes, 2015; Lumbroso *et al.*, 2017). In 2007, a severe storm surge induced by the super-cyclone Sidr hit coastal Bangladesh and caused a death toll around 3,000 people with approximately $450 million economic loss. Around 30% of the total flood-related damage in coastal Bangladesh directly occurs in the household and agricultural sectors, while 40% of damage happens in the infrastructures such as embankments, roads, and other establishments. As a large portion of the coastal community lives below the poverty line, they are the big sufferer from these coastal floods. In the 1960s, several polders were built in the coastal region to protect the agricultural lands from saline intrusion due to coastal flooding. That initiative brought an immediate benefit to the farmers by protecting their croplands, but as a long-term effect, permanent waterlogging situations developed inside many of those polders in the western coastal region, particularly in Jashore, Khulna, and Bagerhat districts because of the damage of natural drainage systems (Noor, 2018; FAO, 2015). This situation also modified the normal flooding characteristics and triggered land subsidence in the western coastal region of the country (Auerbach *et al.*, 2015).

The flood forecasting and warning systems have improved in the recent decade, which has reduced the death toll significantly in the current years as compared to the previous flooding events. Besides, several infrastructural and non-infrastructural measures have been undertaken by the government in the coastal area to reduce the community's vulnerability to flooding events. Among these, the construction and improvement of embankments and polders, the mangrove plantation along the coastal belt, and the enhancement of livelihoods are worth mentioning.

2.2.3 Tropical cyclones and storm surge

Among all the natural hazards, the tropical cyclone is considered as the most devastating hydro-meteorological hazard of coastal Bangladesh, which causes loss of life as well as socio-economic and environmental damages (Brammer 2016; Kumar *et al.*, 2011). Due to the unique geolocation, low elevation, high population density, and funnel shape of the coastal region, it is highly exposed to the tropical cyclones that originated in the Bay of Bengal (Ali, 1996; Khalil, 1992). Every year, coastal Bangladesh experiences at least one cyclone landfall, with a severe one in every three years (Ahammad *et al.*, 2013). Since 1877, nearly one million deaths occurred in the coastal area with billions of US dollar economic damage (Dasgupta *et al.*, 2010). In the last 30-40 years both the frequencies and intensities of the tropical cyclones have been increased, probably as effects of climate change (Varotsos *et al.*, 2014). Since the late 18th century, almost 70 of the deadliest cyclones with made landfall on the Bangladesh coast and caused the deaths of around 1.5 million people (Alam *et al.*, 2014). Among them, 18 cyclones were very severe in nature with respect to wind speed and surge heights (Quader *et al.*, 2017). Some of the most catastrophic cyclones that caused notorious damage in the coastal region were Bhola (1970), Urir Char (1985), Chittagong (1991), Sidr (2007), Aila (2009), Mora (2017), and Amphan (2020). Only the Bhola 1970 cyclone, in the central coast, and the Chattogram 1991 cyclone, in the eastern coast, together caused 0.6 million deaths due to their extremely high record-breaking wind speeds (>240 km per hour) and storm surges (>6 m) (Bern *et al.*, 1993; Frank and Husain, 1971; Khalil, 1993).

However, a spatial variability of cyclone hazards is observed in the coastal region in Bangladesh regarding locations of landfall and frequencies of occurrences. According to Quader *et al.* (2017), the density of the cyclone track is higher in the western coastal region, particularly in areas around the Sundarbans, but the risk level of the population is lower due to the presence of the Sundarbans mangrove forest, which reduces most of the energy of each cyclone before reaching human occupation. The hilly areas of the eastern coast also fall under lower risk categories (Quader *et al.*, 2017).

Depending on the demographic and socio-economic conditions of the local community, the western coastal region is lowly vulnerable to cyclones except for some of the unions surrounding the Sundarbans due to their poor access to the basic facilities. In contrast, the unions of Gopalganj district fall under higher vulnerability categories (Quader *et al.*, 2017). The unions of the central coast having higher proximity to the sea, unions located along major rivers, and the coastal islands have medium to very high vulnerability, whereas the southeastern coast and area around Chattogram city have a low vulnerability although Maheshkhali and Kutubdia islands represent a high vulnerability to cyclone hazard. In the case of southeastern parts of the country Sandwip, Sonagazi, Kutubdia, Maheskhali, Chakaria, Teknaf, and parts of Chattogram Sadar, which are situated in proximity to the coastline are identified as high-risk zones. These areas are under the primary impact of cyclones (*e.g.,* high wind speed, high storm surges, and heavy rainfall); on the other hand, Hathazari, Fatikchhari, Feni Sadar, and Patiya which are located away from the coastline are also under considerable risk of cyclones, these areas are basically subjected to the secondary impact of cyclones (*e.g.,* heavy rainfall, mudslide, and thunderstorms) (Hoque *et al.*, 2019b).

The increased vulnerability in the different parts of the coast is mainly due to the low adaptive capacity over dependencies on the natural resources (Alam and Collins, 2010). After the independence of Bangladesh in 1971, the government implemented several measures on different levels, such as the Standing Order on Disaster (SOD); the infrastructural development, like construction of cyclone shelters, coastal embankments, and polders; the mangrove plantation along the coastal belt; awareness raising among the coastal communities; and the conduction of extensive cyclone preparedness programmes, resulting in decreased vulnerability with decreased loss of lives in the last decades.

Cyclone-induced storm surge is a common hazard during the wet monsoon along the Bay of Bengal.
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2.2.4 Sea-level rise

The Intergovernmental Panel on Climate Change (IPCC) projected an average 3 mm to 4 mm annual sea-level rise in the 21st century (Oppenheimer *et al.*, 2019). The eustatic sea-level rise driven by accelerated global warming has further been forecasted between 0.5 m and 2.0 m by the end of the 21st century (Nicholls *et al.*, 2011). For a low-lying coastal state like Bangladesh, the impact of such sea-level rise will be tremendous due to the high density of population and over dependencies of agricultural activities (Nicholls *et al.*, 2007; Parvin *et al.*, 2008; Woodroffe, 2010). To investigate the spatial variation of sea-level rise in the coastal region of Bangladesh, an analysis was conducted based on 20-year global Permanent Mean Sea-Level (PMSL) data (1978-2000) collected on four stations along the coast of Bangladesh, which confirmed an increasing sea-level on the Bangladesh coast (Figure 2.2). The analysis revealed an increasing trend of the sea-level in all four stations. A maximum 7.31 mm per year sea-level rise was found in the central coast (at Charchanga station), followed by Cox's Bazar and Chattogram coasts, in the eastern coastal region. The lowest sea-level increase (+2.77 mm per year) was estimated on the western coast (at Hiron Point Station).

A study conducted by the Department of Environment (DoE, 2016) estimated the magnitude of the increase is between 7-8 mm per year in the western coast to 11-21 mm per year in the eastern coast (Figure 2.3). According to Singh (2002), the sea-level rise rate in the eastern coast is almost twice than on the western coast, with the difference of about 4 mm per year between them being mainly due to land subsidence. Both studies identified the maximum trend of sea-level rise in the Chattogram and Cox's Bazaar coasts. These results, however, were criticized by Morner (2010) because of the low reliance on the used tidal gauge stations, that are placed on unconsolidated sediments, as well as due to the incompleteness of the used data.

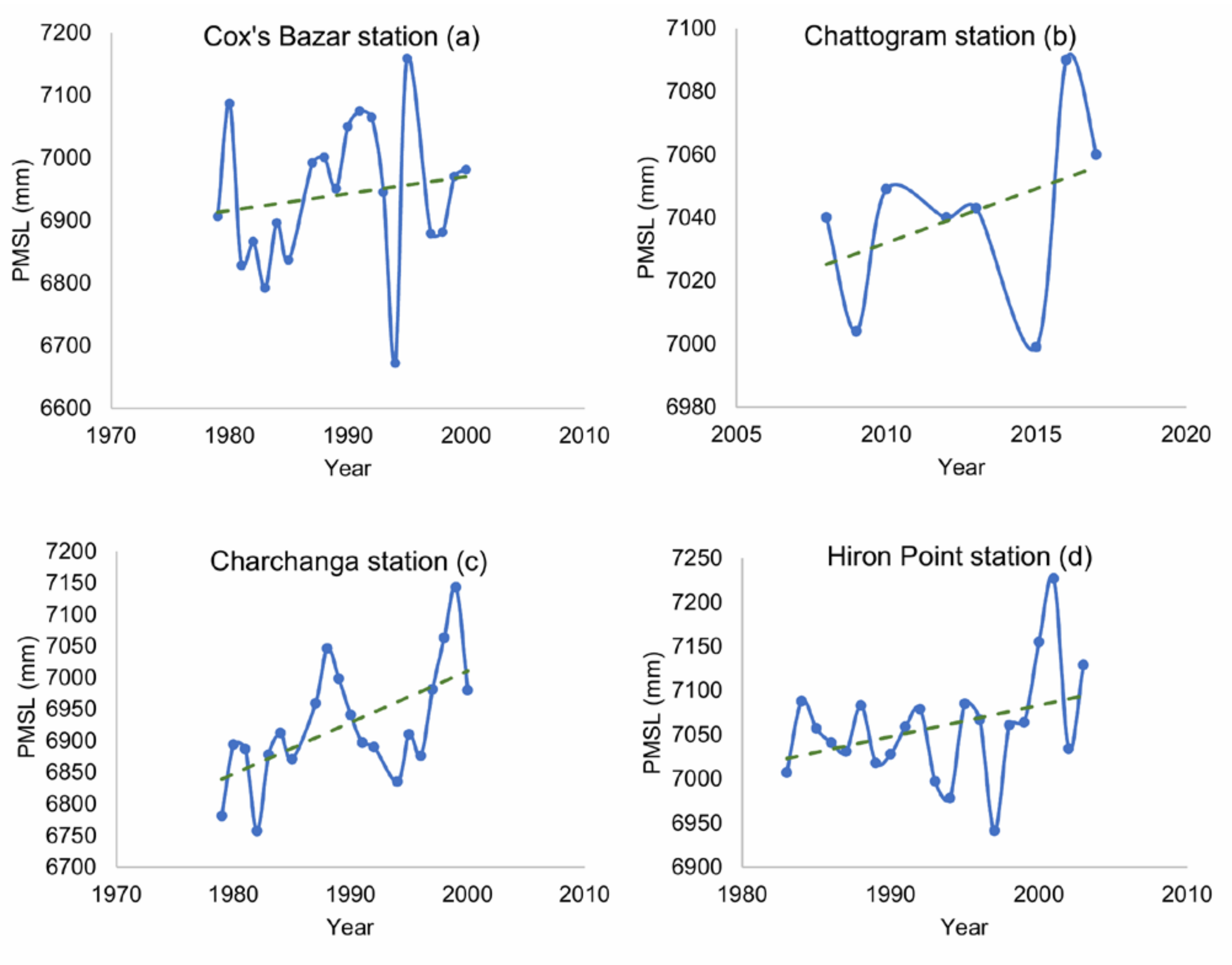

Figure 2.2 Trends of sea-level rise on the Bangladesh coast.
Source: Sanjoy Roy based on global PMSL data collected from https://www.psmsl.org/

Based on observational findings at the Hiron Point, Morner (2010) claimed that there is no evidence for global sea-level rise in the southwestern coast of Bangladesh. In this region, the annual trend of 4 mm per year sea-level rise may be attributed to the impact of monsoon rains and warming of sea waters (Morner, 2010; Singh, 2002). Historically, mangrove forests can adjust its growing surface to the rising sea-level through sediment accretion and thickening peat deposition by biotic activities.

The natural adjustment mechanism of the mangrove forest in the southwestern coast of the country to the increasing sea-level is no longer working. This is due to the reduction in sediment accretion associated with coastal erosion due to cyclones, floods, and tsunami, as well as reduced supply of sediment due to the construction of dams in the upstream of the Ganges (Bose, 2016, Morner, 2010).

However, a comprehensive study is necessary to properly quantify the sea-level change along the coast of Bangladesh. Whatever the rate of sea-level rise along the coast of the country, the central and western coastal regions would be worst affected due to lower adaptation and resilience.

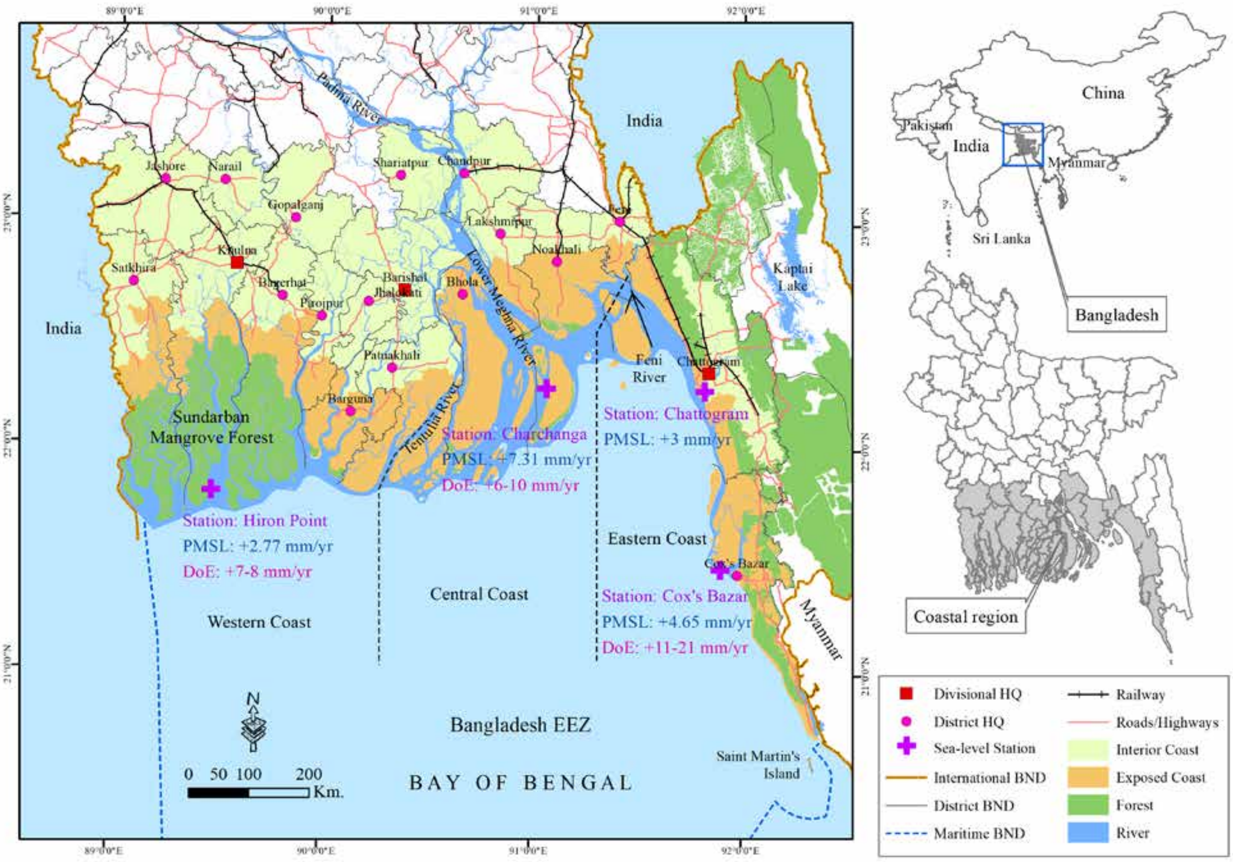

Figure 2.3 Trends of sea-level rise on the Bangladesh coast based on global PMSL data and government report.
Note: BND-Boundary, EEZ-Exclusive Economic Zone, and HQ-Headquarter.
Source: Sanjoy Roy based on global PMSL data collected from https://www.psmsl.org/ and DoE (2016)

2.2.5 Saline intrusion

In a low-lying deltaic system like Bangladesh, saline intrusion is one of the major concerns in the coastal region, which is likely to increase due to climate change and rising sea level. In the last decades, coastal Bangladesh has been facing an increasing level of saline intrusion in both the surface and aquifers, especially in the southwestern coastal region of the country (Sarwar, 2005). Apart from sea-level rise, several other natural and anthropogenic causes such as lower elevation, storm surges, shrimp farming, etc., are responsible for increasing salinity in the southwestern coast of the country. According to Soil Resource Development Institute (SRDI, 2010), the intrusion of saline water has been extended up to 15 km north from the coast from 2000 to 2009, reaching up to 160 km towards inland during the dry season, when the freshwater flow decreases upstream. Due to this phenomenon, the salinity intruded area increased from 8,330 km^2 in 1973, to 10,560 km^2 in 2009 (SRDI, 2010). The GBM river system is the most sediment-laden river system in the world, carrying billions of tons of sediment to the Bay of Bengal. A portion of this sediment is deposited in the riverbed of the coastal region, which reduces the streamflow of the rivers and thereby assists saline intrusion in the tidal canals (Milliman *et al.*, 1983). The backwater effect is another natural reason for saline intrusion, which particularly takes place at the mouth of the coastal rivers while freshwater inflow is not sufficient to counter the tide moving upstream (Ali, 1999). The tropical cyclone-induced storm surges intensify the phenomena by pushing seawater to the coastal agricultural lands, freshwater ponds, canals, and rivers. The damage of the natural drainage system due to the construction of embankments and polders in the coastal region also plays a catalytic role in the intrusion of salinity in both surface water and groundwater aquifers. Furthermore, the unsustainable extraction of groundwater for irrigation since 1969 has been accelerating the saline intrusion phenomena in different parts of the southwestern coastal region of the country. Comparatively, the eastern coastal region has a lower vulnerability to saline intrusion in the groundwater aquifers due to higher topography (Zahid *et al.*, 2016).

Agriculture, a prominent livelihood source for the people in the coastal region, has been hampered by the saline intrusion effects on the surface water, soil, and as well as in the groundwater. The saline water intruded in the southwestern coastal region during Sidr and Aila cyclones is still affecting the agricultural production in that region. This situation may be worsened in the future. The aquatic ecosystem is likely to be altered if the salinity level increases at a higher rate. There are nearly five hundred thousand fishing households in the coastal areas of Bangladesh (DFID, 2007), who depend on fishing for their livelihood. The composition of the fisheries during the dry season is likely to be changed. Many freshwater fishes, such as Catla (*Catla catla*), Rui (*Labeo rohita*), and Mrigal (*Cirrhina mrigala*) are likely to be declined in the wild due to saline intrusion, and other indigenous freshwater fishes are likely to be decreased in the wild. The administrative areas of the coastal districts Barguna, Barisal, Bagerhat, Bhola, Khulna, Jhalokati, Patuakhali, and Pirojpur will be badly affected by saline intrusion under the changing climate scenario by 2050. The freshwater storages in Barishal, Pirojpur, and Bagerhat district are expected to be reduced by 85%, 81%, and 71%, respectively, due to saline intrusion (Dasgupta *et al.*, 2014). The unsustainable extraction of groundwater also increases the risk of saline intrusion in the aquifers, degrading the groundwater quality as well. Although the occurrences of saline water in the coastal aquifers vary vertically and spatially, the increase in the sea-level rise will intensify the vulnerability of the coastal community soon (Anware *et al.*, 2016). The scarcity of drinking water in the coastal region will therefore be a serious public health issue.

2.2.6 Pollution of marine and coastal waters

Along with several coastal hazards associated with the various physical phenomena addressed above, the pollution of marine and coastal waters in Bangladesh induced by a few anthropogenic activities has been increasing the vulnerability of the coastal livelihoods, while threatening the marine and coastal biodiversity as well. Due to the inadequacy of waste treatment facilities in the coastal urban areas and lack of proper monitoring over the shipping activities in the Bay of Bengal, the pollution of marine and coastal waters has been increasing. A few point and non-point sources of pollution are identified in the coastal region. These include untreated effluents from coastal cities and industries, oil-spills from ships and shipbreaking industries, unregulated discharge of ballast water from ships in the port and outer anchorage areas. Also due todumping of garbage from ships, dumping of domestic solid-wastes in the rivers, discharge of heavy metals, untreated sewage flow from the residential areas, unregulated use of antibiotics in the aquaculture farms, excessive use of pesticides in the agricultural lands, and exploration activities of offshore hydrocarbons.

Annually, more than three thousand ships, including bulk carriers and oil tankers, are being handled by the ports of the country. Due to the lack of proper monitoring systems, every year around 2,500 tons of oil is spilled in the coastal area of the country from the operation of ships, port, and land-based activities (BOBLME, 2011). The oil spills largely occur in the Chattogram and Mongla seaport areas. On the coastal surface water, 2.3 to 3.4 μg/kg of the hydrocarbons and petroleum residues were recorded, while it was 21.7 to 11.2 μg/kg on the surface water along the tanker routes in the Bay of Bengal (Alam, 2004). This scenario is much worsened in the ship breaking areas of Chattogram, where a maximum of 160 mg/l of hydrocarbon was recorded on the surface water in the monsoon with a minimum of 30 mg/l in pre-monsoon periods (Hossain, 2010).

Local and foreign ships most frequently take advantage of the Port Authorities' inadequate control facilities and dump their waste in the outer Chattogram port anchorage, which causes significant water pollution. In the coastal zone, especially along the coast of Chattogram and Sundarbans, the contamination of heavy metals (Fe, Mn, Pb, Cr, and As) from port and ship breaking activities has been alarming (Datta *et al.*, 2008; Hossain, 2010; Tamanna and Hossain, 2010). More than 8,000 production and processing industries including fertilizers, textiles, tannery, food and beverage, pharmaceuticals, and cement clinker developed in the Chattogram and Khulna area have been contributing to the coastal water pollution through discharging both solid wastes and effluents containing toxic chemicals and heavy metals in the nearby rivers, which ultimately end up in the coastal water. Another important source of water pollution is the direct discharge of approximately 36 million untreated wastes (BBS, 2011) from 19 coastal districts by various rivers into the coastal system. This mixing of sewage in the coastal water has been raising the vulnerability of the coastal community to numerous water-borne diseases such as Diarrhoea, Typhoid, etc. In addition, unregulated mass tourism activities have been increasing litter in the coastal waters, particularly in Saint Martin's Island and Cox's Bazar regions, causing severe ecological damage. In recent decades, many farmers shifted to shrimp and crab farming from traditional agricultural practices in Satkhira, Bagerhat, Khulna, and Cox's Bazar districts. In these farms, the uncontrolled use of antibiotics and Urea is very common, which ultimately comes into the coastal water (Kamal *et al.*, 2015). Such contamination of the country's marine and coastal water has not only been causing significant harm to the mangrove environment, benthic ecosystems, and marine mammal and fish nursery grounds but also posing significant health hazards for the coastal population.

Chittagong ship-breaking yard, Bangladesh.
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2.2.7 Ocean acidification

Owing to the absorption of atmospheric CO_2, the drop in ocean pH is called ocean or marine acidification (Turley *et al.*, 2010). The global ocean consumes about 30% of atmospheric CO_2. The increased CO_2 emission in the atmosphere due to several anthropogenic activities is mainly responsible for increasing marine acidification because the excessive CO_2 of the atmosphere is absorbed in the ocean and creates carbonic acid, which reduces ocean pH. Global ocean acidification has increased by 30% compared to the pre-industrial period (Kibria and Haroon, 2017). This rising acidification can have significant negative impacts on marine and coastal habitats. Rashid *et al.*, (2013) found that the pH on the eastern coast of Bangladesh has reduced by 0.2 units compared to 1994. This study also revealed a 17% reduction in the chemical composition of oysters and shells compared to their normal chemical composition, which means that the increasing ocean acidification in the Bay of Bengal has weakened the shell membrane of those marine organisms.

As the pH in Bangladesh's marine and coastal waters increased, the number of finfish species decreased from 475 to 98 between 1971 and 2011 (Hussain, 1971; Chowdhury *et al.*, 2011). The detrimental impact on the coral ecosystem is also found in Saint Martin's Island, Bangladesh's only coral island. This island is also one of the biodiversity hotspots in coastal Bangladesh, inhabiting around 66 species of corals, 187 species of molluscs, 12 species of crabs, 154 species of marine algae, and 234 species of marine fishes (Kibria and Haroon, 2017). But the increased ocean acidity along with human activity intensified, the number of coral species on this island decreased by 26 from 1997 to 2008 (Tomascik, 1997; Sultana *et al.*, 2008).

Ocean acidification also reduces the production of commercial fishers through damaging feeding and breeding grounds (Hossain *et al.*, 2015). The marine and coastal fisheries of Bangladesh share around 16.3% of the whole fisheries production of the country, where approximately 0.5 million population of the coastal region are actively engaged (FRSS, 2016). The increasing ocean acidity would directly affect the livelihood of this large coastal community by reducing potential fishery production in the future. Along with the declining seafood security of the country, this phenomenon would increase coastal erosion by damaging coastal mangroves, thereby raising the vulnerability of the coastal community to food security and land erosion together.

2.3 Coastal risk management in Bangladesh

Bangladesh has a well-developed disaster management framework constituted with different levels of the administration, ministries, and regulatory guidelines, such as disaster management policies and plans (Figure 2.4). Under the institutional framework, the National Disaster Management Council, headed by the Prime Minister, formulates the disaster management relevant policies, which are coordinated and implemented by the Inter-Ministerial Disaster Management Coordination Committee that is led by the minister of the Ministry of Disaster Management and Relief. There are several subnational committees established, which aim to ensure proper coordination in disaster management actions at the community level. In the organizational framework, the Ministry of Disaster Management and Relief acts as the main governing body. It provides relief to the affected community during disaster events. Additionally, it undertakes comprehensive disaster management plans and policies to reduce losses.

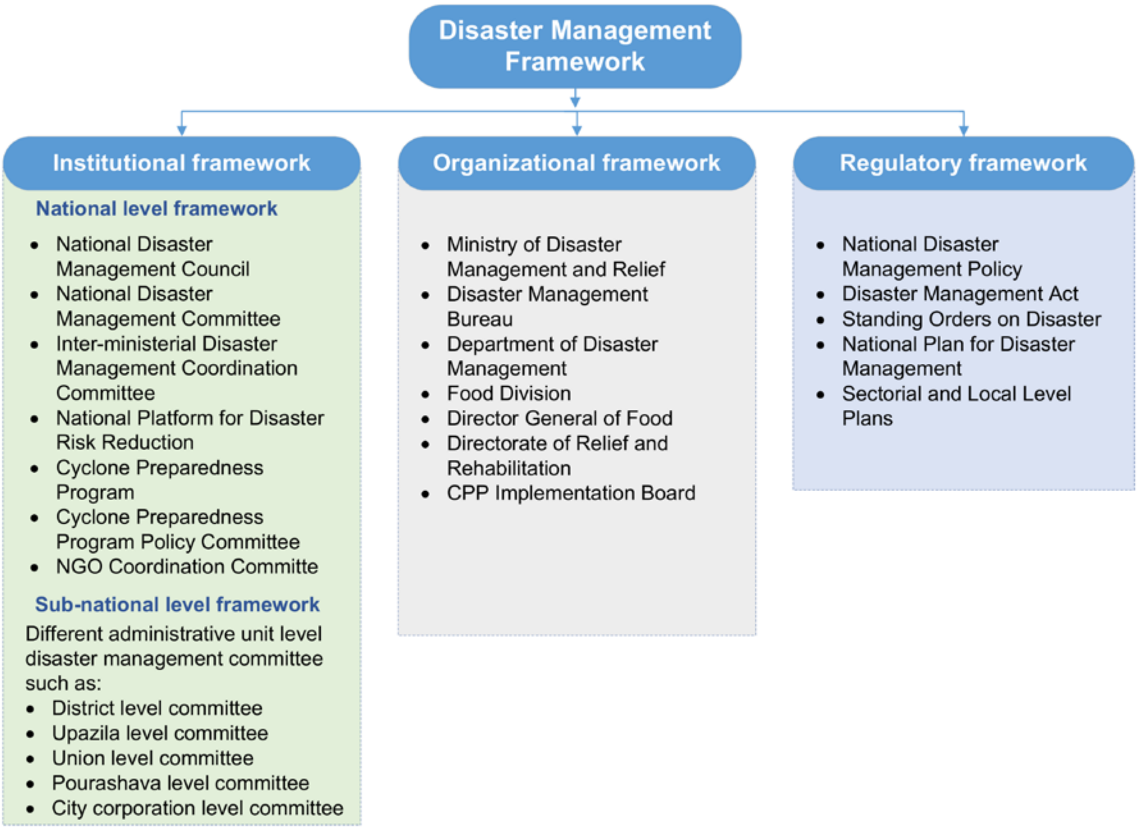

Figure 2.4 Disaster management framework in Bangladesh.
Source: Sanjoy Roy based on Haque *et al.* (2019)

The Department of Disaster Management focuses on the mainstreaming of the disaster risk reduction measures in the disaster management plans and policies, and the Disaster Management Bureau ensures proper coordination among these different departments or agencies. In the regulatory framework, the Disaster Management Act (2012) guides overall post-disaster activities such as the rescue of the affected people, rehabilitation, providing humanitarian assistance in the affected community, etc. in a view to reducing overall losses. The Disaster Management Policy and the Standing Order on Disaster are included in the regulatory framework, which aims to enhance the disaster management system of the country and to build the capacity of the disaster management relevant bodies and agencies.

2.3.1 Storm surge risk management

The coastal zone of Bangladesh is subjected to frequent flooding induced by the combined effect of tides, cyclones and storm surge. This coastal flooding causes intrusion of saline water in the low-lying coastal areas of the country, which has been considered as one of the major reasons for the reduction of agricultural production. Additionally, the coastal communities are highly exposed to diurnal tidal fluctuation. To protect coastal communities and the agricultural lands in the coastal region from tidal flooding and saline intrusion, the Coastal Embankment Improvement Project (CEIP) was initiated in the 1960s. Under this project, several polders and embankments were developed to protect coastal agricultural lands from being salinized and improved the livelihood conditions of the coastal people (Figure 2.5). Under this project, 5,700 km long embankment and 139 polders were established since 1960, which ultimately brought around 1.2 million hectares of land under protection where approximately 1 million hectares are agricultural land (CEIP-1, 2013). This initiative provided immense benefit to the coastal community by protecting their lands from tidal flooding and saline intrusion, increasing agricultural production, and improving their livelihoods in the past 40 years. In recent decades, these polders have become vulnerable to cyclone-induced storm surges, sea-level rise, climate change effects, and drainage congestion. In many areas, the permanent water logging situation developed because storm surge effect, sea-level rise, and climate change was not considered in the design of those polders. Furthermore, the structure of those polders did not meet the needs of the multipurpose use of the local farmers. Alteration of land uses inside the embankments also caused adverse effects on the water management issue. Recent cyclones, especially Sidr in 2007 and Aila in 2009, caused substantial damage to the embankments and polders in many areas and thereby an improvement in structural design of these polders and embankments was required. In this regard, the Government of Bangladesh focused on a long-term vision to enhance the resilience of the coastal community to natural disasters including cyclones and storm surges through upgrading the entire embankment system in coastal Bangladesh. Hence, the Government adopted a multi-phased embankment improvement and rehabilitation approach over a period of 15 to 20 years under which the Coastal Embankment Improvement Project – Phase 1 (CEIP-1) was initiated in 2013. The major focus of the CEIP-1 was to enhance the resilience of the coastal community to climate change and natural disaster with specific objectives such as the increasing area of protection in selected polders against storm surges and tidal flooding under future climate change scenario; increasing agricultural production in the selected polders by protecting them from saline intrusion; and enhancing expeditious and effective response capacity of the Government to any natural disaster events. Currently, the CEIP-1 is being implemented by the Bangladesh Water Development Board.

2.3.2 Tropical cyclone risk management

The entire coastal region of the country is exposed to strong tropical cyclones and associated storm surges. In the last 30 years, more than 39 tropical cyclones hit the coastal region and caused the loss of lives and substantial damage to properties (CSPS, 1996). The poor socio-economic condition and low resilience of the coastal community are largely responsible for increasing their vulnerability to tropical cyclones. After the 1970 devastating cyclone, the Government of the country has taken a few measures, which effectively reduced loss of lives and damage of properties in the following years. Among these, the effective forecasting of cyclones, the development of early warning systems, and evacuation of vulnerable people before the cyclonic events are worth mentioning. From 1972 onwards, the Bangladesh Red Crescent Society started the Cyclone Preparedness Programme, a volunteer-based disaster preparedness program, which made a great impact on reducing the loss of lives in the following cyclone events (Habiba and Shaw, 2018). After the 1991 cyclone, the Government established several cyclone shelters in the coastal region which significantly reduced the loss of lives and properties. Currently, there are around 2,900 multipurpose cyclone shelters in the 19 coastal districts built by both Government and national NGOs funding (Figure 2.5). These shelters have the capacity to accommodate 500 to 2500 people each and are equipped with the necessary facilities, proper sanitation systems, and drinking water facilities (Zimmermann *et al.*, 2010). During cyclone events, these are used as shelters for people and cattle, and in other times these are used as schools. The World Bank-approved Multipurpose Disaster Shelter Project (MDSP) has been successful since 2015. It aimed to the funding of approximately 556 new shelters, the reconstruction of approximately 450 existing shelters, and the building and upgrading of approximately 550 kilometres of rural roads to enhance shelter access and communication networks.

Several international and national NGOs such as the German Red Cross, OXFAM, CARE Bangladesh, BRAC, Bangladesh Disaster Preparedness Centre, etc., have also been making a ground-breaking impact on reducing coastal community risk to cyclones and storm surges through their community-level awareness-raising programs. Two mobile phones companies of the country also developed an effective early warning system through which the vulnerable communities of Cox's Bazar district get an early warning text message in their mobile phones before the catastrophic events and thus can move to the nearby cyclone shelters to protect themselves. The traditional media of the country, such as television and radio, also play a key role in mitigating cyclone and flood risks through telecasting and broadcasting timely information on the disaster events collected from the Bangladesh Meteorological Department (BMD) and Flood Forecasting and Warning Centre developed by the Bangladesh Water Development Board. The BMD itself developed a Storm Warning Centre (SWC) to provide early warning on tropical cyclones that form in the Bay of Bengal to minimize losses. The SWC provides early warning messages to the National Coordination Committee headed by the Prime Minister and to the other organizations that work on the disaster mitigation programs. Following cyclone Aila, a catastrophic cyclone that hit the coastal region in 2009, the Comprehensive Disaster Management Programme of Bangladesh started piloting Disaster Resilient Habitat (DRH) in the Khulna region. The DRH is a community-based disaster mitigation program where the community themselves enhance resilience through introducing better living conditions by adapting technology, local knowledge, and investing social capital (Habiba and Shaw, 2018). However, the DRH was later conceived as a project and funded by the United Nations Development Programme (UNDP) for constructing DRH in the southeastern coastal region of the country. According to Paul (2009), around 200 earthen structures called *killa* have been constructed in the coastal area to protect livestock from the storm surges.

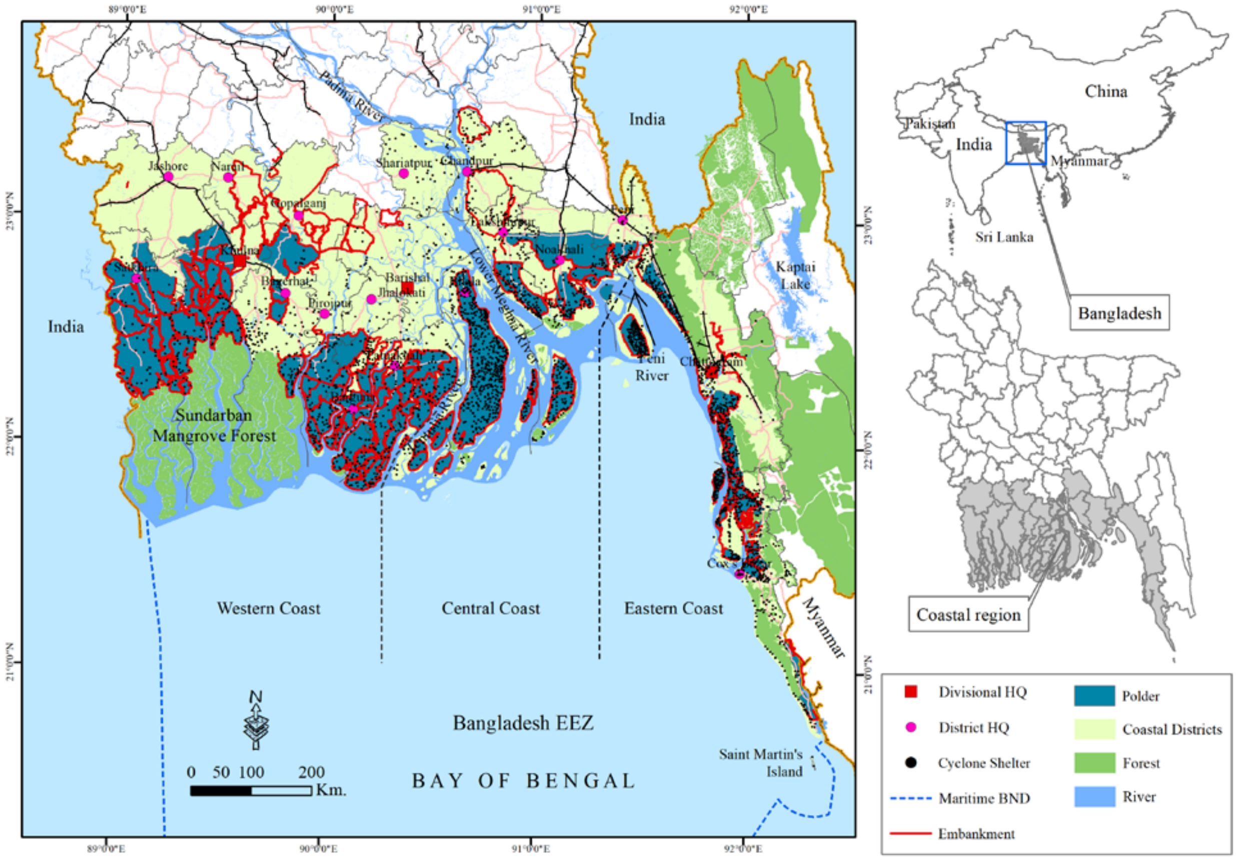

Figure 2.5 Geospatial distribution of embankments, polders, and cyclone shelters in the Coastal region of Bangladesh.
Note: EEZ-Exclusive Economic Zone, BND-Boundary, and HQ-Headquarter.

2.3.3 Coastal afforestation for coastal disaster risk management

Afforestation and reforestation activities in coastal Bangladesh have been effective measures in the reduction of coastal communities' vulnerability to several coastal hazards like cyclones, storm surges, coastal erosion, etc. The Bangladesh Forest Department has been implementing these afforestation and reforestation projects in the coastal area with the target of reducing the loss of lives and properties during disaster events (Das and Siddiqi, 1985). Since 1966 around 1,900 km^2 of newly accreted land in the coastal region has been brought under mangrove plantation (Islam *et al.*, 2013). In 1995, the Coastal Greenbelt Project was initiated under which ten forest divisions brought around 3 million hectares of coastal land under plantation in the next five years. Under that project, 1,394 km of riverine embankment, 4,000 km of rural feeder roads, 420 km of national highways, 20 km of rail-side lands, and 6.7 km^2 of foreshore areas were covered under plantation. After 2005, the massive plantation was carried out by forest divisions of Coastal Circle and Chittagong, Feni, and Cox's Bazar Forest Divisions in the coastal region under several development projects (Figure 2.6).

In 2016, the UNDP initiated the Integrating Community-based Adaptation into Afforestation and Reforestation (ICBAAR) programme, which aims to enhance the socio-economic benefits of the coastal community from forests and increase biodiversity. In the border objective, this program focused on the increase of community resilience to coastal disasters and engaging the local community in the management of coastal forests and sharing benefits from them. It targeted to cover 6.5 km^2 of coastal land under reforestation.

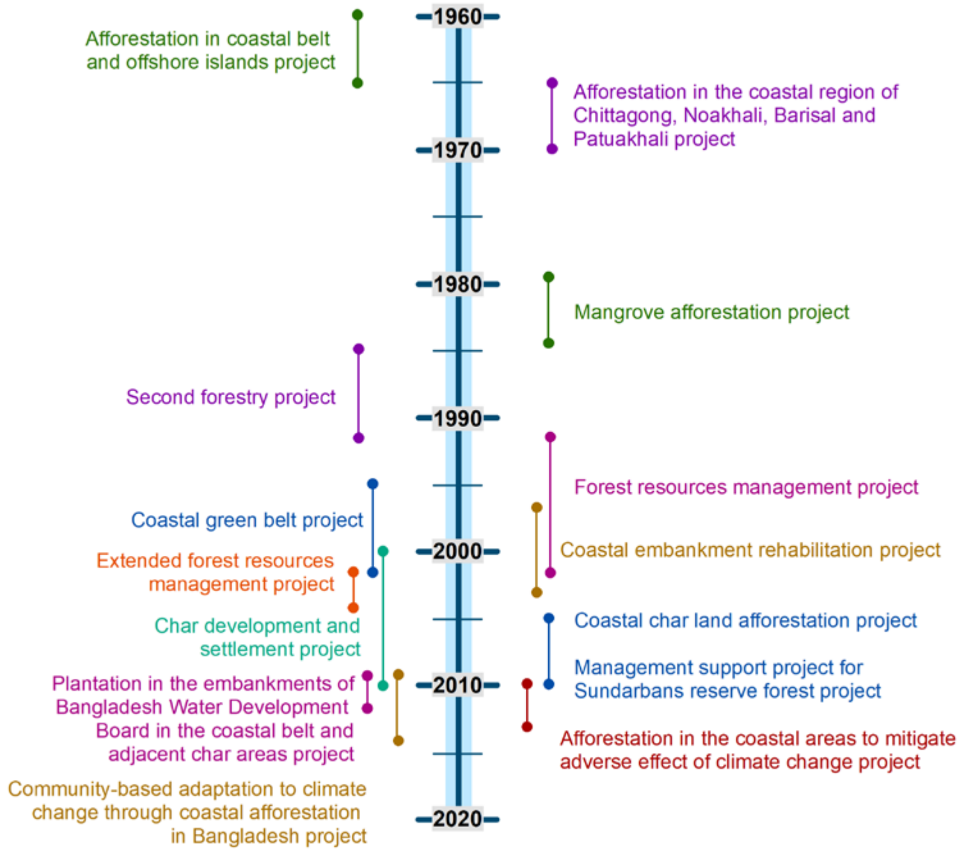

Figure 2.6 Coastal afforestation and reforestation projects implemented since 1960 in the coastal region of Bangladesh.

Breathing roots of Keora trees in Sundarbans, the world's largest mangrove forest, famous for the Royal Bengal Tiger and UNESCO World Heritage site in Bangladesh.

2.3.4 Management of marine and coastal biodiversity

In the coastal region of Bangladesh, several marine and coastal biodiversity conservation and protection sites have been established since 1981 (Figure 2.7). All these have been nationally designated under the Bangladesh Wildlife (Preservation) (Amendment) Act (1947), Marine Fisheries Ordinance (1983), Bangladesh Environment Conservation Act (1995), and Wildlife (Conservation and Security) Act (2012). The major objectives behind the establishment of these protection sites are to preserve marine biodiversity, conserve forest resources, and protect coral and other threatened species in the coastal and marine waters from natural and anthropogenic hazards. Until now, there are 12 protection sites along the coastline and in the marine and coastal water, which together ensure 7,136.20 km^2 area of protection. Among these, there are six wildlife sanctuaries, two ecologically critical areas, two marine protected areas, one marine reserve, and one national park (Table 2.1).

Table 2.1 Different marine and coastal biodiversity protection and conservation sites. (NA: no information available)

Name	Designation type	Status	Year of declaration	Declaration act	Management authority	Total area (km²)
Sundarban West	National	Wildlife Sanctuary (No take zone)	1996	Bangladesh Wildlife (Preservation) (Amendment) Act, 1974	Bangladesh Forest Department	715
Sundarban South	National	Wildlife Sanctuary (No take zone)	1996	Bangladesh Wildlife (Preservation) (Amendment) Act, 1974	Bangladesh Forest Department	369.7
Sundarban East	National	Wildlife Sanctuary (No take zone)	Originally established in 1977 and later extended in 1996	Bangladesh Wildlife (Preservation) (Amendment) Act, 1974	Bangladesh Forest Department	3,12.3
Tengragiri	National	Wildlife Sanctuary	2010	Bangladesh Wildlife (Preservation) (Amendment) Act, 1974	Bangladesh Forest Department	40.5
Kuakata	National	National Park	2010	Bangladesh Wildlife (Preservation) (Amendment) Act, 1974	Bangladesh Forest Department	16.1
Sonarchar	National	Wildlife Sanctuary	2011	Bangladesh Wildlife (Preservation) (Amendment) Act, 1974	Bangladesh Forest Department	20.3
Char Kukri-Mukri	National	Wildlife Sanctuary	1981	Bangladesh Wildlife (Preservation) (Amendment) Act, 1974	Bangladesh Forest Department	0.4
Sonadia Island	National	Ecologically Critical Area	1999	Bangladesh Environment Conservation Act, 1995	Department of Environment	34.7
Saint Martin's Island	National	Ecologically Critical Area	1999	Bangladesh Environment Conservation Act, 1995	Department of Environment	3.2
Swatch of No Ground	National	Marine Protected Area	2014	Wildlife (Conservation and Security) Act, 2012	Bangladesh Forest Department	1,738
Nijhum Dwip	National	Marine Protected Area	2019	Marine Fisheries Ordinance, 1983	Ministry of Fisheries and Livestock	3,188
Unnamed	National	Marine Reserve	2000	NA	NA	698

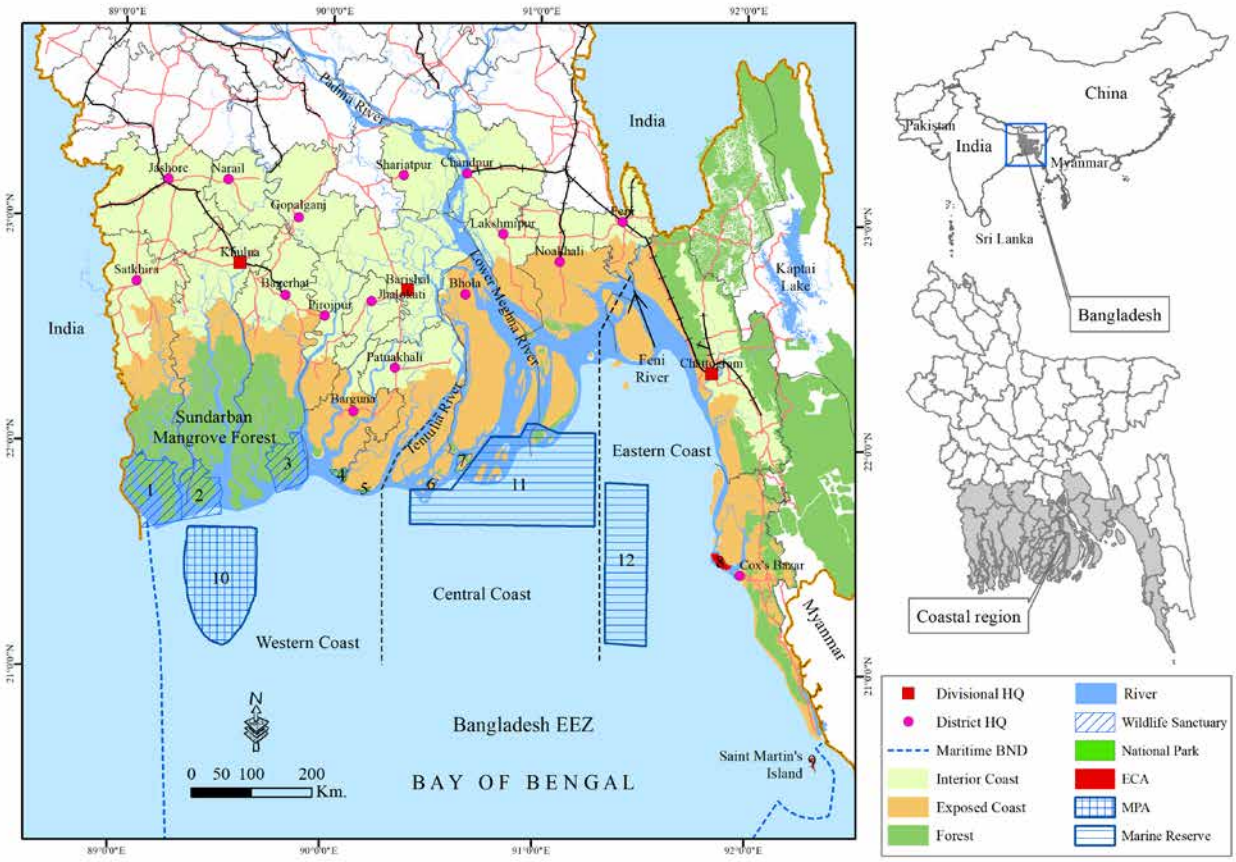

Figure 2.7 Nationally designated marine and coastal biodiversity protection sites.

Note: EEZ- Exclusive Economic Zone, ECA- Ecologically Critical Area, MPA- Marine Protected Area, and HQ- Headquarter.

Source: Sanjoy Roy, based on data collected from the Marine protection Atlas accessed through https://mpatlas.org/

2.3.5 Incorporation of disaster risk management education in academic curriculum

Basic disaster management education has been integrated into the country's primary, secondary, and higher secondary programs under the National Curriculum and Textbook Board to raise awareness of disaster risk management. The aim of this incorporation was to introduce students to several disasters faced by the country and basic early preparedness measures. Few public and private universities have also been offering academic and professional degrees in disaster management. For example, the Department of Geography and Environment of the University of Dhaka has been conducting a professional master's degree in disaster management since 2010. The Begum Rokeya University in Rangpur and the Patuakhali Science and Technology University have specific departments on disaster management, which have been providing academic degrees on it. The BRAC University, a leading private university in Bangladesh, has been providing an academic master's degree in disaster management since 2004. Disaster management related courses are included in the course curriculum by the Department of Environmental Science and Management, Independent University-Bangladesh. Some other public universities have integrated disaster management courses into their academic majors, such as Khulna University, Jahangirnagar University, Mawlana Bhashani Science and Technology University, Rajshahi University, and Chittagong University, and often offer professional and short certification courses. Two engineering universities, such as Chittagong University of Science and Technology (CUET) and Bangladesh University of Science and Technology (BUET) have also been conducting research on disaster management and providing academic degrees on it. While CUET has a separate department called the Department of Disaster Engineering and Management and offers both bachelor's and master's degrees, in the Department of Urban and Regional Planning, the BUET has integrated disaster management courses in bachelor's and master's degree programs.

2.4 Coastal adaptation and risk mitigation in Bangladesh

The government seriously considered disaster risk management vital to national development after the devastating consequences of the 1991 cyclone. Gradually, Bangladesh has proven its aptitude in emergency risk reduction capability and innovativeness by successful disaster management specifically to minimize the loss of human life. While there are several national policies for long term disaster risk reduction and adaptation, the people are yet to realize the benefits. The government has taken up several strategies and projects to achieve disaster risk reduction particularly in the coastal areas of Bangladesh. Structural measures such as polders, embankments, and cyclone shelters have been prioritized in the past while non-structural interventions especially at the community level are starting to gain importance. The government has spent as much as USD 10 million over a period of 35 years to reduce vulnerabilities in coastal areas (GFDRR, 2012). However, while policies and strategies have been formulated up to 2100, the implementation gaps and specific directions in strategies remains a huge concern.

2.4.1 National level adaptation and mitigation strategies

Reducing vulnerabilities to coastal hazards, which are expected to be amplified by climate change, has been prioritized in different governmental policies as part of the greater national development agenda of Bangladesh. The first step towards effective coastal management was the formulation of the Coastal Zone Policy (CZoP, 2005). The policy made way for integrated coastal zone management in the country which made a link between the overall development pathway and therefore facilitated disaster risk reduction in the coastal areas (WARPO, 2006). The first policy specially formulated for the coastal zone addressed the vital problems in the coastal area. The strategies focused on reducing vulnerabilities and suggested innovative adaptation measures such as insurance for the disaster victims, increasing coping capacity especially for the women and children, the safety of livestock, etc. There were also a few mitigation measures, namely coastal afforestation, maintenance of sea dikes, and investments in embankments and coastal infrastructure (CZoP, 2005). In the following year, the Coastal Development Strategy 2006 was formulated. The strategy provided much wider aspects to integrated coastal zone management in addition to those mentioned in the Coastal Zone Policy. It included new measures for disaster adaptation and mitigation such as the effective groundwater management for ensuring freshwater supply, integrated management of coastal infrastructure, coastal land zoning, promoting entrepreneurship, sustainable tourism, promoting renewables such as solar, wind, and tidal energy, sustainable shrimp farming, and other fish resources and emphasize knowledge management and social communication (WARPO, 2006).

In addition to coastal zone management strategies, the adaptation and mitigation measures specified for the coastal region have been addressed by the existing national policies, laws, acts as well as the national strategies for the future development of the nation. The National Sustainable Development Strategy 2010-2021 recommended measures such as the delineation of a coastal buffer zone to prevent overexploitation of natural resources in the coastal area, which is vital to ensure natural adaptation in the coastal area. The prioritised land reclamation for the coastal region, as mentioned in this policy, is vital to improve the livelihood of the coastal people and to reduce the coastal population density in high-risk areas. This policy also recommends further expansion of coastal afforestation and mangrove plantations which are considered as the primary mitigation strategy in the coastal region (GED, 2013).

The coastal zone is one of the six hotspots in the Bangladesh Delta Plan 2100, which is the most futuristic plan taken by the government to date. The plan outlines key adaptation and mitigation strategies such as an increase of drainage infrastructures for reducing flooding in the coastal zone, flood risk protection and preparedness activities, coastal environmental conservation, coastal land reclamation, and coastal afforestation. In summary, the different specific coastal zone policies, and strategies along with the different national plans delineate all the vital strategies and measures that are essential for integrated coastal zone management of the country (Table 2.2). Different plans focus on different aspects while the national level plans deal with the overall mainstreaming of the adaptation and mitigation measures into the national development strategies. However, the major strategies with effect on the reduction of coastal community vulnerability often overlap with different national level policies as presented in Figure 2.8.

Table 2.2 National level policies, strategies, and associated measures for enhancing community adaptation to coastal hazards and mitigation of vulnerabilities in the coastal region of Bangladesh.

Policy	Major Strategies	Measures
National Sustainable Development Strategy (2010-2021)	Protection of coastal aquifers Coastal green belt Land reclamation Ecosystem conservation and management Environmental and socially responsive shrimp farming	Delineation of coastal buffer zone to prevent exploitation Further extension of the coastal afforestation program Make land reclamation a priority Continue mangrove plantation in the reclaimed land Continuation of coastal efforts Semi-intensive shrimp farming to be promoted
Environmental Policy (1992)	Conservation of coastal ecosystem Prevent coastal pollution Sustainable exploitation of coastal fisheries	Promote sustainable use of coastal resources Strengthen research in coastal resource conservation
Coastal Zone Policy (2005)	Reduce coastal vulnerabilities Reduce coastal erosion Enhance safety measure for cyclone Protection of livestock Coastal afforestation	Initiate insurance scheme for disaster affected population Increase Coping capacity of the coastal people Coastal erosion protection measures and rehabilitation for the affected people Maintenance of sea dikes as the first line of defence against storm surge Build cyclone shelters, multi-purpose embankments, *killas*, road system and disaster warning system Special consideration for women and children Safety of livestock during and after disasters Promote planned coastal afforestation with priority for social forestry and plantations with proper maintenance
Coastal Development Strategy (2006)	Promote ICZM Ensuring sufficient and clean water availability Protection from manmade and natural hazards Optimize coastal land use Sustainable natural resource management Improving livelihood of people Environmental conservation Empowerment of population by knowledge management	Equip Coast Guard for environment monitoring Effective groundwater management Sanitation and safe water supply Developing integrated water management plans Improvement and maintenance of sea dikes Multi-purpose cyclone shelter as a coping mechanism Integrated management of coastal water infrastructure Better use of accreted land Promote coastal agriculture Promote coastal land zoning Enterprise development for improving livelihood Tourism development in the coastal zone Socially responsible shrimp farming Promote solar, tidal and wind energy in coastal areas Promote expansion of marine fisheries Especially livelihood programs for the char and islands Rehabilitation program for erosion victims Promote livestock services Integrated and participatory mangrove afforestation program Knowledge management and social communication
National Fisheries Policy (1998)		Shrimp and fish culture will not he expanded to coastal areas that have mangrove Harmful chemicals will not be used in shrimp farms Promote environment friendly shrimp cultivation Ban disposal of untreated chemicals in water bodies
National Adaptation Program of Action (NAPA)		Promote coastal afforestation program Ensure safe drinking water for the coastal community Construct cyclone shelters and information centres Promote research on drought, saline and flood tolerant varieties of crops Adaptation of coastal crop agriculture to combat salinity Promote salt tolerant fisheries to ensure adaptation in coastal fisheries

Policy	Major Strategies	Measures
Bangladesh Climate Change Strategy and Action Plan (BCSAP) (2009)	Food security, social protection, and health Comprehensive disaster management Infrastructure Research and knowledge management Mitigation and low carbon development Capacity building and Institutional strengthening	Climate change resilient cropping systems Develop and Implement Disaster risk surveillance system Develop drinking water and sanitation system Strengthen community-based adaptation Improve disaster warning system Repair existing infrastructure such as embankments, drainage systems etc., and plan and design for future Research the link between climate change, poverty and health Expand coastal greenbelt and mangrove plantation programme Capacity building for relevant government and non-government stakeholders
National Plan for Disaster Management (2010-2015)	Professionalizing disaster management system Mainstreaming risk reduction Empowering communities at risk Expansion of risk reduction programming	Establish a Disaster Management Regulatory Framework Risk reduction and climate change adaptation principles considered in all development efforts Capacity of Disaster Management Committees Strengthen capacity of households to withstand disaster Ensure social safety nets for the most vulnerable population Prepare better hazard maps and develop climate scenarios that might be used to anticipate impacts Make hazard information available in user friendly format Strengthen capacity for erosion monitoring and prediction Build community resilience Build a community alerting system Improve search and rescue mechanisms Focus on post-disaster recovery and reconstruction Establish public private partnerships for disaster risk reduction
Bangladesh Delta Plan 2100	Increase drainage capacity and reduce flood risk at coastal zone Diminish drainage congestion Flood risk protection Flood risk preparedness Resource planning, protection of environment Reclaim new land in the coastal zone Afforestation in the Sundarbans	Extension of early warning services into the communities Extension and improvement of cyclone shelters Flood and storm surge proofing of housing and critical services Social safety net and recovery Accelerate land reclamation process in the Meghna estuary Salt-water sea barriers to regulate dry season flow Groundwater extraction from deeper aquifers Salt-resistant crop farming Adaptation to shrimp or crab farming Non-farm income activities or inland migration

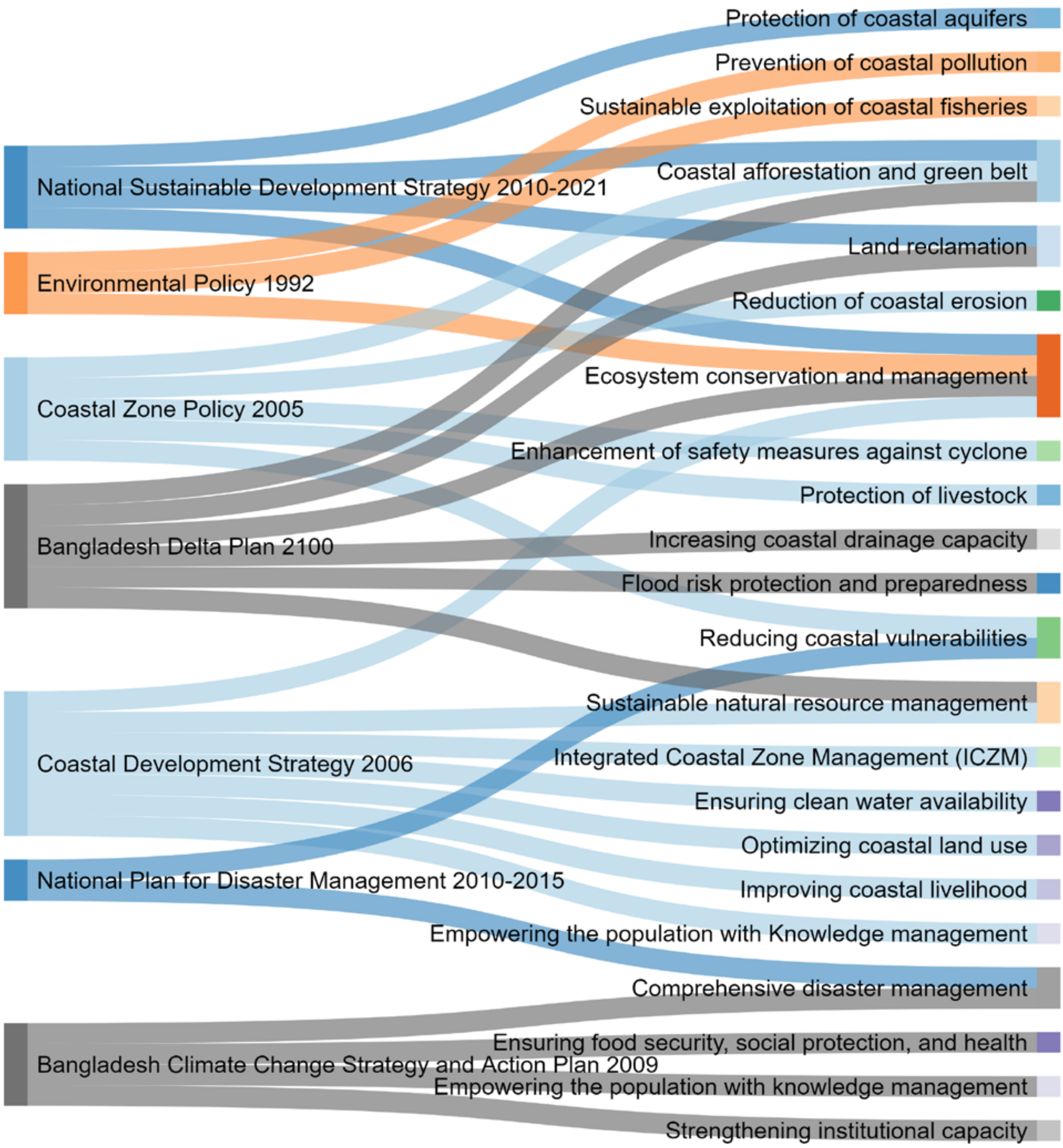

Figure 2.8 Overlapping of strategies (right) with different national level policies (left) focusing on the reduction of community vulnerability to coastal hazards and enhancement of community resilience. This Figure was developed based on Table 2.2. © UNESCO-IOC/Sanjoy Roy

2.4.2 Coastal community adaptation interventions

While national strategies have been formulated and programs are being initiated, the coastal communities have been exposed to disasters since immemorial times, developing several adaptation techniques over the years. According to Agrawala *et al.* (2003), the national strategies have focused on structural protection measures in the coastal areas. which have largely ignored the social construct of the area. It is equally important for the national policies to consider such existing techniques and facilitate their expansion. The coastal adaptation strategies are often techniques that are well suited considering the local environment and therefore need to be considered by policymakers and incorporated in national-level strategies. Alam *et al.* (2003) mention that the key community adaptation strategies are all linked to the livelihood of the people in the coastal area. The livelihood is linked to social, economic, and environmental drivers which are addressed by the people of the area. The prominent coastal community adaptation techniques are summarized in Table 2.3. Most of the techniques are related to ensuring livelihood after a disaster. A large portion of the people are forced to look for the alternative non-farm activity such as rickshaw pulling or construction works in the areas that they have had to migrate to (Pouliotte *et al.*, 2009). Some of the inhabitants must sell their land and they are often compelled to do so by local elites who are eager to buy off the land at very low prices (Alam *et al.*, 2012). The coastal people do some adjustments to their households for safety such as raising their land and planting trees around their households to protect from the impacts of storm surge (Alam, 2003). The people who are living in the area are well suited to the climate and can quickly take health precautions suited for particular seasons (Haq *et al.*, 2013).

However, these traditional adaptation measures, which are often nature-based, are being threatened by the abrupt changes in the climate and associated changes in disaster intensities (Alam *et al.*, 2013). Therefore, the government must ensure that the local community can also adapt to such abrupt changes and continue their community-based adaptation efforts. Community Based Adaptation to Climate Change first addressed the community-based adaptation strategies through Coastal Afforestation project under the National Adaptation Program (NAPA) which piloted the Triple F strategy (Fish, Fruits, and Forests) in several coastal districts (Alam *et al.*, 2013). This was a multi-scale adaptation project where ditches and dykes were constructed and subsequently fishing, fruit cultivation, and forest plantation were encouraged. Through the Coastal Embankment Rehabilitation Project (CERP) 1995-2003, beneficiary participation of the people was promoted primarily for maintenance of the polders and embankments (Gain *et al.*, 2017). Therefore, we see that the government is promoting community-led adaptation often through ensuring participation in the programs that they are conducting the coastal areas. The donor agencies and local NGOs have also played a huge role to establish nature-based adaptation techniques in the coastal areas (Dewan *et al.*, 2014).

Table 2.3 Prominent community adaptation techniques against coastal hazards in coastal Bangladesh.

Coastal community adaptation techniques	Description of techniques
Seasonal household health coping strategies	Households take some health precautions in times of extreme rainfall, heat or cold (Haq *et al.*, 2013).
Shift to non-rice farming	Some coastal households are shifting to a various crop such as jute, plum, wheat, and variety of pulses (Sarker *et al.*, 2013).
Migration primarily to the middle east for better jobs	A section of the working population migrates to different countries in the Middle East and Malaysia, Singapore etc. (Alam, 2018).
Change in type of employment for women	Women are often forced to do intensive labour jobs that are out of their comfort zone (Abedin *et al.*, 2013).
Diversifying income sources	People often look for different income opportunities such as wage labour, setting up a small business, etc. They often must shift to works that they are not best suited at such as construction works or ship breaking (Pouliotte *et al.*, 2009).
Land selling and loans	Some poor communities are forced to sell their households and land to local elites often at very low prices (Alam *et al.*, 2012).
Financial support from relatives and close contacts	Coastal people often must rely on their social capital and take loans from relatives (Alam, 2018).
Internal migration	Often shift from the coast to offshore island, to interior parts of an island or anywhere that seem convenient and relatively safer. Some people manage to migrate from offshore island to mainland but are forced to stay in risky slopes of hills, lowlands, or swamps etc. (Alam, 2018).
Household modifications	Tent-type temporary household arrangements for the people who lose their homes during a disaster (Alam and Collins, 2010).
Planting trees around households	People often plan trees around their household to reduce the impact of storm surge (Alam, 2018).
Raising household land levels	This is usually done by coastal people to reduce the impacts of storm surges (Alam, 2003).

2.4.3 Evaluation of adaptation and mitigation strategies

Considering several policies and strategies, Bangladesh has made a wide range of efforts to reduce disaster vulnerability in the coastal areas including the Comprehensive Disaster Management Programs Phase I and II (Roy, 2019). With the support of The Comprehensive Disaster Management Programme (CDMP), Bangladesh implemented a robust disaster management system model of risk reduction, which encouraged national stakeholders to consider current disaster risks, and the impacts of climate extremes expected in national and community building (Rahman *et al.*, 2017). To maintain proper coordination among the Ministries, Local Government Body (LGD), and community stakeholders while ensuring proper functioning to alleviate people's suffering, the government has established a collection of structures for Councils and Committees from national (top-down) to grass-root levels (Rahman *et al.*, 2017). More than 6,000 government officials were given training under the CDM (Rahman *et al.*, 2017). According to Roy (2019), the government is providing clean drinking water, restoring coastal embankments, and raising awareness among the local people as risk reduction interventions. Several awareness programs ranging from leaflet distribution, knowledge sharing, meetings, dramas, and improved knowledge on warning signals have been implemented in the coastal area (Roy, 2019).

While the policies try to strike a balance between structural and non-structural measures for reducing vulnerabilities, in coastal areas, studies have shown that the programs that are prioritized by the agencies are often structural interventions such as building and repairing coastal embankments, unplanned coastal afforestation, cyclone shelter construction, etc. Mallick *et al.* (2011) criticize the construction of structural interventions such as earthed embankments to lack climate sensitivity as they have not been built considering the future changes in climate change and its impact. Alam *et al.* (2013) mention the morphological shifts in coastal boundaries that are set to threaten the lives of the at-risk coastal areas but none of the policy documents mentions strategies to address coastal boundary shifting. While the policy documents address natural climate change and its impacts, the strategies for destructive human interventions such as hill cutting, illegal fishing and have not been addressed although these activities present further man-made disasters to the coastal people.

The Bangladesh Delta Plan 2100 considered the maintenance of natural drainage and waterlogging in the coastal areas as a major problem, but the rest of the documents, including the Coastal Zone Policy, do not mention strategies for the drainage congestion management. Studies have shown that the structural measures, such as polders and embankments, do not consider the natural drainage patterns in the area which leads to severe waterlogging especially after flooding (Rashid *et al.*, 2013). This phenomenon was also evident after cyclone Amphan as the flooded waters were not drained out weeks after the cyclone.

While tsunami have not caused devastating impacts in the past in coastal Bangladesh, studies have shown that they may be a potential threat in the future. However, the policies and strategies do not consider tsunami threats. A study by Hyder (2009) has shown that the existing cyclone shelters do not consider the thrust of tsunami and therefore are highly vulnerable.

The implemented afforestation programs have been criticized to have an exclusionist approach and often departmentalised, which means that the local people are not fully benefited (Iftekhar, 2006). The influx of Rohingya refugees in Ukhiya Upazila in Cox's Bazar, continued illegal deforestation in the Sundarbans, unplanned expansion of shrimp farming, etc., have posed a great threat to the aim of coastal afforestation. While the government promotes coastal afforestation, it has allowed some destructive development projects such as the Rampal coal power plant and the Matarbari coal power plant, which are going to pose great threats to the coastal environment in the future (Choudhury, 2017).

The analysed policies lack pathways for the reduction of coastal pollution. While the National Sustainable Strategy 2010-2021 had suggested the creation of a coastal buffer zone for preventing exploitation, such strategies have still not been implemented. The strategies for human-induced disasters such as oil spills in the Sundarbans are missing even though, with the increase in the activities in the Mongla Port, this could be a potential disaster in the future for the coastal environment. While the saline intrusion problem has been addressed, shrimp farming is still promoted as a strategy although such interventions have led to the destruction of major mangrove areas in the past. Managing environmental threats in the coastal environment is a vital part of hazard mitigation in the area provided the fact that a large portion of the people is dependent on coastal resources. The structural measures or interventions should consider the coastal community adaptation practices and be in-line with the existing practices.

One of the biggest challenges of the adaptation or mitigation processes in Bangladesh is its proper implementation.

In general, the centralised bureaucracy presents various challenges to the project-based interventions aimed at adaptation or mitigation in the coastal areas. Rahman and Tosun (2018) has shown that the project director role is vital for any adaptation or mitigation project, and that if there is an appointment of specialist project directors the success rate is higher. The study has also shown that specialist project directors are most likely to be placed if there is significant foreign funding. The government needs to address such inconsistencies in the strategies and formulate integrated long-term management initiatives with proper monitoring and maintenance to ensure integrated coastal zone management. While Bangladesh has shown great strides in immediate disaster response, adaptation and mitigation strategies for disaster risk reduction considering the risk of climate change should be prioritised especially for the coastal area of the country.

2.5 Final remarks

Bangladesh is one of the most multi-disaster-prone countries in the world. The country's coastal area, despite its enormous potential, is highly exposed to numerous natural and anthropogenic hazards and disasters. Every year hundreds of families in the coastal region experience loss of lives and tremendous damage of properties. Several disaster risk reduction initiatives were conceived at the national level following the great 1970 cyclone, which significantly reduced damage over the following years. In recent decades, the national disaster management system has implemented a range of policies and initiatives that have been successful in reducing the vulnerability of coastal communities and increasing their resilience to natural disasters. Nevertheless, in combating human-induced hazards in the coastal area, they are still ineffective.

The existing disaster management system focuses heavily on raising awareness and building capacity for reducing loss during the disaster event. Unfortunately, post-disaster management activities, such as the provision of aid, emergency health care, and long-term economic help to rebuild livelihoods, have not been sufficiently emphasised. These considerations are important since any disaster occurrence continues to bring long-term suffering to the coastal community, including health and economic crisis. As the percentage of the marginal population is high in the coastal region of the country, the disaster-induced loss of properties makes them a long-term sufferer. Therefore, post-disaster management activities need to be emphasised in the existing disaster management framework of the country, which will ensure that community livelihoods are rebuilt after the disaster occurrence.

Many local-scale disaster risk management measures in the country are project-based. In addition, these projects have a short implementation period, and multiple projects are often undertaken with an emphasis on the same goal. This recurrence under different project titles of the same project activities shifts the emphasis from the previous one to the current one. As a result, the prior project's learning and successes are not carried into the next step. Due to the lack of long-term monitoring of the project output, most of the projects fail to achieve the holistic goal of management. Instead of taking on occasional short-term projects, a long-term project monitoring framework should be built to achieve goals and sustainability. In this case, the consideration of the multiple implementation phases of the same project may be a good practice in which learning from the implementation of the previous phase is carried forward into the next phase and monitored properly.

The current hazard mitigation and adaptation policies of the country are developed prioritizing natural hazards and disasters. There are a few anthropogenic hazards in the coastal region of the country such as intensified siltation and damage of hydrological connectivity due to infrastructural development, water pollution from ship-breaking industry, and uncontrolled mass tourism, saline intrusion from shrimp farming, and environmental degradation due to refugee influx. Furthermore, the changing of land uses in the coastal region has been posing pressure on the natural ecosystem. These hazards cause long-term detrimental effects on both the environment and inhabitants and in some instances the damages induced from them are irreversible. Unfortunately, in the current policies, sufficient guiding principles for the management of all these anthropogenic hazards are neither well defined nor adequately addressed. In this regard, it is important to integrate relevant policy documents into the current regulatory system to minimize the long-term effects of these hazards in the coastal area.

Lastly, the improvement in the coastal region's community livelihood conditions will substantially reduce their vulnerability to both natural and anthropogenic hazards and disasters. Non-government agencies are currently conducting most of the coastal livelihood development initiatives in coastal Bangladesh. These interventions have been carried out in most cases on a smaller geographic scale, concentrating on a particular problem area. However, a large-scale government-level initiative should be taken to improve the overall living conditions in the coastal area to increase the resilience of coastal people against numerous coastal hazards and disasters.

Acronyms and abbreviations

BBS	Bangladesh Bureau of Statistics
BMD	Bangladesh Meteorological Department
BOBLME	Bay of Bengal Large Marine Ecosystem
BUET	Bangladesh University of Science and Technology
CEIP	Coastal Embankment Improvement Project
CEIP-1	Coastal Embankment Improvement Project – Phase 1
CSPS	Cyclone Shelter Preparatory Study
CUET	Chittagong University of Science and Technology
CZoP	Coastal Zone Policy
DFID	Department for International Development
DRH	Disaster Resilient Habitat
DoE	Department of Environment
ECA	Ecological Critical Area
EEZ	Exclusive Economic Zone
FAO	Food and Agriculture Organisation
FRSS	Fisheries Resources Survey System
GBM	Ganges-Brahmaputra-Meghna
GED	General Economics Division
GFDRR	Global Facility for Disaster Reduction and Recovery
HQ	Headquarter
ICZM	Integrated Coastal Zone Management
IPCC	Intergovernmental Panel on Climate Change
ICBAAR	Integrating Community-based Adaptation into Afforestation and Reforestation
MDSP	Multipurpose Disaster Shelter Project
MoF	Ministry of Environment and Forests
MoFDM	Ministry of Food and Disaster Management
MPA	Marine Protected Area
NGO	Non-Governmental Organisation
PMSL	Permanent Mean Sea-Level
SOD	Standing Order on Disaster
SRDI	Soil Resource Development Institute
SWC	Storm Warning Centre
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
WARPO	Water Resource Planning Organization

Cyclone-affected people build a dike in Shyamnagar, Bangladesh.

3. The case of Costa Rica

Playa Naranjo and Roca Bruja (Witch's Rock), a famous surfing destination located in the Guanacaste province of Costa Rica whose name is derived from a legend of a witch living on the island.
© Paul Urena Mora/Shutterstock.com

Author: Natalia Solís-Miranda

3.1 Costa Rica and its coastal zone

At an interoceanic and intercontinental position, located in the heart of the narrow Central American Isthmus lies Costa Rica (9.7489° N, 83.7534° W), a small country in-between two great masses of land, North America and South America, and two vast water masses, the Atlantic Ocean and the Pacific Ocean (Alvarado and Cárdenes, 2016) (Figure 3.1). The country is located between Nicaragua and Panama, involving a landmass of 51,100 km^2. In 2018, it reached five million inhabitants, with a density of population of 97.9 persons per km^2 (INEC, 2018).

It borders the Caribbean Sea in the east and the Pacific Ocean, Colombia, and Ecuador in the west. Thanks to Isla del Coco in the Pacific Ocean, the Exclusive Economic Zone of Costa Rica is 589,683 km^2, more than ten times the landmass (Cortés and Wehrtmann, 2009).

The terrain's geographical and geological complexity exposes the country to the atmospheric and oceanographic influence of the Caribbean Sea and the Pacific Ocean. Furthermore, the constant tectonic and volcanic activity, the mountain chain system, and the vast and profound hydrological basins are considered a constant threat to the human settlements (Chavarría-Córdoba, Barrantes-Castillo and Quesada-Román, 2016; CNE, 2015)

Costa Rica has suffered changes in climate patterns, causing more and more extreme events. The country has

Figure 3.1 Location map of Costa Rica.

already experienced changes in the ocean's biological and physicochemical properties, but the trends will worsen (Figure 3.2), exacerbating the vulnerability of the coastal areas (BIOMARCC/SINAC/GIZ, 2013). The latter and other socio-environmental triggers reinforce the need of advancing with Integrated Coastal Zone Management (ICZM), prioritising the potential risks, and addressing them with the stakeholders' active involvement.

Reduction	Increase	Constantly changing	Will increase or decrease severely
• Salinity • Primary productivity (chlorophyll) • Oxigen concentration • Nutrient availability • Fisheries	• Temperature • Ocean acidification • Sea-level rise • Frequency and roughness of the marine storms	• Marine currents	• Precipitation patterns • River flows

Figure 3.2 Expected trends in climate and oceanographic variables.
Source: Natalia Solís-Miranda based on Ross Salazar *et al.* (2018)

3.1.1 Geographical context

Costa Rica is privileged to have two coasts: the Caribbean and the Pacific. The Caribbean coastline is 212 kilometres long, characterized in the north for being regular with few geographical accidents, high-energy sandy beaches, and coastal lagoons, whereas the south Caribbean coastline is well-known for its sandy beaches and rocky points with coral reefs (Cortés and Wehrtmann, 2009). In contrast, the Pacific coast is six times larger than the Caribbean coastline, with 1,254 kilometres, and highly heterogeneous. It presents rocky intertidal zones, soft bottoms, mangroves, estuaries, coastal islands, two gulfs, and other geographical features. These characteristics are present typically on tropical beaches, where the risk to climate change, namely sea-level rise, is considerably high (Carranza Maxera, 2013) (Figure 3.3).


Figure 3.3 The Punta Uva on the southern Caribbean coast and Playa Grande on the northern Pacific coast, Costa Rica. © UNESCO-IOC/Natalia Solís-Miranda and Gustavo Montero

3.1.2 Meteorological and oceanographic context

Costa Rica is in the Tropical Convergence Zone. Its tropical climate and generally well-defined annual patterns are periodically affected by the interaction of different factors, such as the surrounding ocean basins, the interaction of the atmospheric circulation with the mountain range that runs from northeast to southeast dividing the country into Pacific Slope and Caribbean Slope, and the El Niño-Southern Oscillation (ENSO) phenomena (IMN/CRRH, 2008; GFDRR (2011), IMN, 2020). El Niño is a large-scale ocean-atmosphere climate phenomenon associated with regular warming in the Sea Surface Temperature (SST) in the Pacific in the central and east-central equatorial areas (IMN, 2020). When El Niño occurs, a warm phase of the El Niño-Southern Oscillation (ENSO) cycle happens and causes severe droughts affecting the Pacific, whereas the Caribbean slope of the country suffers heavy rains that cause flooding (GFDRR, 2011, IMN, 2020). It is worth mentioning that the number of hurricanes that affect the Caribbean Sea determines the intensity of El Niño, which means that when El Niño is strongly affecting the Pacific, the number of tropical storms or hurricanes in the Caribbean is low (IMN/CRRH, 2008).

The Pacific slope of Costa Rica has two well defined seasons, the rainy season that goes from May to October, and the dry season that extends from December to March (IMN/CRRH, 2008). The Caribbean slope does not present a defined dry season. It is rainy all year round with total rainfall varying from less than 1,500 mm in the south up to more than 5,000 mm in the north. In the coastal areas, there are two dry periods. The first one happens between February and March, and the second occurs between September and October (IMN/CRRH, 2008).

In the ocean, Costa Rica presents a unique and dynamic offshore upwelling system that significantly influences the eastern tropical Pacific Ocean's ecological functioning, the so-called Costa Rica Thermal Dome (Johnson *et al.*, 2018). This upwelling mobilises a colossal water mass (approximately 3.5 million m^3) rich in nutrients to the surface, and when these nutrients reach the sunlight, a massive primary production occurs, benefitting all marine organisms of that area (Fiedler, 2002), and of course the fisheries.

3.1.3 Biogeographical context and management of ecosystems

Costa Rica's management has been centralized under governance with a land-based perspective, keen to manage and conserve mostly terrestrial resources (SINAC, 2009). In recent years, its agenda has changed, adopting marine resources management, and taking the premise that these resources are part of the national heritage and public property; hence its exploitation is of public interest and a social matter (Fargier, Hartmann, and Molina-Ureña, 2014). According to Fargier, Hartmann, and Molina-Ureña (2014), coastal integration became part of development plans during two consecutive governmental administrations (2006-2010 and 2010-2014). By this means, a National Strategy for Integrated Management of Coastal Marine Resources was achieved for the first time in 2007 (Fargier, Hartmann, and Molina-Ureña, 2014), in accordance with a joint effort among public institutions, the academia, NGOs, and the public in general (Morales-Ramírez, Benavides and

González-Gairaud, 2010). Up to date, Costa Rica counts 171 Protected Areas, of which 34 are Marine Protected Areas categorized in National Park, Wetlands, Marine Management Area, National Wildlife Refuge, Biological Reserve, and Biological Nature Reserve (SINAC, 2020) (Figure 3.4). As a result, Costa Rica country hosts a variety of 6,778 coastal-marine species, representing 4% of the coastal-marine biodiversity of the world (Cortés and Wehrtmann, 2009; Cortés, 2016). Around 67% of such species were found on the Pacific coast, almost the double of the species registered in the Caribbean (SINAC, 2009).

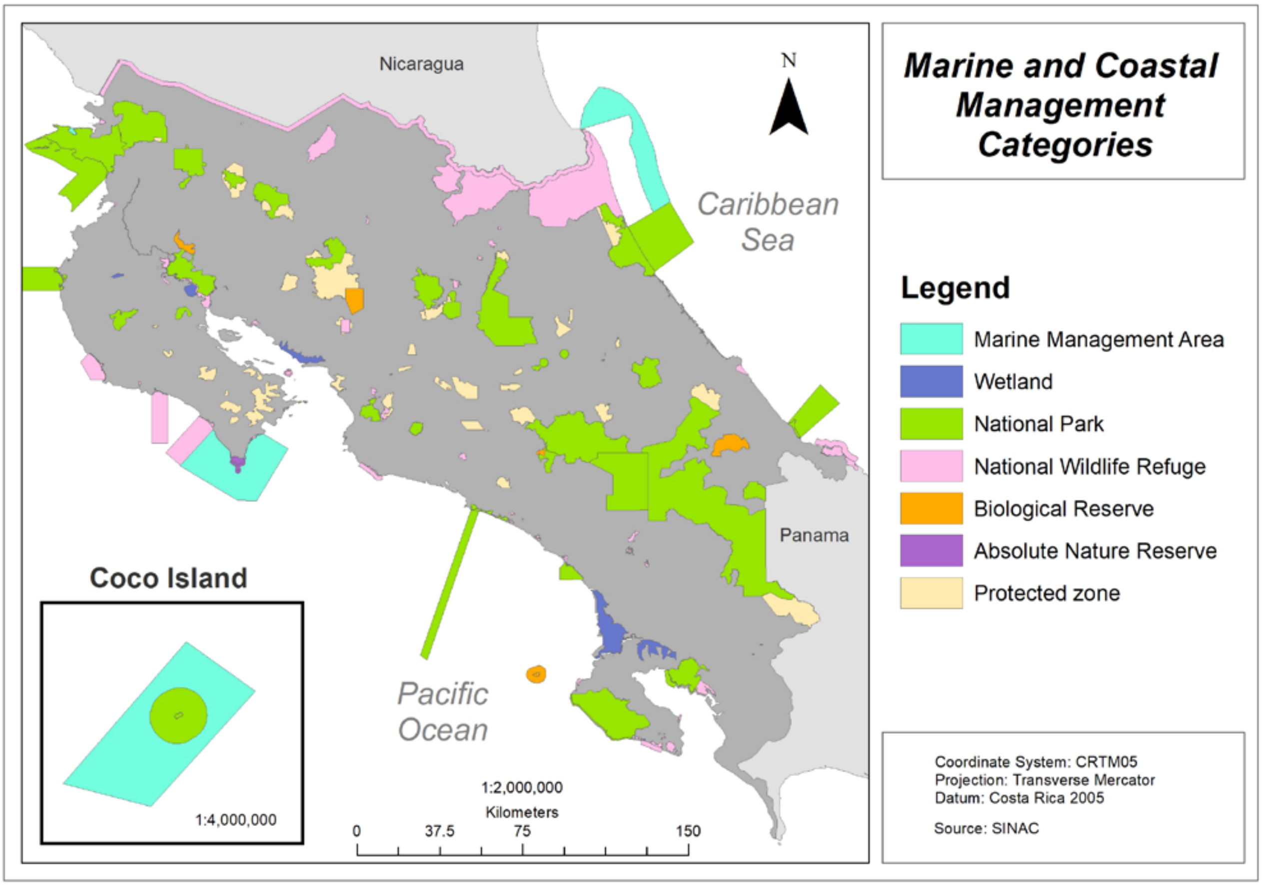

Figure 3.4 Marine and coastal management categories in Costa Rica.
Source: Natalia Solís-Miranda based on SINAC (2020)

3.1.4 Socio-economic context

Costa Rica is divided into seven provinces, subdivided into 82 cantons supported by only eight district boards. Each canton manages and copes with climate challenges in different ways according to their demography, environmental and socio-economic realms (CCT/SUM Consulting, 2019). There is no doubt that heterogeneity marks the social development of the country, where 20% of the cantons, mainly the coastal ones (*i.e.*, Coto Brus, Buenos Aires, Osa, and Nandayure), present the highest poverty index (Costa Rica-MIDEPLAN, 2018; CCT/SUM Consulting, 2019). For most coastal communities, the economic development is complex, and they do not have the tools or the capabilities to compete against the more developed cantons (CCT/SUM Consulting, 2019). In this regard, the socio-economic vulnerabilities are relevant to understand how disproportionate the impacts of the environmental hazards are and understand how these hazards worsen the conditions of already low-income families, with particular attention to those led by females (CNE, 2015).

Artisanal fisheries, coastal tourism, and protected areas are the primary income for the coastal populations. However, during the last three decades, tourism has caused urban sprawling, putting pressure on the marine-coastal zones, and creating vulnerable conditions by increasing the exposure to hazards (CNE, 2015).

3.2 Coastal hazards in Costa Rica

In Central America, the most common disasters that affect the populations are extreme events such as floods, droughts, hurricanes, and storm surges (Román, 2015). Costa Rica is not an exception, and most of the emergencies detected by the National Commission for Risk Prevention and Emergency Attention (hereafter, CNE), are associated with floods, landslides, storm surges, flash floods that occur any time of the year (CNE, 2015). At a local scale, the increase of air temperature, changes in the rainfall patterns and sea-level rise are the three main threats affecting the coastal cantons (CCT/SUM Consulting, 2019).

3.2.1 Sea-level rise

Global mean sea-level will continue rising and accelerating and, according to Oppenheimer *et al.* (2019), there is evidence that coastal ecosystems are suffering from the combination of sea-level rise (SLR), climate-related ocean changes, and the consequences of human activities on the ocean and land. The uncertainty and threat of coastal populations to cope and adapt is tangible.

Studies have shown that the sea-level is not rising uniformly, and it varies according to the geographical distribution of the ocean thermal expansion, the influence of gravitational forces, the salinity variations, ocean currents, or land movements (Nicholls and Cazenave, 2010). Globally, it is expected to rise 3.2 mm per year, however in the Nicoya Peninsula – Northern Pacific coast of Costa Rica – the sea-level is falling 1 mm per year. This local trend is caused by the subduction process between the Cocos and the Caribbean tectonic plates, promoting changes in the relative sea-level. That means that the land is currently rising at a rate of 5 mm per year, while the relative sea-level is rising 4 mm per year; hence, in this place specifically, the sea-level is not rising but falling (Protti, Ballestero and Fonseca, 2010; Fonseca, 2011). On the Caribbean coast, the observed SLR of 1-2 mm per year could be associated with the ENSO phenomena, the gyre between Panama and Colombia, or the change in the circulation of the Caribbean Current (BIOMARCC/USAID, 2013), rather than tectonic movements.

According to Kibria (2016), SLR can cause significant effects on coastal ecosystems and habitats, such as wetlands. Various environmental services, such as coastal protection, nutrient cycling, carbon fixation, and biodiversity conservation, will also suffer. Likewise, fisheries may be diminished much more due to salinity changes and other properties that help commercial species to grow in these nursery areas. Risk in public health may also grow since SLR may lead to increased breeding of salinity-tolerant mosquitos that can transmit Cholera or other infectious diseases (Kibria, 2016). It may also cause losses in infrastructures and assets and promote the migration of human settlements.

3.2.2 Storm surge and coastal flooding

The XXII National State Report mentions that, between 1985-2015, many coastal hazards events happened in Costa Rica, of which 2% were storm surges (Brenes, 2016). The passage of hurricanes and tropical storms near the coast tend to combine the effect of extraordinary low atmospheric pressure, strong onshore wind, and large waves, causing important coastal flooding, mostly during high tides. It is predicted that storm intensity will increase, and so, the wave heights. The latter, combined with storm surges and the SLR, will cause the waves to penetrate inland, even more, intensifying the floods and coastal erosion (Lizano and Lizano, 2010).

In Costa Rica, the risk of coastal floods is increasing on both coasts (Figure 3.5). Consequently, various physical impacts take place, such as coastal erosion, overwash, and salinisation of coastal lands and aquifers (BIOMARCC/SINAC/GIZ, 2013). Additionally, this type of hazard may cause human and animal losses, destruction of plantations, properties, and public infrastructure (Huguenin and Vega, 2016).

Most of the coastal municipalities lack coastal regulatory plans that integrate climate change and its associated hazards. The local government's lack of action jeopardizes the lives of hundreds of families in poor conditions who have nowhere else to go (Chavez, 2018). Thus, traditional coastal livelihoods may also be impacted by the occurrence of coastal flooding in Costa Rica.

Academia experts have been studying the impacts of this hazard in Puntarenas for more than ten years, creating models to project different scenarios to understand the flooding caused by the rise of the sea level. Every 4.7 years, the highest astronomical tides can reach up to 3.3 m. A study of the 20-year high tides for Puntarenas determined that the frequency of exceeding the 3 m tide happens 42.3 times per year (Figure 3.6a). By 2050 with an additional 0.30 m scenario, the frequency of having high tides equal or greater than 3 m would be 391 times per year. And for scenarios projected to 2070 and 2100 (Figure 3.6b), Puntarenas will be flooded every day (Lizano, 2020; Lizano and Lizano, 2020).

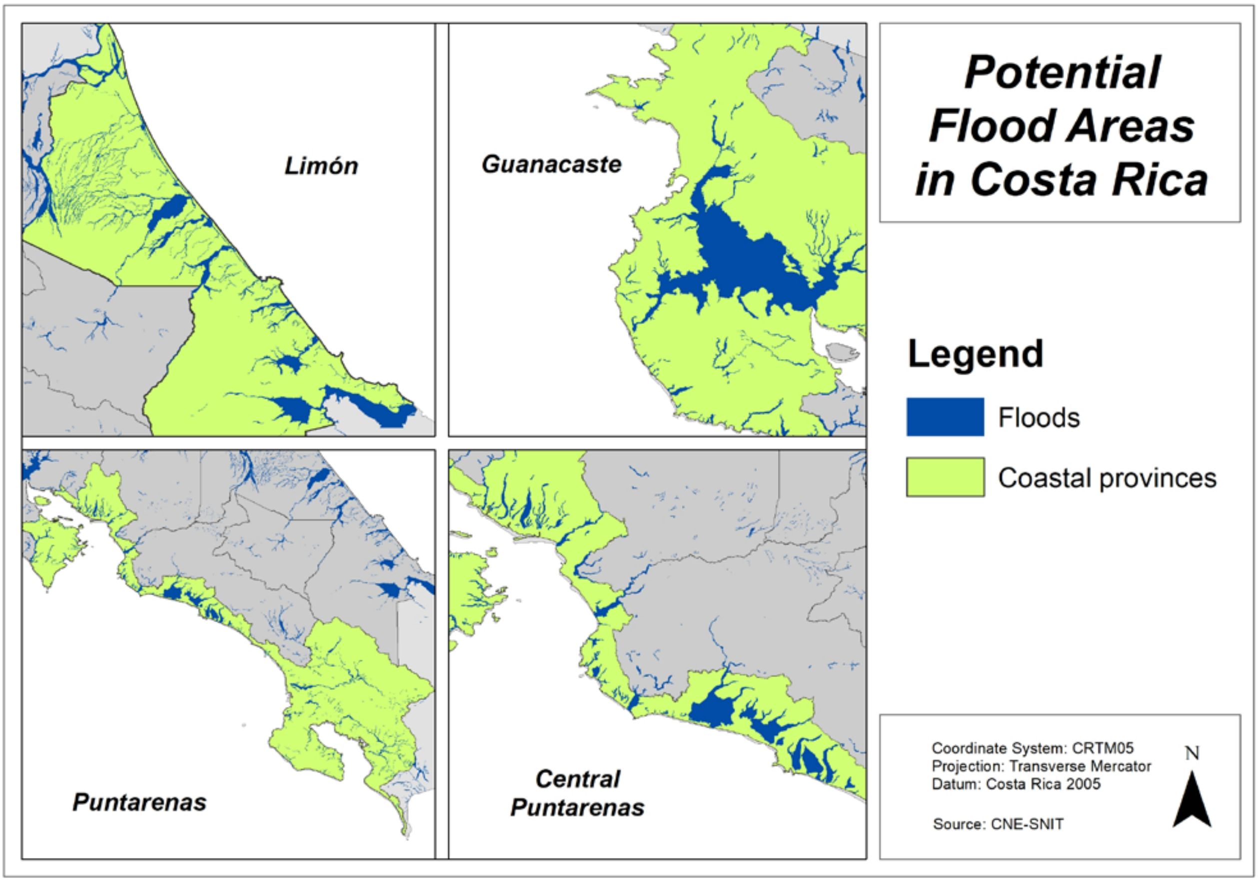

Figure 3.5 Potential coastal flood areas in Costa Rica.
© Natalia Solís-Miranda

As highlighted by Rodríguez (2009), in some coastal locations, like Puntarenas, the local authorities' response to coastal flooding is perceived by the population as insufficient. The intervention of the central government is therefore desired. According to Lizano (2014), the coastal zone management legislation is inconsistent with the current coastal dynamics. In some cases, the current laws and regulations are obsolete, for instance the Maritime-Terrestrial Law (Law ZMT 6043). Furthermore, the public zone is based on the Puntarenas sea-level records until 1966. Since then, the coastal zone has completely changed, and is expected to continue perhaps even more rapidly soon. Rodríguez (2019) pointed out that CNE aims to create a joint long-term strategy with the Ministry of National Planning and Economic Policy (MIDEPLAN) to promote the prevention of coastal floods and sea-level rise in the coastal regulatory plans. However, it seems that the plan is still a work in progress since the National Environmental Technical Secretariat (SETENA) registers 57 coastal regulatory plans in which 54 are archived or with no paperwork registered (SETENA, 2017).

Coastal flooding risk management therefore is urgently needed in places such as Puntarenas, where the future scenarios are not very optimistic. According to Zanuttigh, Nicholls, and Hanson (2015), strategies that address coastal hazards must be developed within a long-term and multidisciplinary vision.. Such measures are challenging and require solid political will. Further public participation is needed to force the government to act accordingly. Key actions can be carried on if the population gets the proper tools, knowledge and becomes empowered with the support of the governmental bodies at local and national level.

3.2.3 Coastal erosion

During the past 20 years, researchers have identified important shoreline changes along the Costa Rican coasts, putting in evidence the occurrence of coastal erosion processes (Cárdenes Sandí, 2003; Cárdenes and Guillermo Obando, 2006; Ortiz Malavasi, 2008; Lizano Rodríguez and Gutiérrez, 2011; Lizano, 2013).

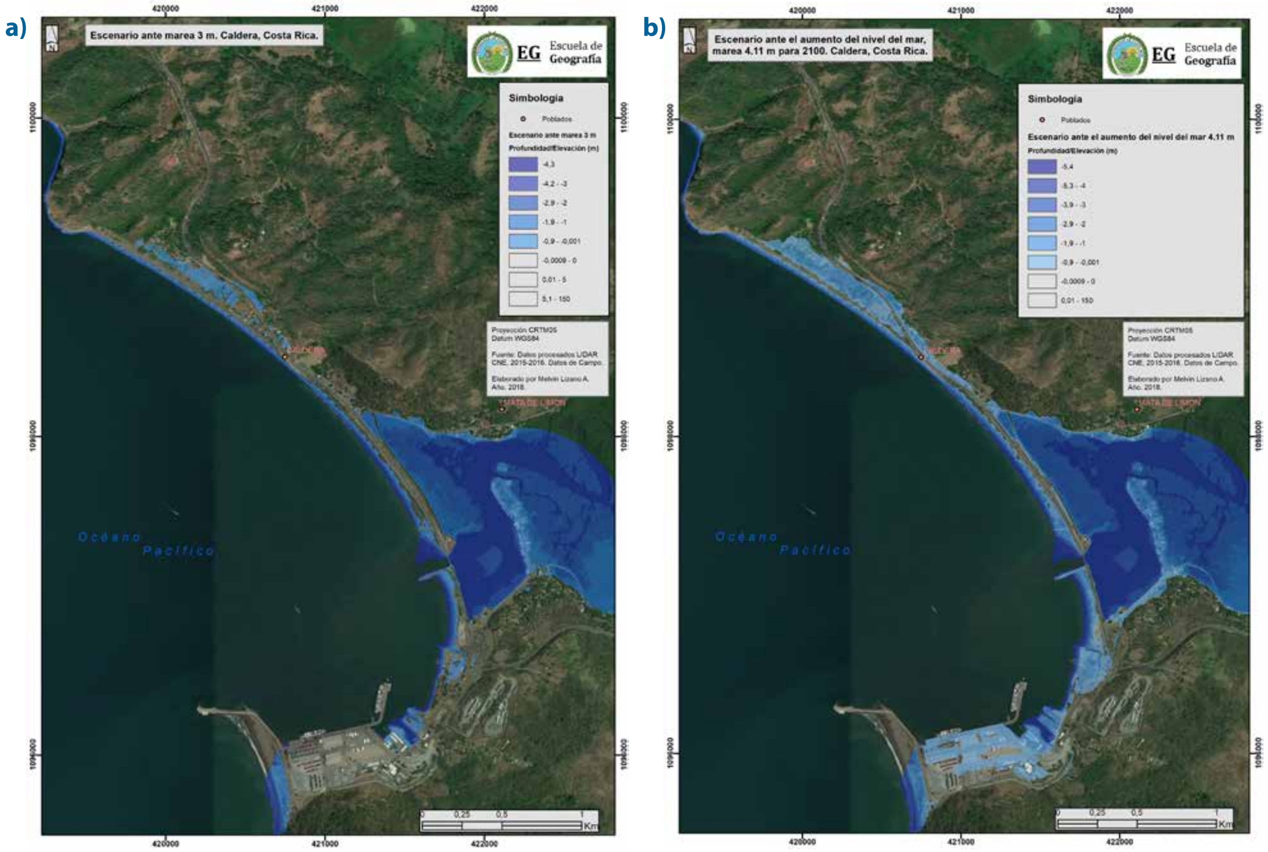

Figure 3.6 Example of coastal flood maps for the Pacific coast near Caldera, Puntarenas. a) Current coastal floods with a tide of 3 m. b) 2100 scenario of coastal flooding.

Several phenomena are influencing the coastal erosion processes. The most notorious is sea-level rise (Barrantes-Castillo *et al.*, 2019; Lizano, 2013). However, when the combination of oceanographic and meteorological events such as El Niño, storm surges, large waves, and other related to cyclone activity occur, coastal erosion episodes can convert the worst scenarios into reality, especially on the Caribbean coast (Barrantes-Castillo *et al.*, 2019).

Ortiz Malavasi (2008) claimed that in the Pacific, the coastal erosion effects are evident in the breaching and disappearance of barrier islands (*e.g.*, Damas Island near Quepos, Puntarenas) and mangroves. In the Caribbean, the effects are related to the disappearance of barriers such as wetlands and coastal lagoons. For Lizano (2013), the uplift and sink of the land due to tectonic movements also contribute tremendously to coastal erosion.

The Caribbean coast has been showing an accelerating coastal erosion process that concerns the population, mainly in Puerto Vargas and in the Cahuita National Park. Barrantes-Castillo *et al.* (2019) compared shoreline changes in six sectors in the southern Limon province over two periods, 2005-2010 and 2010-2016. Their work revealed 11 coastal erosion hotspots, with three of them presenting the most significant shoreline retreat increases (Table 3.1).

Table 3.1 Comparison of the most significant surface losses due to increased rates of coastal erosion processes in the southern Caribbean coast of Costa Rica.

Locations	Period 2005-2010	Period 2010-2016	Difference
Puerto Vargas in Punta Cahuita	2,480 m^2/year	9,510 m^2/year	7,030 m^2/year
Puerto Vargas Beach south of the old berth	986 m^2/year	8,953 m^2/year	7,967 m^2/year
Gandoca Beach up to the mouth of the Sixaola River	1,697 m^2/year	7,456 m^2/year	5,759 m^2/year

Source: Natalia Solís-Miranda based on Barrantes-Castillo *et al.* (2019)

The authors concluded that erosion occurs in places such as concave and straight beaches, river mouths, pocket beaches, and even in areas with coral reefs protection. It also reaffirmed the coastal erosion process is damaging properties along the Caribbean coast (Barrantes-Castillo *et al.*, 2019). The local community tends to deploy sandbags to mitigate coastal erosion. However, this is not enough. The municipalities must address this issue with the private sector and involve the community to create coastal zone management plans (Lizano Rodríguez and Gutiérrez, 2011). Another way to address this issue is by restoring different ecosystems, such as wetlands, seagrass meadows, and coral reefs which tend to be more cost-effective in comparison to other alternatives.

3.2.4 Tsunamis

The largest tsunamis ever recorded in Central America have occurred on the Pacific coast, but the ones that have caused significant damage and even life losses have been recorded on the Caribbean coast of Central America (Fernandez *et al.*, 2000). As for Costa Rica, the country records tsunamis as sporadic events (Chacón-Barrantes and Gutiérrez-Echeverría, 2017); nevertheless, the threat should not be ignored (Zamora and Babeyko, 2016). Twenty-one tsunami events were registered between 1979 and 2015. Two human losses were registered in 1991, after Limón's earthquake tsunami (Chacón-Barrantes and Gutiérrez-Echeverría, 2017). The earthquake itself provoked the uplifting of 34 localities in four kilometres from the coast, with heights from zero to 157 cm in the north of Limón (Plafker and Ward, 1992). Nonetheless, there is no report of damages caused by that tsunami and possibly the uplifting served as a barrier and undermined the earthquake's damages (Chacón-Barrantes and Zamora, 2017).

Many studies have been carried out in Costa Rica to simulate the potential risk associated with tsunami events (Zamora and Babeyko, 2016; Chacón-Barrantes, 2018a, 2018b; Chacón-Barrantes *et al.*, 2018). Fortunately, most of the tsunami events recorded by the tide gauges in Costa Rica, originated in other countries such as Chile and did not represent a significant concern. Even so, earthquakes originally happening at distant locations, such as the southwest Pacific, may have important impacts on the Costa Rica's coast (Chacón-Barrantes and Gutiérrez-Echeverría, 2017).

Most of the Costa Rican tide gauges are on the Pacific coast in Quepos (data since 1999 till present), Isla del Coco (data since 2018), and one on the Caribbean coast at the JAPDEVA pier (data since 1997). Since 2014, the SINAMOT has led the tsunami risk reduction by preparing and building capacities amongst the coastal communities and monitoring the potential tsunami continuously. It is also part of the NTWC and the Tsunami Ready Pilot Program of the IOC/UNESCO, a program that aims to help the coastal communities to be prepared for any eventual tsunami event (SINAMOT, 2020). Furthermore, the SINAMOT-CNE alliance developed the capacities on 34 coastal communities, where they mapped tsunami evacuation routes. In 2020, the project deployed tsunami alerts on popular beaches (*i.e.,* Jacó, Esterillos Oeste, Quepos, and Tivives) (CNE, 2020a).

3.2.5 Rip currents

Rip currents are strong wave-induced water flows, from the beach to the sea (Lizano, 2017) and occur to balance the accumulation of water against the shoreline. They are one of the leading deaths causes among swimmers and can occur on almost any beach with breaking waves (National Geographic, 2020).

In Costa Rica, many aquatic accidents associated with rip currents occur when the Easter holidays coincide with very large spring tides and relatively high waves. The registered casualties have occurred in popular beaches, such as Playa Jacó in Puntarenas. Nonetheless, this does not necessarily indicate that the beach is dangerous (Lizano, 2012) since a key factor is inadequate human behaviour. According to Lizano (2012), it is easy to recognise a rip current in most beaches due to the sediment suspension. However, in beaches where the sediments are heavy and are less likely to be suspended/visible, it can be more difficult to spot a rip current. In such cases, a useful indicator is the seawater surface roughness created by the rip current. Despite all the advertisements placed on the beaches and the awareness raised, people do not always understand the information and take risk behaviours. Nowadays, people can be informed about the wind and ocean currents to prevent aquatic accidents by using the Oceanographic Informative Module (MIO-CIMAR) from the University of Costa Rica. This tool aims to prevent accidents by informing the population, the tourism industry, the port authorities, and the local government about the most common threats that can affect swimmers and sailors (Lizano, 2017).

3.2.6 Droughts

Various scenarios forecast that, within the next 35 years, Central America's rainfall will decrease by 5%, and the temperatures will rise 4 °C (Vargas Bolaños, 2019). In Costa Rica, the rainfall in the northern Pacific coast will decline at least 20%, and possibly more than 50% (Alvarado *et al.*, 2012).

During the last two decades, Costa Rica has experienced a decline in rainfall (Vargas Bolaños, 2019). In 2015, the National Meteorological Institute (IMN) declared an extreme ENSO period, mainly in Guanacaste, where precipitations dropped by 60% (IMN, 2016) (Figure 3.7).

It is worth mentioning that Guanacaste is known for its extreme dry events and long dry season. The lack and irregular periods of rain promote desertification in the area, where it is expected that erosive agents such as temperature, lack of rain, and winds intensify shortly (IMN, 2020). Consequently, if the rainfall decrease trends remain, disputes for water and illegal exploitation of wells will increase.

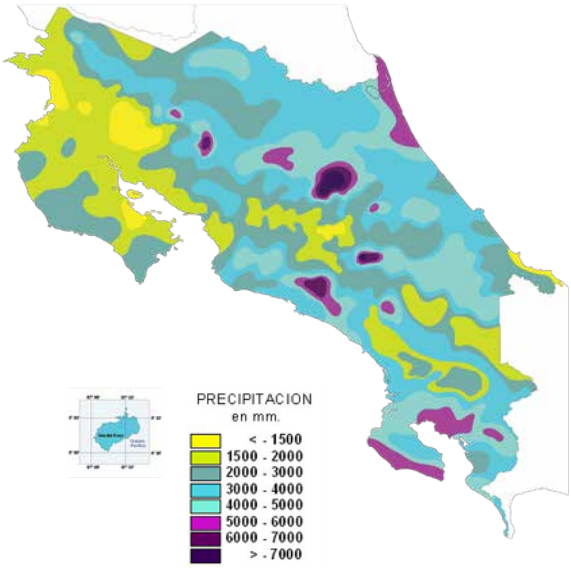

Figure 3.7 Annual rainfall in Costa Rica.
© IMN, 2005

3.2.7 Salinisation of surface water and groundwater

Climate changes are forcing the country to develop strategies based on each province's needs and take into account the lack of water in coming years (MINAET/BID, 2008; Costa Rica-AyA, 2016). Coastal communities should be aware that the rising sea-level will impoverish water quantity and quality due to salinization (Costa Rica-AyA, 2016).

In the northern Pacific region of Costa Rica, water deficiencies are a common problem caused by the overexploitation of water reservoirs. Likewise, the intensive extraction of water by ASADAS is leading to the salinisation of the primary sources of water of the country (Ballestero Vargas, 2013; Orias-Arguedas, 2015; Vargas Bolaños, 2019). To solve this problem and fulfil the water demands, in 2016, hoteliers installed the first desalination plant in the hotel Reserva Conchal, in Guanacaste, with the capacity to extract 23 L per second of seawater and turn it for human consumption through a reverse osmosis system (Chavarría, 2016).

According to Vargas Bolaños (2019), the water suppliers, such as AyA, must evaluate and determine the best hydrogeological conditions to establish new water reservoirs without attempting the existing ones or causing any problem populations since access to these plants is still not feasible. Additionally, the AyA and SENARA should map all the wells to determine which are illegal, which are overexploited, which are vulnerable to saline intrusion, or contaminated by chemicals or bacteria (Orias-Arguedas, 2015).

3.2.8 Change and loss of wetlands

Wetlands are an essential ecosystem in Costa Rica, covering 7% of the territory (Costa Rica-MINAE, 2017). According to the National Wetland Policy 2017-2030, Costa Rica counts 359 wetlands, of which 30% are protected, and 12 of them are considered as Ramsar sites. Most of the wetlands are located on the Pacific coast, mainly in Golfo de Nicoya (north) and Golfo Dulce (south) (Benavides-Varela, Samper-Villarreal, and Cortés, 2016). The biggest and one of the country's most important wetlands is the National Wetland Térraba-Sierpe (HNTS), which generates USD 1,130 per day from shellfish extraction and tourism (Costa Rica-MINAE, 2017). However, this wetland and many others around the country are threatened by human and natural hazards.

Agriculture, overexploitation, logging for timber, among others, are the most common human threats to wetlands or associated ecosystems (Benavides-Varela, Samper-Villarreal, and Cortés, 2016). Although all coastal wetlands in Costa Rica are no-take areas, the vegetation coverage loss is also linked to tourism's urban expansion. For instance, the mangrove associated with Playa Panamá (northern Pacific coast) started to disrupt as the urban expansion started in 2003. The beach is currently surrounded by roads, infrastructures, and second residences (Benavides-Varela, Samper-Villarreal, and Cortés, 2016).

Other impacts, such as SLR, sedimentation, and erosion, also have an impact on human populations and mangroves (Valverde *et al.*, 2016). For instance, the HNTS is known for its erosion processes and its human development along the beachfront that has caused the disappearance of vegetation and other changes in the natural coverage (Silva Benavides *et al.*, 2015). According to Silva Benavides *et al.* (2015), between 1948 and 2011, Isla Coco in HNTS lost 59% of mangrove coverage due to erosion, and Isla Zacate lost 46% of terrain (Figure 3.8).

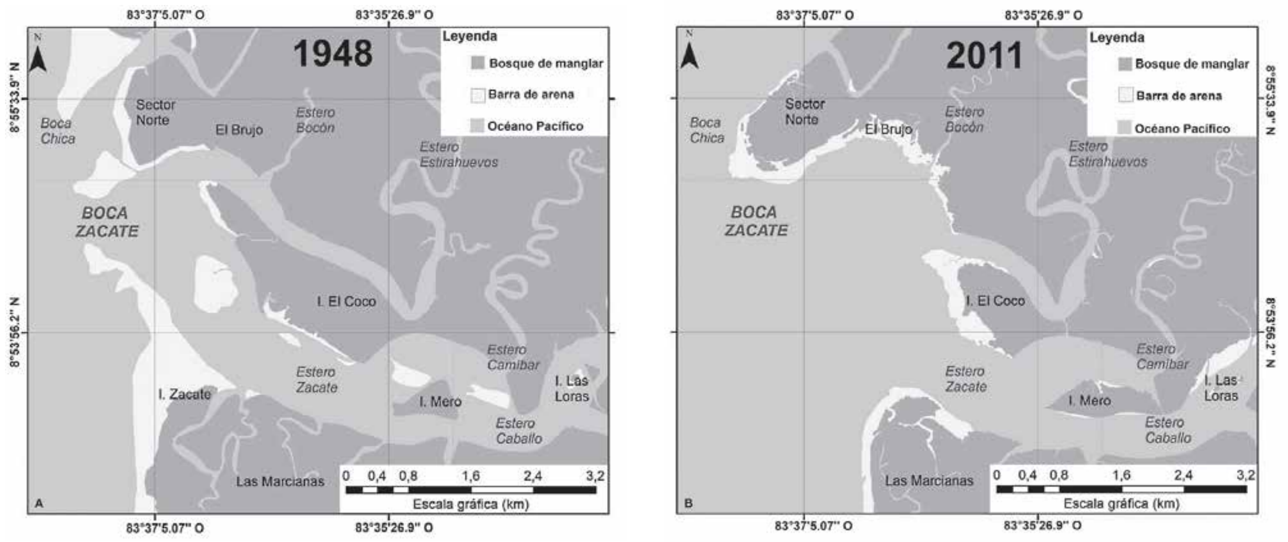

Figure 3.8 Geomorphology variations due to erosion processes in-between 1948 and 2011 in Boca Zacate in HNTS.
Source: Silva Benavides *et al.* (2015)

Additionally, the increase of sea surface temperature and its thermal expansion is exposing the mangroves to more extended periods of floods and salinity concentrations. Consequently, some species that tolerate higher salinity concentrations are pushing away the least tolerant ones and influencing the geomorphology and composition of the landscape (Valverde *et al.*, 2016).

Sedimentation is another changing component affecting the geomorphology of the HNTS (BIOMARCC/SINAC/GIZ, 2013). According to Silva Benavides *et al.* (2015), the accumulation of sediments brought by the Térraba-Grande river is hampering the aerobic processes and the capacity to accumulate nutrients. Therefore, the vegetation is dying, turning the landscape into a dismal place. In parallel, the ongoing erosion processes are also promoting the loss of coverage and the shoreline to retreat. Silva Benavides *et al.* (2015) therefore recommended conservation actions within an integrated coastal zone management plan to protect the HNTS. Otherwise, extreme events will impact the local population, the habitats and the ecosystem services provided by the wetland.

3.2.9 Changes in seawater quality and marine pollution

The changes in seawater quality can be triggered by isolated events or by the continuous ecosystem's degradation. Therefore, it is essential to continually evaluate the water quality of the coastal areas, especially in countries like Costa Rica, where its 400 beaches represent an important touristic asset (Badilla-Aguilar and Mora-Alvarado, 2019a; Mora-Alvarado, Vega-Molina and González-Fernández, 2019). Since the 2000s, Costa Rican beaches are evaluated with the Health Risk Index (IRS), a tool that evaluates the potential risk of waters to become contaminated by land-based pollution (Mora-Alvarado, Vega-Molina and González-Fernández, 2019), and by the "Regulations to Evaluate and Classify the Quality of Water Bodies of Superficial Waters – N°33903-MINAE-S" (MINAE-S, 2007). Both tools have helped to rethink the coastal zone management process in Costa Rica. Nevertheless, some locations do not consider them as part of their coastal zone management and suffer the consequences of being provided by non-drinkable and non-usable water.

A study conducted by Mora-Alvarado, Vega-Molina, and González-Fernández (2019) on both coasts revealed that 157 out of 184 beaches present a "low", "very low" or "null" risk to get contaminated by faecal coliforms from land-based sources. Moreover, 134 beaches were categorized as AA, which corresponds to excellent water quality. Badilla-Aguilar and Mora-Alvarado, (2019a) studied the 123 littoral water bodies (river mouths, streams, and estuaries) from 84 beaches of both coasts. They claimed that 55% of the tested beaches were classified as Class 2 (20-1000 CFU/100 ml), meaning that the water can be used to supply (after conventional water treatment) aquaculture, crop irrigation, and other uses (MINAE-S, 2007). The creation of voluntary schemes, such as the Ecological Blue Flag Program, has shown positive results to keep good water quality on some of the Costa Rican beaches. However, it is essential to recall that 45% of the beaches do not comply with these standards. Studies have found metals in coastal molluscs (Vargas *et al.*, 2015, 2018), faecal bacteria in the sand (Badilla-Aguilar and Mora-Alvarado, 2019b) and molluscs (Vega Corrales and Marín-

Vindas, 2014), and fuel in coastal waters (Acuña-González *et al.*, 2004; Vargas *et al.*, 2016). As such, there is still a long way to go to secure the quality of water in Costa Rican coastal areas.

Marine pollution is a transboundary issue that has drastic and negative consequences (Alpizar *et al.*, 2020). Unfortunately, Costa Rica has been part of the problem although it is on its way to become part of the solution. In 2014, the number of solid waste produced per day in Costa Rica was 4,000 tons, of which 25% finished in the beaches and rivers of the country (Costa Rica-MINSA, 2016). Every day, Costa Rica discards 550 tons of plastic waste, in which more than half are carried to the Pacific beaches through the rivers Tempisque and Tárcoles (Zamora Bolaños, 2019), and 110 tons of single-use plastic remain in the environment (MINSA/MINAE/PNUD, 2017). This problem is becoming more conspicuous in the locations with higher human population density. A clear example of this situation is present in the coastal districts such as Sardinal, located in the northern Pacific coast of Costa Rica. According to Saravia-Arguedas *et al.* (2019), the waste production in Sardinal is 3,342 tons annually, produced by approximately 14,900 inhabitants within an area of 210.4 km^2. Unfortunately, not all the solid waste is treated and managed correctly. There is a high chance that such waste ends up in the beaches and kills marine and terrestrial mammals, birds, fish, or other organisms that get entangled or ingest microplastics and bigger pieces of plastic as well (MINSA/MINAE/PNUD, 2017).

Recently, Costa Rica started to make efforts to determine microplastics in marine and coastal areas (Blanco, 2019). Preliminary results of a study started in 2019 by the University of Costa Rica recorded microplastics in 11 beaches, five from the Caribbean, and six from the Pacific. In a single beach, 68% of the microplastics found were Styrofoam (Blanco, 2019). Another study conducted by Bermúdez-Guzmán *et al.*, (2020) studied the digestive content of 30 individuals of a type of sardine – *Ophistomena sp.* – collected from the Pacific coast of Costa Rica. They found 1,101 pieces of microplastics in the 30 individuals sampled, and the pieces were classified 20.5% as particles and 79.5% as fibres (Figure 3.9).

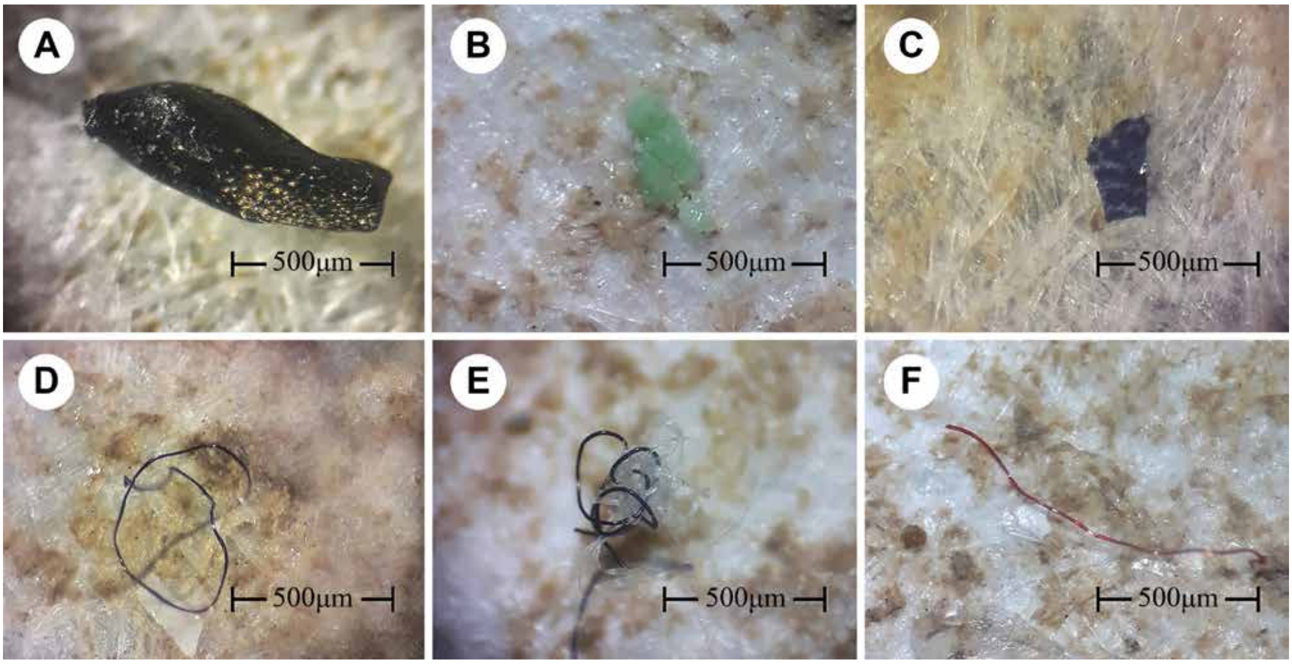

Figure 3.9 Microplastics found in the digestive tract of *Opisthonema sp*. Images A, B, C are particles, whereas images D, E, F are fibres.
Source: Bermudez-Guzmán *et al.* (2020)

Another study carried by Johnson *et al.* (2018) in the Areas Beyond National Jurisdiction (ABNJ), specifically in the Costa Rican Thermal Dome, collected microplastics by subsampling 13 out of 14 zooplankton found in trawls samples. The authors recorded 250 microplastics found in all samples and suggested that most come from land-based pollution, ending up being carried by rivers to the ocean (Johnson *et al.*, 2018).

All studies highlight the importance of further research to verify how microplastics affect the trophic levels and humans that consume marine organisms contaminated with them. Johnson *et al.* (2018) recall the need to acknowledge land-sea interactions and their impact on marine pollution through education, corporate responsibilities, and transboundary actions.

There is an urgency to enforce Law No. 8839 on Integrated Waste Management (Asamblea Legislativa, 2010) and avoid that more waste, which can be recycled, ends at the beaches or the ABNJ. In addition, Costa Rica must follow up the agenda to tackle marine debris, which include the compliance of the National Plan for Integrated Waste Management 2016-2021, as well as the compliance of the Integrated Waste Management National Policy 2010-2021 and the National Strategy for the replacement of single-use plastic for compostable and renewable alternatives 2017-2021. The latter aims to promote voluntary and collective action to reduce the presence of single-use plastic in terrestrial and marine spaces and replace them for renewable and compostable materials based on the international Regulation ASTM 7081-05, which establishes that all materials must disintegrate and biodegrade while being exposed to marine environments, without threatening or damaging them (MINSA/MINAE/PNUD, 2017).

3.2.10 Impacts on biodiversity

There is no secret that the marine species' distribution and abundance are changing (Ramírez, 2014). Climate change causes a temperature increase in the ocean that is associated with various physical and chemical changes, such as ocean acidification, oxygen concentration, salinity and chlorophyll variations, ocean circulation disruptions, among others, are becoming more conspicuous (Lizano Rodríguez, 2019). The ocean primary productivity is no longer the same; tropical and subtropical species are migrating to other latitudes causing the economy, that is dependent on these commercial and other interest species, to become more vulnerable (Ramírez, 2014; Ross Salazar *et al.*, 2018).

According to MINAET/WWF/EcoAdapt/CI/IFAW/TNC/WDCS/IAI/PROMAR (2009), all the changes mentioned above will affect the marine ecosystems' biological components (Figure 3.10), jeopardising the provision of some essential goods.

Invasive alien species are also changing the biological composition and function of the marine ecosystems and their services (Sandel *et al.*, 2015; Nagy *et al.*, 2019). For instance, on the southern Caribbean coast of Costa Rica (Limón province), fishers have noticed a drastic reduction in the catches of red snappers and groupers since the invasion of the Indo-Pacific lionfish *Pterois volitans/miles* in 2011, impacting negatively not only the ecosystem but also their economic livelihoods (Sandel *et al.*, 2015). It could be considered as one of the worst biological circumstances that could ever happen in the country (Molina Ureña cited by Umaña, 2015). Nowadays, the consumption of lionfish has been promoted as a control mechanism, providing a very nutritional source of protein and, at the same time, reducing the pressure on the fisheries resources (Morris *et al.*, 2011; Sandel *et al.*, 2015). Additionally, communities on the southern Caribbean coast of Costa Rica are also promoting fish tournaments to control this invasive species (Umaña, 2015).

Plankton

- A reduction in the upwellings will be reflected on the primary productivity.
- Changes in the reproductive cycles, species composition, latitudinal and depth distribution, adaptation to temperatures and pH changes, more algal blooms.

Fish and fisheries

- Changes in species composition and reproduction due to temperature changes. Latitudinal migrations, increase in invasive species, spread of diseases, others.

Top predators – sharks

- More affected by indirect effects. Reduction of prey, habitat loss for nursery and feeding areas due to sea-level rise, storms, others.

Sea turtles

- Nests: increased temperature will affect the sex ratio of the surviving hatchings. Loss of nesting beaches due to sea-level rise.
- Sea: changes in temperatures and current patterns may influence the distribution and migration. More diseases due to chemical and temperature changes; food scarcity.

Coral reefs

- Changing temperatures, pH, nutrients, sediments by run off will stress and bleach more the coral.
- Weakening of the coral structure. More macro algaes suppressing the coral growth.

Cetaceans

- Affected by changes in food supply and reproduction.

Figure 3.10 Biological and ecological implications due to climate change.
Source: Natalia Solís-Miranda based on MINAET/WWF/EcoAdapt/CI/IFAW/TNC/WDCS/IAI/PROMAR (2009)

Human pressures caused in the environment can be both visible and quantifiable. Sánchez-Noguera, Jiménez, and Cortés (2018) identified that in Bahía Culebra (northern Pacific coast) coastal pollution, the coral reefs, and the nutrient concentration showed the main changes in the "socio-ecosystem". The authors determined that the tourism industry is causing severe problems in the coral reefs, and it is changing the concentrations of nutrients the runs off to the sea, causing coral bleaching and harmful algal blooms. Gulf courses, agriculture activities, presence of marinas, and lousy sewage water treatment accelerate the detriment of the marine biological component. They claim the need to enforce a program of responsible water consumption, environmental education, and the execution of strategies that enable stop the pollution process and stop degrading the natural resources- the area's primary income. Otherwise, this area's attraction will be lost, and tourism will diminish (Sánchez-Noguera, Jiménez, and Cortés, 2018).

3.2.11 Impact of human development on coastal communities

In 1977, Costa Rica endorsed the Law of Maritime Terrestrial Zone (ZMT) – Law No. 6043 – establishing that all space in-between the high tide line and 200 m inland can be either for public use or restricted use. Both uses are fundamental for coastal livelihoods, recreational activities, and access to marine resources (Picón, Hernández, and Bravo, 2014). The extraction of flora and fauna, logging, or construction of any kind of infrastructure is forbidden, unless a concession is provided by the ICT (Asamblea Legislativa, 1977). Over the past 30 years, urban sprawling and infrastructure development started to increase due to the lack of government control, hampering the enforcement of the ZMT Law (Honey, Vargas, and Durham, 2010; Irazábal, 2018) (Figure 3.11). Therefore, depletion of marine resources, the degradation of coastal and marine habitats, pollution of aquifers, unappropriated solid waste management, and other problems started to unveil the consequences of mass tourism (Moreno Díaz, 2015; Irazábal, 2018; Samper-Villarreal, Mora-Rodríguez, and Morales-Ramírez, 2020). For instance, the beaches along the Pacific coast have been polluted directly by hotels, second residences, and businesses that illegally discharge wastewater directly to the rivers and streams that flow to the ocean. Inadequate infrastructure for wastewater treatment is present in almost every development infrastructure, resulting in significant water pollution problems from septic tanks leakage or from their limited capacity (Honey, Vargas and Durham, 2010). Developers show a careless attitude about wastewater treatment and are not committed to protecting the environment. It should be noted that the previous governments were also responsible for these issues since they disrespected the existing laws and regulations, never denounced irregularities or stopped giving concessions, nor reviewed the coastal regulatory plans correctly (Barrantes Reynolds, 2013).

Unfortunately, coastal populations are fighting for space, with social unrest occurring where the business sector controls the access to land (Picón, Hernández, and Bravo, 2014; Moreno Díaz, 2015), forcing the locals to sell their properties and move away from the ocean, or limiting their access to the beaches (Honey, Vargas and Durham, 2010). Additionally, coastal mass tourism creates jobs, though, mainly in construction, informal jobs, and giving back low economic returns to the local community, which does not help poverty alleviation (Barrantes Reynolds, 2013; Irazábal, 2018). However, communities such as Osa and Punta Islita are genuinely benefitting from ecotourism and committed to enhancing their communities' sustainable development. Hoteliers and small businesses prioritise to attract tourists interested in engaging with the local community and concerned with social, economic, and environmental matters (Irazábal, 2018).

Climate change is also affecting the social, economic, and cultural aspects of the coastal populations. Fishers are no longer fishing the same number of fish they used to; thus, their incomes are limited. Tourism is also becoming more affected due to coastal erosion, storm surge, mud sedimentation, but mostly due to the extension of the dry season that is increasing the water demand by the population and the touristic amenities (golf courses, pools, among others) (Honey, Vargas and Durham, 2010; Picón, Hernández and Bravo, 2014; Moreno Díaz, 2015).

According to USAID/CATIE/TNC (2012), in areas dependent on tourism, climate change will diminish the environmental assets enormously and severely damage the infrastructure (Figure 3.12).

Figure 3.11 An example of the lack of enforcement of the ZMT Law by the coastal tourism developers at Tamarindo, Guanacaste.
© Gustavo Montero

OBJECT	CLIMATE CHANGE EFFECT	POSSIBLE DAMAGES CAUSED BY CLIMATE CHANGE
Tourist attractions	Increase in SLR, storm intensity, increase in the SST	Direct impact on coral reefs, schools of fish, beaches, and tourist attractions
Tourist infrastructure	SLR, increase in storm intensity	Damages in the infrastructure, increase in cost maintenance
Coastal communities, communication, transport, ports, marinas, docks	SLR, increase in storm intensity	Damages in the infrastructure, increase in maintenance

Figure 3.12 Impacts of climate change in the tourism sector.
Source: Natalia Solís-Miranda based on USAID/CATIE/TNC (2012)

3.3 Coastal risk management in Costa Rica

Coastal risk management is assessed differently according to the needs and realities of each stakeholder. For this chapter, representatives from the community, authorities and academia were interviewed. Figure 3.13 summarizes the main ideas discussed.

All stakeholders interviewed agreed that the phenomena described previously are getting stronger in Costa Rica. For instance, the maritime transportation sector acknowledges that the maritime climate has changed drastically, including meteorological and oceanographic dynamics. Nowadays, stronger extreme storms take place more often, affecting human development, infrastructure, and logistics, causing significant economic losses. There are times that the port operations must stop entirely for hours or days to avoid accidents (*i.e.,* oil spills, damages on the port infrastructure or ships, among others). At the same time, the maritime transportation sector is complaining about how difficult it is to enter the Caldera port, opening the discussion to a possible expansion of that infrastructure. Such intervention is likely to increase other problems like sedimentation as the port's currents would be diminished. At present, the Port Authority is spending millions of dollars on bathymetric studies every trimester (to evaluate where to dredge, and then, once the dredging is complete, to monitor the work done). The dredged sediments are deposited five kilometres away from the coast, in an area with environmental liability approved by SETENA. Nevertheless, there is the will to use these sediments on land reclamation in areas affected by the construction of that port.

In the case of coastal communities, especially in small islands, their challenge is to fish under extreme weather conditions. Their boats are small and unstable, and they do not want to risk themselves. Hence, they must stop fishing during storms. In isolated rural areas, many families that rely on fisheries struggle to the extent of hunger. Moreover, fishing communities acknowledge that the abundance and the variety of species is no longer the same; thus, they must introduce other species to their diet and sales. Another constraint is the constant struggling they suffered against commercial fisheries. The latter has sophisticated equipment, or they are using forbidden gears and not respecting the closure periods. These communities also recognise mangrove abundance are diminishing rapidly and it has mainly occurred during last decades. Despite the restoration efforts communities are doing, the increasing number of boats is accelerating the diminishing of these ecosystems. According to one representative of the community of Isla Venado, boaters are always traveling at very high speeds, battering the plantules and removing them from the soil. This situation is also hampering their process to create alternative income sources, such as tourism. In fact, in Puntarenas the INCOP is constantly proposing and trying to create new jobs for the local fishers in Puntarenas. For instance, they created a project called "Puertos Verdes", a circular economy project where fishers do beach clean-ups, classify, and sell the valuable waste, and repair infrastructure to attract tourism. The INCOP is also helping the community to build capacities on entrepreneurship and diversify their incomes. Community members constantly remark that they need more capacity building to diversify their incomes and stop relying on fishing only. Currently, they are growing vegetables for sale or to exchange with other members of the community, becoming the best alternative when they cannot fish. However, not all people are doing this, and some members prefer to overexploit the fish resources instead.

Other hazards to which coastal communities are exposed are flooding and coastal erosion. Experts say that models used to project future scenarios indicate that the sea-level will rise faster in the next 100 years and consequently, floods will become more frequent. However, if prevention and mitigation actions are considered, the consequences of this hazard could get delayed.

Human interventions, mainly urban expansion, are accelerating the erosion process in coastal areas. For experts of the academia and the CNE, "it is unfortunate that the coastal transformations are proceeding with government permission". They expressed that it urges to update and truly enforce the coastal regulatory plans. They also claim that the updated plans "must include climate change variables or at least the sea-level variable"; and must consider local risk factors according and incorporate risk management measures in the local development plans. The academia knows that due to coastal erosion processes (natural or human-induced), beach morphologies have changed. Therefore, "the 200 m ZMT established by law at that time no longer exists", and the landmarks deployed more than 40 years ago have been replaced by constructions or removed.

The municipalities and the ICT have different interests, hence priorities. The representative of the CNE expressed his concern about the authorities' denial and the fact they are not accepting that coastal areas, mainly those in Puntarenas, are disappearing. Moreover, the interviewees expressed that the lack of articulation among institutions is hampering the efforts to address climate change in coastal areas, and one effective way to articulate efforts is through forums or round tables where people share their experiences. Alliances among communities have blossom during such meetings and it has demonstrated that communication is crucial to tackle climate change problems in coastal and landlocked areas and that all institutions must understand each other's competencies. Otherwise, the efforts will address other non-relevant issues or may be duplicated.

Hazards	Current Measures	Needs	Constraints
• Coastal floods • Erosion • Sea-level rise • Storms • Rip tides • Maritime climate • Biodiversity changes-overexploitation • Droughts • Marine litter • Urban sprawling	• Dredging • Investment in infrastructure • Beach clean-ups • Mangrove and rivers reforestation • Education and capacity building • Relocation of public services and main roads • Sharing experiences among stakeholders	• Community empowerment • Updated plans • Incorporate climate change variables in plans • More studies • Protocols • Data with quality • Monitoring tools • Human development • Public-private partnerships	• Law enforcement • Denial • Lack of articulation among institutions • Political will

Figure 3.13 Main ideas discussed with stakeholders from the community, academia and authorities.
Source: Natalia Solís-Miranda

Creating alliances can help to extend the quality and quantity of data available to plan with criteria and in a more effective way. The academia is doing their best with the tools they have. However, they insist that they must have the best data quality to be able to help the municipalities and other institutions. A way to ensure data quality is by creating more private-public partnerships. Most of the time, the private sector's data is more robust and has better quality than the public one, and over the years, it has been proven that these alliances work (*e.g.,* SINAMOT-IOC/UNESCO).

Another issue expressed is the need for more capacity building and empowerment. It should be noted that this must be a constant work to be done every year because the generations change, and people migrate or die. Investing in education (*i.e.,* talks, forums, training, and others) is perceived as the best way to prevent coastal risks, and it is less expensive than mitigation measures.

Costa Rica needs to stop undermining the coastal communities and, instead, give them tools to enable their involvement and become empowered. Local communities are the best ally to enhance coastal risk management and describe better the vulnerabilities based on their knowledge and daily life experiences (Mora Rodríguez, 2014).

Since 1949, with the creation of the National Constitution – Article 50 – Costa Rica started to focus on environmental protection and obey the constitutional statement that everybody has the right to enjoy a healthy and ecologically sustainable environment. Its inhabitants, institutions, and the State are committed to conserving it and working for the common wellbeing (Costa Rica, 1949). However, for a long time, the political agenda focused on land issues, and until the second half of the 20th century, the country did not start to address coastal-marine issues and risks.

3.3.1 Addressing risks

Costa Rica began paying attention to risk management after the Irazú Volcano's eruption in 1963 (CNE, 2020b). Years after the eruption, a series of laws and decrees emerged to create the CNE, and the current National Emergency Law No. 8488, endorsed in 2006, comprises the risk management on land and sea (Figure 3.14). Since then, the CNE has been obliged to design and execute the National Plan of Risk Management (PNGR), in which the State, the private sector, and the civil society apply the Law to reduce the vulnerability of Costa Ricans. When emergencies occur, the CNE acts with the support of different coordination branches or committees at different scales (regional, municipal, and communal committees).

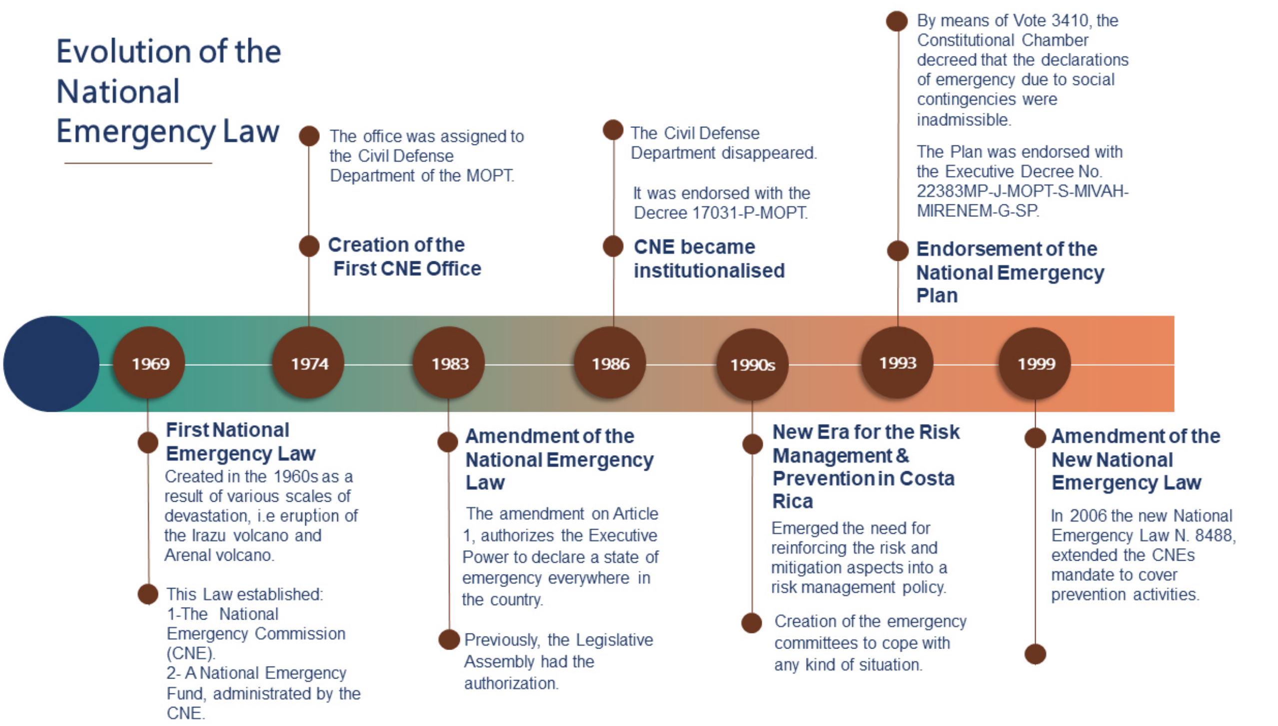

Figure 3.14 Evolution of the Costa Rican National Emergency Law and the National Emergency Commission.
Source: Natalia Solís-Miranda based on CNE (2020b)

The CNE recognizes the constant dynamics and exposure coastal areas suffer and the impacts that may affect the populations. Therefore, the CNE is regularly consulting the multidisciplinary Technical/Sector Advisory Committees (CATS) to support the decision-making with technical studies (CNE, 2020c; González, 2013).

Costa Rica was the first country in Central America to pass a law on coastal zone management (Picón, Hernández y Bravo, 2014), with the Law ZMT No. 6043. The ZMT Law states that part of the national patrimony belonging to the State, is inalienable and imprescriptible (Asamblea Legislativa, 1977). It comprises a 200 m strip along the coast, which is divided into two regimes: The Public Zone, comprising the first 50 m inland from the high tide line; and the Restricted Zone, comprising the remaining 150 m, where only infrastructures and construction works are allowed by the competent authority or institution: for instance, ICT or municipalities. (Legislative Assembly, 1977). The Public Zone is dedicated to public use and free transit of people and no development is allowed, and the Restricted Zone is where concessions can be given, with special exceptions indicated in the ZMT Law. Unfortunately, this zone is very close to the Public Zone, which favours the invasion of these spaces by tourist promoters and exposes visitors and local inhabitants to coastal hazards.

The ZMT Law, the Organic Law of the Environment No. 7554 (established in 1995), and the Urban Planning Law No. 4240 (established in 1999) are existing laws that help generate the Regulatory Plans in coastal areas. It was not until 2008 that Costa Rica created the National Strategy for the Integrated Management of Marine and Coastal Resources, and in 2013, the country adopted the National Marine Policy 2013-2018; two dynamic and integrated approaches addressing the relationship between humans with the marine environment by following an ecosystem-based management (Barragán Muñoz, 2020). Nowadays, ICZM is the best approach to prevent and adapt to the coastal hazards resulting from climate change, and to sustainable use the marine resources while articulating actions and communication amongst the community, the local government, and the public institutions (Mora Rodríguez, 2014; Barragán Muñoz, 2020).

3.3.2 Tools that support coastal zone management in Costa Rica

According to Samper-Villarreal, Mora-Rodríguez and Morales-Ramírez (2020), Costa Rica has advanced in developing tools to successfully build ICZM. The authors also support that the country has built institutional capacity and strengthened the regional and national governance frameworks that have also enhanced the articulation among institutions. However, they claim that success can only be reached with further political will and financial support. Likewise, there must exist a commitment to create and implement an ICZM that can help alleviate the pressures on the coastal and marine habitats and resources, and not limit the activities that support the coastal livelihoods. Costa Rica counts with policies, strategies, and plans to promote research, knowledge, and enhancement of coastal populations' wellbeing and safeguard marine and coastal resources (Figure 3.15 and Table 3.2).

Figure 3.15 Summary of instruments relevant to coastal zone management applied in the last two decades in Costa Rica. *Source:* Natalia Solís-Miranda

Table 3.2 Summary of the policies, strategies, and action plans under implementation.

Category	Policy	Strategy	Plans
Risk Management	National Politics of Risk Management 2016-2030		National Plan of Risk Management 2015-2030 Sendai Framework for Disaster Risk Reduction 2015-2030**
Coastal-Marine Ecosystems and Biodiversity	National Policy of the Sea 2013-2028 National Wetland Policy 2017-2030 National Biodiversity Policy 2015-2030	Strategy for the Adaptation of Costa Rica's Biodiversity Sector to Climate Change 2016-2025 Costa Rica's National Strategy on Marine Turtles Conservation and Protection (2018) Regional Strategy for the conservation and Management of Golfo de Nicoya Mangroves 2019-2030 Convention on Biological Diversity-Aichi Targets 2020**	Sectoral Marine Agenda 2016-2021
Territory Planning	National Territory Management Policy 2012-2040		Land-use Planning National Plan 2014-2020
Climate Change	National Policy on Adaptation to Climate Change 2018-2030	National Strategy on Climate Change 2009-2021 Intended Nationally Determined Contribution 2015-2030	Action Plan for the National Strategy on Climate Change National Decarbonization Plan 2018-2050 UNFCCC Paris Agreement COP21 2015**
Waste Management	Integrated Waste Management National Policy 2010-2021	Integrated Waste Management National Policy 2010-2021 and the National Strategy for the Replacement of Single-Use Plastic for Compostable and Renewable Alternatives 2017-2021	National Plan for Integrated Waste Management 2016-2021
Water Management	National Drinking Water Policy of Costa Rica 2017-2030 National Wastewater Treatment Policy 2016-2045	Integrated Water Management Strategy	Water Agenda 2013-2030
Human Development	Policy for the Costa Rican Territory Rural Development 2015-2030		Rural Territory Development National Plan 2017-2022 National Development Plan 2019-2022 Costa Rica's National Tourism Development Plan 2017-2021 2030 Agenda for Sustainable Development**

*** International agreements*
Source: Natalia Solís-Miranda

3.3.3 Adaptation pathways and existing portfolios

Costa Rica must consider and implement the climate change measures included in the above-mentioned policies, strategies, and plans. Likewise, the country must reorganize its investments, projects, and others to safeguard its assets and avoid cost increases by mitigating damage. It is easier and more affordable to invest in prevention measures than mitigation.

Adaptation pathways must include and prioritise the environment, socio-economic realities, as well as the limitations in governance structures (UNESCO/IOC, 2020). Costa Rica still does not have an adaptation plan; therefore, the following is a summary of the proposals for Adaptation Pathways (AP) and Intervention Portfolios (IP) that can alleviate the current constraints in coastal areas, inspired by the National Adaptation Plans of the United Nations Framework Convention on Climate Change (UNFCCC).

Adaptation Pathways

- **AP1 – Prevention and risk management through the creation, implementation, and adaptation of Coastal Regulatory Plans**

Coastal communities are at the forefront of risks such as extreme storms, coastal erosion, SLR, coastal floods, others that are becoming more frequent and more aggressive. They are also the first line to tackle disasters, and one way to prevent these issues is by implementing and evaluating Risk Plans and Coastal Regulatory Plans. Currently, 155 Coastal Regulatory Plans have been submitted in Costa Rica, though they have never been implemented nor evaluated. It is worth noting that the 1977 ZMT Law was not supported by a proper document for institutional consultation. The "Manual for the elaboration of Coastal Regulatory Plans in the Maritime-Terrestrial Zone" was created only in 2016. Additionally, the integration of climate change variables, namely SLR, is still missing when creating, updating, or adapting the Coastal Regulatory Plan. Likewise, it is crucial to promote an ecosystem-based approach and promote the community's participation in the risk management and in the elaboration of Coastal Regulatory Plans.

- **AP2 – Strengthen the protection, management, and restoration of coastal and marine resources and ecosystems with the support of nature-based solutions to address climate change effectively and adaptively**

Costa Rica is recognised worldwide for its commitments to protect the environment. However, these commitments must be ratified, strengthened, and implemented to ensure that its inhabitants are provided with healthy, productive, and resilient ecosystems. To ensure it overtime, Costa Rica must apply nature-based solutions that will help to maintain or improve human wellbeing, guaranteeing the benefits of ecosystem services. It is essential to recognise that incorporating an ecosystem approach provides an opportunity to effectively utilise nature to help solve some of the main societal challenges (*i.e.,* climate change, food security, risk reduction of natural hazards).

- **AP3 – Create more and strengthen public-private partnerships to advance the coastal and climate resilience agenda**

Public-private partnerships are an effective means of developing actions, creating new proposals, and exchanging information and experiences that can facilitate, improve, and upscale resilient practices to advance the climate action agenda. By having two components (public and private sector) with different structures, perspectives, strengths, and ways of addressing problems, these strategies facilitate agreements, promote commitment towards action, and enrich the implementation of measure. However, it is vital to consider the shared responsibilities and the differentiated capabilities of each party involved.

- **AP4 – Create a climate-resilient economy**

Excessive consumption patterns and overexploitation of resources are part of the climate crises. COVID-19 showed that the global economy is fragile and not at all resilient in the face of a pandemic. "Business as usual" is no longer an option for maintaining the economy and human well-being. Humankind needs to move from an extractive economy to a circular economy (IOC/UNESCO, 2020), where nature and humans coexist in a balanced way. This can be achieved by understanding the economic value of existing ecosystem services and by showing to the people that living species are more profitable than extinct species. It is also essential to train coastal populations, mainly artisanal fishers, empowering them to know the value of their efforts, and that these efforts are adequately rewarded.

Implementing existing ideas in plans that reward people for protecting the coastal and marine ecosystem (*e.g.,* payment for coastal and marine environmental services) can also create a resilient economy. Building capacity in other activities (*e.g.,* ecotourism, and small-scale mariculture) is also vital so that the coastal community can have options and vary their livelihoods.

- **AP5 – Capacity building and open access knowledge to strengthen the dissemination of climate scenario information**

To adapt to the adversities of climate change, it is important to generate information, to have it centralised and accessible so that it can support decision-making at all levels of society. It is crucial to manage knowledge and adapt it with a simple language to ensure its effective dissemination and communication. It is also crucial to strengthen the capacity of institutions and the educational system so that there is a better understanding of climate scenarios, their effects, and communities can be prepared and become resilient (Gobierno de Costa Rica, 2018).

- **AP6 – Promote research and surveillance programs to protect and monitor aquatic and coastal marine resources to safeguard water and food security**

Prevention is key to face climate change. This can be achieved through the creation, investment, and strengthening of research and monitoring programs. Based on research and constant monitoring, it is possible to elaborate scenarios that can contribute to innovative adaptation plans. It should be noted that monitoring is also essential to assess the cumulative environmental impacts that can affect water and food security and threaten human wellbeing.

- **AP7 – Advance the implementation of the legal and political agenda for climate adaptation**

Costa Rica must fulfil both its national and international environmental commitments using the existing tools. However, there is a need to harmonise these tools (namely their timeframes and objectives) and advance more effectively in implementing climate change-related strategies. It is essential to consider the different sectors that may be affected and reach a consensus for a common benefit through dialogue. It is also important to create adequate spaces for political will to promote prevention and adaptation measures.

- **AP8 – Strengthen the infrastructure to safeguard socio-environmental health and human development**

Monitoring and evaluation can determine whether existing infrastructure needs to be modified or strengthened so that it does not threaten public health and safety. Coastal municipalities need to create their regulatory plans based on existing needs, but they must consider climate change variables. Similarly, a type of coastal building code needs to be developed to counteract material damage and avoid injury or death when extreme events occur.

Intervention Portfolios

IP1 – Waste Management

- Marine Litter National Action Plan supports the National Waste Management Plan 2016-2021. Nine months in 2020-2021. Leading Institution(s) – MINAE
- National Strategy for the Replacement of Single-Use Plastics with Renewable and Compostable Alternatives 2016-2021. Leading Institution(s) – PNUD
- Prevention and Reduction of Marine and Coastal Pollution in the Pacific and Caribbean of Costa Rica recognises and analyses degradation agents in marine ecosystems to prevent and reduce pollution in the Pacific and Caribbean coastal marine area of Costa Rica. Subprograms: Recycling programs/ Improving the quality of mangrove ecosystems/Capacity building on climate change helps create proposals in adaptation and mitigation. Leading Institution(s) – INCOPESCA

IP2 – Water Management

- Adapta2+ offers opportunities for proper water resources management, such as managing and protecting watersheds in vulnerable areas and recovering and reforesting areas on the banks of rivers and streams, others. Leading Institution(s) – Fundecooperación para el Desarrollo Sostenible-MINAE
- Strengthening Communal Aqueducts to Cope with the Risks of Climate Change aims to strengthen the infrastructure and operational capacity of more than 300 ASADAS in the cantons of Liberia, La Cruz, Cañas, Carrillo, Santa Cruz, Nicoya, and Hojancha in the Chorotega region and the cantons of Los Chile, Upala, and Guatuso in the northern territory, by incorporating the adoption of ecosystem-based adaptation measures. Leading Institution(s) – PNUD
- Phase II Technical Assistance for Groundwater Monitoring responds to the urgency to mitigate and

provide solutions to the effects of drought and climate change, allowing adequate management and analysis of water resources at the national level, to obtain technical knowledge and scientific certainty availability behaviour. Leading Institution(s) – PNUD-MINAE

IP3 – Coastal-Marine Ecosystems and Biodiversity

- Blue Growth Program seeks to increase Costa Rica's export fisheries' competitiveness by creating systems for designation of origin. Two traceability systems for the shrimp and snapper fisheries enabling full control throughout the chain, thus meeting the international standards enforced by our main trading partners. Leading Institution(s) – CRUSA
- Ecological Monitoring Protocol for Large Pelagic Species seeks to measure the effectiveness of existing protected areas. Leading Institution(s) – FAICO-SINAC-CIMAR
- Restoration, Conservation, and Sustainable Management of mangroves in Costa Rica and Benín to Confront Climate Change seek to transfer conservation, restoration, and participatory education methodologies to improve climate change mitigation and adaptation in three sites in Costa Rica. Leading Institution(s) – Neotrópica/MINAE/SINAC Foundation
- National Development Plan 2019-2022 establishes a budget of 4,054 million of colones to implement the National Policy of the Sea in terms of surveillance and control of the coastal-maritime space
- National Development Plan 2019-2022 plans to deploy two radars for surveillance and control of the maritime space. Funding is provided by the Forever Costa Rica Association

IP4 – Climate Change

- Plan A: Resilient territories to Climate Change seeks to reduce the vulnerability and build the resilience of Costa Rica to the impacts of climate change and climate variability by strengthening capacities to integrate climate change adaptation actions into its regional and municipal planning. Leading Institution(s) – MINAE-DCC-UNEP-Green Climate Fund
- Strengthening the Management and Monitoring of Climate Action aims to support the government to achieve the goals established in the National Strategy on Climate Change, under the strand Monitoring and Management of climate action. Leading Institution(s)-BID

IP5 – Territory Planning

- Management and Consolidation of Public Property on the Lands of the Humedal Nacional Térraba-Sierpe and its periphery. Leading Institution(s)- ACOSA-ACRXS

IP6 – Risk Management

- Risk Management National Strategy 2016-2020 planned to create 20 coastal regulatory plans based on risk analysis, with protection measures in the wetlands and biodiversity
- Risk Management National Strategy 2016-2020 planned to make an Agriculture Impact Assessment to determine the impacts of agriculture on the coastal wetlands
- Tsunami Ready Program seeks to ensure that identified communities possess the necessary tools, knowledge, operational procedures, and skills to effectively take the necessary response actions in the event of a tsunami threat to save lives and property. Leading Institution(s) – SINAMOT-IOC/UNESCO
- MIO-CIMAR aims to inform the different meteorological-oceanographic events representing a threat to the coastal communities. Leading Institution(s) – MIO-CIMAR-CNE

IP7 – Human Development

- Adapta2+ in coastal areas helps to formulate and implement good practices for sustainable tourism and fishing, recovering mangrove areas, restoring coral reefs, and many more such actions. Leading Institution(s) – Fundecooperación para el Desarrollo Sostenible-MINAE
- Sustainable Development of Fisheries and Aquaculture Program aims to improve the management of fishing and aquaculture activities in Costa Rica to increase the benefits of priority resources for the national economy and stimulate the socio-economic development of the Costa Rican fisheries sector by strengthening institutional governance, developing value chains and strengthening participatory mechanisms for social and environmental sustainability. Leading Institution(s) – INCOPESCA-World Bank
- Pesca con Ciencia supports the entrepreneurship of the Chamber of Fishermen of Guanacaste, the administrator of a collection centre for fishery products. At the same time, fishers are encouraged to start their biological monitoring of fisheries serving as a basis for future decision-making and thus generate financial-accounting information to project a business plan in a value chain to ensure its competitiveness market.

Leading Institution(s)- INCOPESCA-ACRXS – Fishermen Chamber of Guanacaste

- PEZCA Towards Efficient, Sustainable, and Intelligent Fisheries is a near-real-time satellite and model data distribution platform for the Central American region to monitor the ocean conditions while promoting good practices. Leading Institution(s) – FECOP-INCOPESCA
- Share Vessel Tracking Data to register Costa Rica's commercial fishing vessels into the Global Fishing Watch platform, enhancing monitoring and market opportunities for local fishers by raising their international profile. Leading Institution(s) – Global Fishing Watch-INCOPESCA-PACIFICO
- Reducing the Vulnerability by Focusing on Critical Sectors (Agriculture, Water Resources and Coastlines) to Reduce the Negative Impacts of Climate Change and Improve the Resilience of these Sectors seeks to increase climate resilience by working directly with local stakeholders and anticipated beneficiaries through the implementation of adaptation projects in each of the geographical areas selected. Leading Institution(s) – Adaptation Fund-MINAE

3.4 Final remarks

The current chapter has presented the different risks that coastal communities in Costa Rica are facing, which can worsen if actions are not taken responsibly and promptly. Coastal erosion has been identified as one of the hazards that most affects both the Pacific and Caribbean coasts of the country. Similarly, coastal flooding and loss of biodiversity and coastal ecosystems are seriously impacting the environmental and socio-economic sustainability.

Although tourism is one of the primary sources of income for the country, it is also the primary source of urban expansion, pollution, and resource exploitation in the coastal areas. Additionally, its influence has caused local populations to be displaced or limited in their access to the coastal zone and its resources.

Coastal communities must update their regulatory plans and include climate change variables, mainly SLR. Scientific and technical studies must support the updating of the plans. Many landmarks used in the existing plans no longer exist, and the baseline of the ZMT has been modified over time. By including climate change variables, the municipalities and the ICT will be somehow obliged to monitor the ZMT continually. Therefore, updated data will support decision-making and the adaptation of the plans. The monitoring process can also be supported by citizen participation, which at the same time will empower them by becoming more active in the participatory processes.

One of the best ways to prevent coastal risks is through awareness raising and training of the general population. The lack of ocean literacy is a problem that undoubtedly affects the Costa Rican population. Since actions implemented inland have an impact on the coastal and marine environments, it is important to make the people aware of how the land and the ocean ecosystems are connected. The application of prevention and adaptation models with nature-based solutions involving the local communities is one of the best ways to create more sustainable and resilient ecosystems and economies.

Costa Rica has the tools to create a climate change adaptation plan, which needs to be consistent with the proposed policy and strategy. Likewise, this instrument must contemplate the coastal areas. More political will is needed to implement actions because the "business as usual" model is evidently not sustainable and constitutes a threat to nature conservancy and puts at great risk the coastal populations.

Acronyms and abbreviations

ABNJ Areas Beyond National Jurisdiction
ASADAS Administrative Associations of the Communal Water and Sewage Systems
AyA Water and Sewage Institute of Costa Rica
BID Inter-American Development Bank
BIOMARCC Marine-Coastal Biodiversity of Costa Rica
CATS Technical/Sector Advisory Committees
CNE National Emergency Commission
CRRH Regional Committee on Hydraulic Resources
DCC Climate Change Directorate
EEZ Exclusive Economic Zone
ENSO El Niño-Southern Oscillation
GFDRR Global Facility for Disaster Reduction and Recovery
GIZ Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
HNTS National Wetland Térraba-Sierpe
ICT Costa Rican Tourism Board
ICZM Integrated Coastal Zone Management
IMN National Meteorological Institute
INCOP Costa Rican Institute of Ports of the Pacific
INCOPESCA Directorate of Fisheries Resources and Aquaculture
INEC National Institute of Statistics and Censuses
INVU National Institute of Housing and Urban Development
IRS Risk Assessment Index
JAPDEVA Board of Port Administration and Economic Development of the Atlantic Coast
MIDEPLAN Ministry of Economy and Planning
MINAE Ministry of Environment and Energy
MINAET Ministry of Environment, Energy and Technology
MIO-CIMAR Oceanographic Informative Module
MOPT Ministry of Public Works and Transport
NGO Non-Governmental Organizations
NTWC National Tsunami Warning Centre
PNGR National Plan of Risk Management
Ramsar Ramsar Convention on Wetlands
SENARA National Groundwater, Irrigation, and Drainage Service
SETENA National Environmental Technical Secretariat
SINAC National System of Conservation Areas
SINAMOT National Tsunami Monitory System
SLR Sea-Level Rise
SST Sea Surface Temperature
UNFCCC United Nations Framework Convention on Climate Change
UCR University of Costa Rica
UNA National University of Costa Rica
ZMT Maritime Terrestrial Zone

Uvita Beach, Costa Rica

4. The case of Gabon

Beach scene in Gabon.
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4.1 Gabon and its coastal area

Located in the Gulf of Guinea, Gabon has a coastline of around 950 km that overlooks the Atlantic Ocean (Figure 4.1). The geomorphology of the coastal regions of Gabon corresponds to the country's coastal sedimentary basin (Hudeley and Belmonte, 1970) with continental elevations peaking up to 900 m in the hinterland. This sedimentary basin is approximately 50,000 km^2 in size, about 600 km from north to south and 200 km from west to east. This sedimentary package is bounded to the north by the Cocobeach region, the Mouni estuary and the border with Equatorial Guinea; to the east by the Lambaréné and the great lakes regions; to the south by the bottom of the Banio lagoon and the Congolese borders; and to the west by Cape Lopez, Mandji Island and the Atlantic Ocean (Mombo, 2017).

Geomorphologically, three large systems are aligned along the Gabonese coastline:

- An estuarine system in the north characterized by three large river valleys: the Komo estuary which is the outlet of the Komo River that springs from the foot of the Crystal Mountains, the latter representing a watershed of about 5,000 km^2. Libreville is located on the right bank of this estuary; Mondah Bay located north of Libreville; and Mouni Bay at the northern end of the Gabonese coastline, on the border with Equatorial Guinea, and whose main town is Cocobeach. This entire northern part of the country contains important rocky cliffs forged in Sibang limestone.

Figure 4.1 Location map of Gabon.
© UNESCO-IOC

- A deltaic system in the centre extending from the Bam-Bam cirque area to the Nkomi lagoon, with about 200 km of coastline, the delta was built at the outlet of the Ogooué River and is developing over an area of approximately 5,100 km^2. The Ogooué is the largest river in the country with a watershed of nearly 215,000 km^2 and an average annual flow of 4,730 m^3 per second at the Lambaréné station (Lebigre, 1983). The Ogooué travels the country from east to west for 1,000 km before flowing into the Atlantic Ocean, north and south of Port-Gentil. With a total length of 1,200 km, its initial 200 km are upstream in the Republic of the Congo.

- A lagoon system in the south where four large lagoons follow one another from north to south: Nkomi (558 km^2), Iguéla (202 km^2), Ndogo (502 km^2) and Banio (147 km^2) along the border with Congo.

From a geomorphological point of view, the Gabonese coastal zone is characterized first by low-laying coasts with muddy marshes or sandy barriers, artificial (urban) low-laying coasts, mixed coasts (beach rocks or beach with small mud cliffs) and finally, low rocky coasts with reef flats or cliffs with a height of less than 15 meters. All these types of beaches are found in Libreville and its region, in contrast with the Port-Gentil region where there are only low-laying coasts with muddy marshes or sandy barriers and artificial low-laying coasts.

Regarding geology, sands from the coastal sandy barriers characterize the city of Port-Gentil. In Libreville, on the other hand, there is a diversity of geological features materialised by the presence of clayey sand, sandstone, limestone and marl, but also the coastal sandy barriers. These geomorphological and geological characteristics are critical factors in the characterization of coastal hazards impacting Gabon.

Gabon experiences an warm and humid equatorial climate characterized by four seasons (Maloba Makanga, 2010) distributed as follows:

- Long dry season, from June to August
- Short rainy season, from September to November
- Short dry season, from December to February
- Long rainy season, from March to May

Average monthly temperatures range from 24 °C to 27 °C in Libreville in July-August and March-April, respectively. While in Port-Gentil, average monthly temperatures are high all year round, ranging from 23 °C to 28 °C. The lowest temperatures are observed during the dry season, from June to August, with July being the coolest month with 23.3 °C; the highest monthly averages occur in April (27.2 °C). Rainfall in Libreville fluctuates around 2,870 mm while in Port-Gentil it averages nearly 2,000 mm per year (Maloba Makanga, 2010). Rainfall varies throughout the seasons. The wind patterns in Gabon are also subject to the rhythm of the climatic seasons.

The Gabonese maritime domain represented by its Exclusive Economic Zone (EEZ) covers approximately 191,944 km^2 (Sea Around Us, 2015) and can extend up to 233,000 km^2, representing a surface area nearly equivalent to the country's continental area (267,667 km^2). Its continental shelf covers 41,900 km^2 and is rich in biological and mineral resources. An outstanding attractive area, the Gabonese coastal area is home to nearly 80% of the population (Libreville and Port-Gentil) and concentrates a significant part of national economic activities.

An Atlantic Ocean beach in Gabon, with human occupation by the shoreline.
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4.2 Coastal vulnerability in Gabon

4.2.1 Rainfall flooding and coastal flooding

Flood hazard is ever increasing in Gabon. Floods happen mainly in the country's two main cities, Libreville, the administrative capital, and Port-Gentil, the economic capital. Gabon's population increased from 447,864 inhabitants in 1960 to 1,014,976 in 1993, and then to 1,811,079 in 2013. These two cities host around 60% of the country's population. Floods affect low-lying areas, lowlands, watershed bottoms, rivers and some of their banks, thus causing significant damage to the environment as well as socio-economic issues.

In Libreville, the bottom of the watersheds is usually flooded and the damage to the populations is even more important because of the construction built in the river beds. During the last quarter of 2020, the Ogooué River experienced significant floods, inundating almost everything in its path. Some neighbourhoods of the cities located along its path and most the bordering villages were completely flooded (Figures 4.2 and 4.3).

The flooding phenomenon is amplified by the unsanitary conditions that obstruct the various pipes built throughout the city of Port-Gentil, as they no longer serve as storm-water drainage. Apart from this, the consequences on human health remain to be determined (water diseases, malaria, among others) because latrines and other toilets are built in these same flood-prone areas.

Figure 4.2 Floods in Ndjolé, Gabon.
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Figure 4.3 Floods in Lambaréné, Gabon.
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Gabon is also vulnerable to coastal flooding. Almost the entire coast of Gabon is affected by this hazard, but it is more evident in Mandji Island which is home to the city of Port-Gentil. Mandji Island, in fact, is a sand spit whose altitude varies from 3 to 6 m above sea level. This low altitude makes it very vulnerable to coastal hazards, especially coastal flooding. For example, the Mandji Island vulnerability study estimates that 64% of the island's surface area is prone to floods and that this proportion could rise to 90% by the year 2100.The low altitude of Mandji Island coupled with the subsidence of this area under its own weight makes the city of Port-Gentil vulnerable to coastal flooding. After analysing all the causes of maritime climate variability, measures taken in 2011 on the Gabonese coastal vulnerability show a sea-level rise of 2.6 mm per year that will lead to an increase in the average sea level of some 10.2 cm by 2050.

4.2.2 Sea-level rise and storm surge

The latest figures of the IPCC report[1] show a global trend towards a rise in sea level, projecting a sea-level rise of 60 cm by 2100. An increase of a few centimetres can flood several areas and cause natural disasters, especially in low-lying zones. Projections based on tidal data indicate an effective rise in sea level in Gabon. Indeed, two scenarios of the impacts of sea-level rise around Mandji Island were carried out for 2050 and 2100. The first hypothesis, considered as the most likely scenario, estimated a sea-level rise of 20 cm by 2050 and 50 cm by 2100. The second hypothesis on the other hand, considered as the worst-case scenario, estimated a sea level rise of 50 cm by 2050 and 1 meter by 2100. For each hypothesis, the variation in the altitude of Mandji Island under the effects of sea-level rise was carried out based on numerical modelling. While sea-level rise may affect the coasts around Libreville to some extent, it poses serious threats to Mandji Island and Port-Gentil. It is therefore important to update the study on the vulnerability of the Gabonese coast. Indeed, the socio-economic impacts of sea-level rise on the coast are varied and have probably not all been identified or assessed, especially at the local level.

The National Strategy for the Adaption of the Gabonese Coast to the effects of Climate Change developed in 2011 shows that there will be an increase in storm surge of 10 to 14% compared to the current situation.

4.2.3 Coastal erosion

Coastal erosion, resulting in a shoreline retreat, is one of the main coastal hazards on the Gabonese coast. Coastal erosion problems are mainly observed in exposed coastal segments of the Gabonese coast, which are subject to significant degradation. Human actions intensify the impact of these natural processes. Indeed, in various coastal areas, fishermen have long cut mangroves to prepare food and smoke the products of their fishing activities. There are also sand mining activities on beaches and coastal barriers (Libreville and Port-Gentil) which have impacts on landscapes and on the coastal dynamics. There is also land occupation in areas along the coast that does not respect *non aedificandi* zones that prohibit construction in the first 50 m from the shoreline[2]. Additionally, in Gabon there are cases of the perverse effect of inadequate protective structures built piece by piece.

Since the early 2000s, the rate of coastal retreat has accelerated, and, in general, the ocean has gained more than 1 m per year on average. Between Cape Santa Clara and La Sablière in the Akouango Bay, there is intense shoreline retreat. In this sector, Mouyalou (2017) estimated a shoreline retreat of 3 m per year. Apart from the artificialized areas with various and relatively stabilized ripraps, the northern coast of Libreville has alternated phases of coastal erosion and accretion, averaging 1 m per year over the last 25 years (Mombo and Mouyalou, 2017).

On the side of Pointe Denis, across from Libreville on the left bank of the Komo estuary, the phenomenon of coastal erosion is even more spectacular. The threat is even more worrying because it affects the nesting of sea turtles, tourist facilities and high-end secondary dwellings along the coast. Between 1960 and 1980, the shoreline of Pongara Point retreated 300 m. This trend is confirmed by the work of the National Centre for Oceanographic Data and Information (NCODI) which recorded an average of 120 m of shoreline retreat between 1991 and 2012, corresponding to an average speed of around 6 m per year over the entire coastline between Wingombé Point and Pongara Point (Figure 4.4). However, this shoreline retreat can reach up to 10 m per year in some places. The rate of the shoreline retreat is increasing; it was 10 m per year before 2008 and reached nearly 12 m per year between 2008 and 2012 (Koumba Mabert, Rabenkogo, Ango Mougouba, 2017). In August 2020, the shoreline retreated by almost 20 m in some parts of this area (Figure 4.5).

1. https://www.franceinter.fr/environnement/rapport-du-giec-le-niveau-de-la-mer-pourrait-selever-de-1-1m-d-ici-2100-avec-des-consequences-dramatiques
2. Decree 00440/PR/MFDE of 21/09/1967 specifies it for the northern area of Libreville.

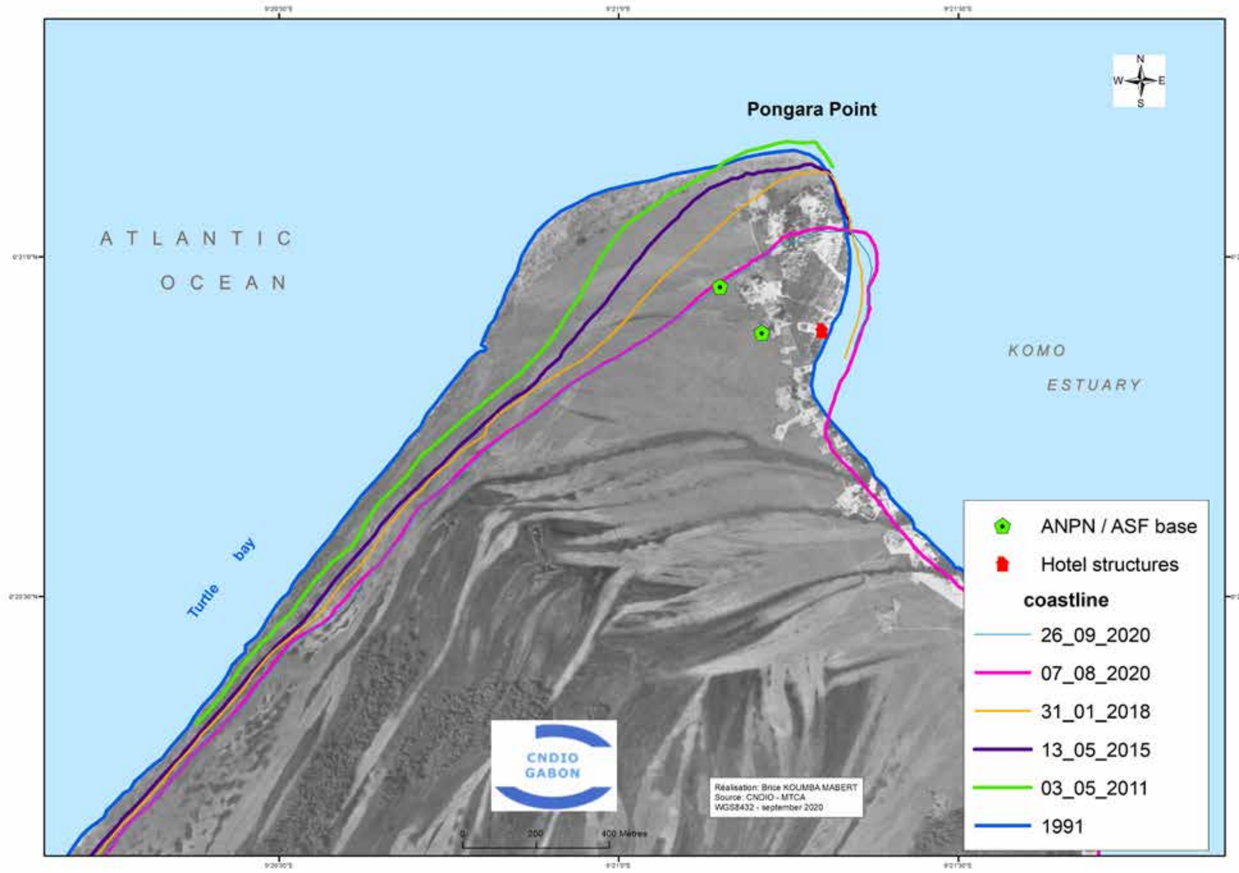

Figure 4.4 Evolution of the shoreline position in Pongara from 1991 to 2020.
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Figure 4.5 Evidence of rapid shoreline retreat in the Pongara Point area. The left picture was taken on April 2019 and the right picture was taken on September 2020. The blue house belongs to the NGO Adventures Without Borders[3].
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3. https://www.facebook.com/AventuresSansFrontieres/videos/1276116662724502

Pongara Point, Gabon.
© Tiago Conte /Shutterstock.com

4.2.4 Salinisation of surface water and groundwater

The exposed lands on the Gabonese coast will experience salinisation of surface water and groundwater. This is already visible in the city of Port-Gentil. During the dry season, poor people drink saltwater due to salinisation of water in the Mandorové pumping area that hosts the station of the Gabon Society for Energy and Water (SEEG). This consumption of saltwater can have an impact on the population's health. NCODI is in the process of setting up a project on the study of water quality between Port-Gentil and Mandorové and on water wells used by the populations. This study will better quantify the evolution of salinity according to the seasons and in the context of the effects of climate change.

4.2.5 Change and loss of wetlands, loss of dry lands

Some wetlands in Gabon are disappearing, being replaced by rampant and uncontrolled urbanisation. Urban sprawl is causing people to destroy mangroves, thus disrupting spawning areas. This is particularly the case in northern Libreville and in the Owendo area, in the south of Libreville. This phenomenon continues despite the prohibitions enacted by law, not only in relation to the Environmental Code but also those formulated in the National Parks Act.

4.2.6 Marine pollution and changes in water quality

Along the Gabonese coast, it is possible to encounter hydrocarbon residues from offshore oil exploitation that drifted to shore with the ocean currents. Over the past decade, Gabon's coasts have suffered from cases of oil pollution. The beaches of Mayumba, in southern Gabon, were subjected to widespread pollution in 2011, killing several animals in Mayumba National Park. It was a grainy and viscous slick of tar covering more than 20 km on Mayumba Beach between the place called Bam and Mayumba Airfield. This situation was particularly concerning as this part of the country is one of the most important breeding areas in the world for leatherback turtles. In February 2019, hydrocarbon residues covered the Cape Santa Clara beach in northern Libreville. This umpteenth pollution event was an opportunity to initiate the National Emergency Plan, in accordance with the Decree No. 653/PR/MTEPN of 21 May 2003, on the preparation and control of pollution by hydrocarbon and other harmful substances.

In addition to this pollution by hydrocarbons, there is also land-based pollution linked to coastal urbanisation. No coastal city in Gabon has a sewage treatment system. Wastewaters are discharged into the river streams that drain to the sea. Without a national coastal water quality monitoring program, it is difficult to assess the degree of deterioration of these waters. The "Arc d'Emeraude" Program, in which NCODI participated in collaboration with the Research Institute for Development (IRD) and piloted by the Parks Agency, has built a model that has simulated the evolution of the oil slick according to the trajectory of ocean currents along the Gabonese coast. If an oil accident occurs, the consequences on the coasts would be detrimental to marine protected areas, beaches and fisheries. This model has also been applied to urban waste generated by the city of Libreville.

Rubbish along a river mouth in Gabon.
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4.2.7 Changes in the distribution and abundance of coastal and marine species

Climate variability, by changing physical ocean parameters such as seawater temperature and pH, affects marine species distribution and abundance. In Gabon, very few studies have addressed the distribution of fish in space and time. The country has set up the Blue Gabon Programme, which is an effective tool to monitor fishing activities by using devices to assess the fishing effort in the Gabonese maritime space. The conclusions of this programme should lead to the establishment of a real fisheries policy in Gabon. This is even more important since the country has experienced two major natural hazards events in 2020. First, the Ogooué River has seen its waters rise significantly, causing flooding along the way. This increase in water levels has led to a decrease in fish resource in the Lambaréné and lakes region. Even today, people downstream of Lambaréné are struggling to find fish in their nets. Second, the region experienced significant mortality of some fish species, including the so-called Lambaréné carp.

In Mayumba, the local population and fishers are increasingly facing a reduction in resources. The oysters of Mayumba have been managed by the Fishers and Resellers of the Mayumba Oysters Association. Oysters are now captured by sector and every two years, and not on the entire Banio lagoon. The introduction of this method of management has reduced the availability of the resource to local populations, the only ones allowed to catch oysters. The same is true for fish resources. The movement of fisheries northwards towards Mayumba, due to the creation of the Mayumba National Park and the Banio Mouth Marine Park, has reduced the amount of fish resources by Beninese communities living in this part of the Gabonese coast.

A leatherback sea turtle crawls up the beach to complete the nesting process.

The projected rise in global sea level presents a major concern for the conservation of marine and coastal ecosystems. It is already known that one of the consequences of the increase in average sea level is the aggravation of the shoreline retreat and coastal flooding. Gabon's beaches are one of the world's important sites for the nesting of leatherback sea turtles. The consequences observed on the beaches interfere with their nesting. At Pointe Denis, across the bay in front of Libreville, this phenomenon is already noticeable. The NGO Adventures Without Borders noted a reduction in the number of turtle tracks on the beaches every year.

4.3 Coastal risk management in Gabon

4.3.1 Governance

Regarding socio-economic and ecological issues, the Government, through the Green Climate Fund and the National Agency of National Parks has initiated a project on the development of the National Strategy for Adaptation to Climate Change. The aim is to improve the scientific and technical knowledge base on climate change at the national and sub-national levels to better prioritize the need for investment in coastal adaptation. This should lead to the drafting of a National Adaptation Plan (NAP). In this context, vulnerability studies are being conducted with the aim of assessing the future vulnerability and associated risks of various sectors of activity in the coastal zone of the Komo estuary region, the Ogooué delta and the Nkomi lagoon to identify appropriate adaptation options for 2035 and 2050.

In 2017, Gabon developed and adopted an Integrated Maritime Strategy (IMSG). The IMSG affirms Gabon's maritime vision of taking the sea into account as an essential lever for national development. To this end, six strategic objectives are set out:

- Establishment of real maritime governance
- Establishment of maritime training units and scientific research units
- Development of an efficient maritime economy
- Improvement of maritime safety
- Safeguarding the ocean, marine mammals and fisheries
- Strengthening maritime defence

Gabon's institutional framework for coastal hazards management involves:

High-ranking institutions specializing in environmental issues. The National Climate Council (NCC) created by decree on 23 April 2010. It is responsible for developing the climate component of the Emerging Gabon Strategic Plan (EGSP) to identify actions for each sector. It suggests to the Government an integrated development approach to adapt our consumption and production patterns to the objectives set by the international community. In 2012, the NCC developed the country's strategic development plan, which set out the sectoral actions of the National Climate Plan in 2013 The latter includes all national and international measures to reduce greenhouse gases (GHGs) emissions and the Intended Nationally Determined Contributions (INDCs) which outlines the country's international commitments to reduce GHGs.

National Council of the Sea (NCS). Created by Decree No. 0312/PR/MRIC of 25 September 2014, this institution is responsible for the design and coordination of government action, particularly in the field of planning and protection of the marine, river and lagoon environment. From 23 to 25 October 2020, the institution organised a national workshop on combating maritime piracy, as part of the management of the sea in Gabon. In addition to the military approach, it was also a matter of *"defining our maritime borders, preserving the marine environment and aquatic ecosystems, combating marine pollution and promoting an effective and sustainable blue economy"*, according to the Minister for Water, Forestry, Sea and Environment.

Office of the High Commissioner for the Environment and Living Conditions. Created by Decree No. 0076/PR of 11 June 2019 through Article 3, the Office of the High Commissioner assists the President of the Republic of Gabon in the implementation, monitoring and control of the policy on environmental protection and improvement of the living conditions, as well as coordinates and monitors the action of stakeholders in these sectors. All environmental studies, programs and management plans shall be forwarded to the High Commissioner.

Ministry directly involved in environmental management. The Ministry of the Environment and Nature Protection has two Directorates-General for this purpose (Directorate-General for the Environment and Nature Protection, GDENP, and Directorate-General for Aquatic Ecosystems, GDAE).

Ministries dealing directly or indirectly with environmental issues and their technical services. Include:

- Ministry of Fisheries and Aquaculture
- Ministry of Foreign Affairs and Cooperation
- Ministry of the Interior
- Ministry of Equipment, Infrastructure and Land-Use Planning
- Ministry of Mines, Oil and Hydrocarbons
- Ministry of Energy and Hydraulic Resources
- Ministry of Economy, Trade, Industry and Tourism
- Ministry of Transport and Merchant Navy
- Ministry of Health, Social Affairs
- Local authorities (governorate, prefecture, county council, municipal council)

4.3.2 Scientific

Research on climate change and its effects in Gabon is carried out mainly by the institutions that are at the heart of national climate policy. These are the Directorate-General of Meteorology, the Agency for the Security of Air Navigation in Africa and Madagascar (ASECNA), the National Centre for Oceanographic Data and Information (NCODI) of CENAREST, the Gabonese Agency for Space Studies and Observation (AGEOS), the Laboratory of Space Analysis and Tropical Environments (LSPANATE) of Omar Bongo University and the National Agency of National Parks (NANP).

The coastal hazards study is part of the Global Climate Observing System (GCOS), a global programme jointly led by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the United Nations Environment Programme (UNEP) and the Gulf of Guinea Large Marine Ecosystem program led by the United Nations Industrial Development Organization (UNIDO).

The **Directorate-General of Meteorology (NMA)** is a technical and scientific department responsible for meteorology and all its applications and the assessment of natural resources by satellite. The missions of the NMA thus seem very extensive, complementary for some fields (meteorology, telecommunications), but difficult to integrate. Today, only three stations remain operational (Libreville, Port-Gentil and Mvengué) for weather observation. These three stations are governed by the ASECNA's community activities which states that the agency shall be responsible for the design, implementation and management of installations and services for the transmission of technical and traffic messages, aircraft guidance, air traffic control, in-flight information, forecasting and transmitting information in the meteorological field, for both *en route* traffic and approach and landing at community airfields.

The **National Centre for Oceanographic Data** and Information (NCODI) was created in 2003 on the initiative of the ODINAFRICA Programme (Oceanographic Data Exchange Network for Africa), led by the IOC-UNESCO, whose aim is to develop ocean-related projects on a regional basis. This program facilitates the creation of appropriate structures for the management of oceanographic data and information. In relation to coastal erosion research, NCODI has been developing the National Programme for the Monitoring and Understanding of Coastal Erosion since 2007. This programme is part of the Congolese Republic's "Loango Initiative" on coastal erosion, held in October 2008 in Pointe Noire. It also follows the workshops in Libreville (13-16 March 2007) and Accra (1-3 October 2007) in which experts and directors of Atlantic front institutes identified priorities in capacity building in the region. Since April 2009, NCODI has been participating in the Global Ocean Monitoring Program with a three buoys donation from the U.S. Navy in March 2009. These drifting Argo buoys were deployed in the Exclusive Economic Zone: from Cape Estérias, Omboué and Mayumba. However, these oceanographic buoys are no longer operational due to their obsolescence. They must be replaced and deployed in the same location.

In addition to Argo buoys and pressure sensors dedicated to research and development, the Gabonese coastline also has a small network of tidal gauges, particularly in Libreville and Port-Gentil for port operations (to ensure safe navigation, docking, equipment and handling operations, maintaining depths). Indeed, the National Port Authority (Gabon Ports and Harbours Office, OPRAG) and Gabon Port Management, the concessionary and partial operator of the commercial ports of Libreville-Owendo and Port-Gentil, have equipped the two port agencies with two tide gauges. Whereas the port of Owendo, property of Gabon Port Management, is functional; the Port-Gentil system installed by OPRAG has been non-operational for five years due to damage to the cable connecting the probe to the tide. For a wider understanding of the oceanographic conditions in Gabon, it is essential to supplement the Argo program with a network of coastal observation stations. In addition to this network, the NCODI has participated in a programme called "Arc d'Emeraude" for the implementation of a model that clearly identifies areas vulnerable to marine weather forcing on the northern part of the Gabonese coastline, between Port-Gentil and Libreville.

More recently since 2015, the NCODI has been involved in the development of the Marine Science Training Program in the Central African subregion. Launched in October 2016, the Regional Master degree on Integrated Management of Coastal and Marine Environments (IMCME) mobilises four universities: Omar Bongo University of Libreville, Yaounde 1 University, Masuku University of Science and Technology and Douala University. NCODI is one of the host laboratories selected for this specialized training in ocean and coastal sciences. The NCODI aims to transform itself into a Research Institute in Coastal Geoscience.

Since 2017, the NCODI has been developing in partnership with the Research Institute for Development (IRD), the Institute of Fisheries Sciences of the University of Douala and the University of Science and Technology of Masuku, the Hydro-sedimentary Modelling Program around the Arc d'Emeraude (Komo estuary in Gabon) funded by the NANP. The model established clearly identifies areas vulnerable to marine weather forcing on the northern part of the Gabonese coastline, between Port-Gentil and Libreville. During the same period, the NCODI also carries out in collaboration with the Institute of Fisheries Sciences in Douala the International Programme on Harmful Algal Blooms funded by the International Atomic Energy Agency (IAEA) and coordinated nationally by the Directorate-General for the Environment. The main objective of this project is to improve knowledge on marine phytoplankton and the acidification of the world's ocean.

Furthermore, as part of the reform of the National Commission for UNESCO, and in order to strengthen the work of its Permanent General Secretariat, a process for creating ten specialized committees was initiated in 2013 with the appointment (Ministerial Decision No. 0044/ MENESTFPRSCJS/CAB/CNU/SGP of 17 October 2013) and the installation, on the occasion of the "Open Doors Day" of the National Commission for UNESCO organized on 25 October 2015, of ten chairpersons of national committees of UNESCO's international or intergovernmental scientific programs. These committees, including the IOC-UNESCO committee, would be integrated as permanent associate bodies of the Gabonese National Commission for UNESCO.

The **Gabonese Agency for Space Studies and Observation (AGEOS)** was established by the Order of 25 February 2010 with the purpose of contributing to the implementation of the Government's policy on the collection, analysis and provision of data from the spatial observation of the national territory for sustainable management of the environment, natural resources, land-use planning, and research and innovation. AGEOS also has an important mission to provide data to detect, measure and prevent the environmental impacts of climate change and to promote research, innovation and development in the field of Earth observation applications at the national, regional and international levels. Finally, the agency is responsible for setting up and piloting the SEAS-Gabon project for the installation of a satellite reception antenna and the construction of a centre of expertise in remote sensing and environmental monitoring in collaboration with development partners. Its flagship project "Satellite-Assisted Environmental Monitoring" was developed in cooperation with the French Research Institute for Development and the Brazilian Space Research Institute (BSRI). It consists of satellite environmental observation by conducting monitoring campaigns on specific areas, particularly forest and coastal. With a high-tech technical infrastructure, images of observation satellites are received in real time. For example, the monitoring campaign of Gabon's EEZ conducted from 24 June to 10 July 2016 has made it possible to detect, in particular: oil pollution of more than 30 km² in national waters; an oil slick of more than 30 km off the coast; threats affecting the sustainability of the fisheries; as well as to locate vessels on the southern border of the area, the presence of which strongly suggests the possibility of a maritime traffic.

Beaches of Libreville, Gabon.

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The **National Agency of National Parks (NANP)** is a public institution of scientific and environmental nature with legal personality and administrative and financial autonomy; it was created by the Law 003/2007 on National Parks and under the auspices of the Presidency of the Republic. Since 2015, it has been developing the Blue Gabon Programme. This programme, initiated jointly by the National Centre for Scientific and Technological Research (NACESTRE) and the Directorate-General for Fisheries (DGFA), consists in the development of the EEZ which extends beyond the outer limit of the territorial sea on which Gabon has the possibility to act in the following ways: 1) to exercise sovereign rights in the exploration and exploitation, conservation and management of the seabed natural resources; and 2) to produce energy from water, currents and marine winds for economic purposes. The programme advocates the creation of 20% of marine protected areas on the 885 km of coastline of the country on its Atlantic coast and aims to develop aquatic tourism and contribute to the national Gross Domestic Product. Various partnerships helped to fund the programme. For example, the 1998 Fisheries Partnership Agreement between Gabon and the European Union was enriched on 24 April 2013 by a new three-year Memorandum of Understanding that paid the country the sum of EUR 1.35 million each year, of which EUR 450,000 were intended to finance the Gabonese fisheries policy. This protocol also provided an opportunity to introduce new control tools to combat illegal fishing. On 14 November 2014, as he took part in the 6th World Parks Congress of the International Union for the Conservation of Nature (IUCN) in Sydney, Australia, the President of the Republic of Gabon announced the creation of a network of marine parks in the country. This announcement was in fact the culmination of an important process of improving the management of aquatic living resources that began in 2012. That year, the National Agency of National Parks collaborated with the National Geographic Society, the NGO Wildlife Conservation Society, the National Oceanographic Data and Information Centre and the Wait Expedition Foundation to conduct a large scientific expedition to explore the Gabonese seabed. This extraordinary adventure called "MEGATRANSECT MARIN GABON 2012" has allowed national and international researchers to examine the depths of the maritime territory of Mayumba in Cape Estérias to collect valuable information on the wealth of maritime resources, but also to identify the main perils that threaten its sustainability. The information collected led the Government to define an operational strategy for the sustainable management of maritime resources, the implementation of which has been entrusted to the NANP, and which is being deployed along five main lines of action: 1) the delimitation, development of the national maritime domain, and its recognition by international bodies and border countries; 2) the planning and strengthening of operational capabilities for maritime surveillance and protection of the maritime domain; 3) the sustainable management and optimization of fisheries resources involving the improvement of knowledge on the resource and fisheries products; 4) the sustainable management and optimization of oil and mining resources involving the fight against marine pollution, as well as strengthening of the oil facilities' protection; and 5) the development and rehabilitation of port infrastructure and the improvement and strengthening of the legal and regulatory framework for maritime and river activities. The major result of the deployment of this strategy is the delimitation of the EEZ covering nearly 231,300 km^2 and an inland river system of 10,000 km^2. The measure announced by the President of the Republic of Gabon concerns the protection of 23% of this area, which includes marine and aquatic parks.

The **Laboratory of Spatial Analysis and Tropical Environments (LANASPET)** of the Department of Geography is a research structure of Omar Bongo University in Libreville. It was created in the late 1990s by a group of teacher-researchers from this institution. This laboratory develops research on applications related to climatology, geomorphology, hydrology, oceanography, mangrove dynamics and climate change. For the past five years, this laboratory has supported the CEMAC Chair in Environment and Sustainable Development, which is developing a Master of Research in this specialty.

4.3.3 Maritime sectors

National Gabon Ports and Harbours Office (OPRAG)

The OPRAG manages, promotes and runs trade in the Gabonese ports. As such, it is responsible for:

- Management of harbours and port areas
- Overall coordination of port activities
- Ship assistance and reception
- Equipment maintenance and renewal, establishment and development of industrial port areas, works and installations of industrial non-concession areas, and risk prevention and environmental protection

Libreville harbour in Gabon.
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Gabonese people during a Sunday mass in a church of Libreville.
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Gabon Port Management (GPM)

The Gabon Port Management is responsible for the maintenance and development of port facilities in Libreville and Port-Gentil. It also conducts several studies on the hydro-sedimentary characteristics of marine and coastal environments.

4.3.4 Civil society

Various national and international NGOs, including WCS, WWF, TNC, Adventures Without Borders, Ibonga, Plurmea, and Keva Initiative H20, participate in the management of biodiversity in Gabon. Some of them have played an important role in the creation of the newly established marine protected areas in Gabon that contribute to environmental conservation.

4.4 Coastal adaptation and risk mitigation in Gabon

4.4.1 Actions under implementation

Gabon's coastal region currently contains almost 60% of the country's total population and about 75% of the country's urban population. This proportion will increase in the next twenty years due to the economic development projects planned by Gabon's political authorities. Urban concentration in this part of the territory is directly exposed to the impacts of climate change, as already noticeable for example in the occurrence of more and larger floods in coastal cities (as in Libreville, Port Gentil, Mayumba, Lambaréné, among others), coastal erosion and flooding, salinisation of freshwater (as in Port-Gentil), and land-based pollution that are also associated with human health issues. All these hazards will be exacerbated by the increasing human occupation of the coastal regions and amplified by the effects of climate change. Therefore, the consideration of socio-economic and environmental issues related to these phenomena must be considered in the context of the sustainable development of the entire country.

Development process of Gabon's National Adaptation Strategy

In a partnership with UNFCCC's Green Climate Fund, Gabon has started work on the development of its National Adaptation Strategy since April 2019, which aims to fill the gap in scientific data on the subject, establish a climate monitoring system and propose policies and projects to address the country's vulnerabilities. The technical activities of the project are carried out by the National Agency of National Parks under the supervision of the National Climate Council. The project's activities focus on the following three themes:

Working Group 1: Establishment of a climate data collection system

- **Outcome 1:** Improving the scientific and technical knowledge base to better guide adaptation planning at the national and sub-national levels

Working Group 2: Establishment of an adaptation financing strategy

- **Outcome 2:** Prioritizing coastal adaptation investments in Gabon and developing a financing strategy

Working Group 3: Capacity building

- **Outcome 3:** Development and strengthening of Gabon's adaptation plan and related processes to identify, prioritize and integrate adaptation strategies and measures

As part of the project, several workshops were held in 2019 in preparation for the National Adaptation Plan development process, namely a workshop to launch activities in April 2019 as well as a validation workshop held in November 2019 on the first deliverables of national and international consultants on adaptation, strategic development, and gender equality carried out in close cooperation with the three inter-ministerial advisory working groups formed under the project. Various reports were produced by the consultants during Phase I of the project on the status and needs of the climate information data management system, the Memorandums of Understanding for with major data and information providers in Gabon, and gender equality assessments for the coastal sector. Under Phase II, four priority themes are being implemented by different groups of consultants, namely:

Thematic 1: Climate information management system and adaptation planning process

- Development of a comprehensive strategy for the climate information system and its terms of reference, identifying the various sources of public, private, bilateral and multilateral funding to fully implement and maintain the climate information system
- Development of a roadmap and a steering mechanism for the advancement of the adaptation planning process to establish an inter-ministerial adaptation team

Thematic 2: Specific assessment of vulnerabilities and risks identified during the adaptation planning process for the two most populated urban areas of Gabon (Libreville and Port-Gentil)

- Status of identified and unidentified vulnerabilities and risks in the study on the National Coastal Strategy for Adaptation to Climate Change
- Update of the 2011 coastal adaptation plan

Thematic 3: Development of a climate-sensitive sectoral strategy and investments in coastal areas that consider climate change risks and opportunities

- Assess the economic impacts and opportunities of climate change using macro data and field data collected in coastal areas

Thematic 4: Identification of adaptation investment priorities in the coastal sector

- Identification of needs in the private sector at both the institutional and specific levels
- Preparation of coastal adaptation projects that could be financed by banks in targeted areas

The main objective of this institutional consultation is to integrate the perceptions and interests of coastal stakeholders into the results of the consultant studies on the coastal areas' exposure to climate change.

Within the consultations with national and private institutions involved in climate change adaptation in coastal areas, it is essential that all stakeholders established in the coastal zone participate in the development of the national climate change adaptation strategy and plan. The need to unite actors is essential to initiate the working groups dynamics focused on the analysis of the vulnerabilities of coastal regions and the national strategy for the adaptation of the coastal area to the effects of climate change. The specific objectives of this initiative are:

- Present the draft National Climate Change Adaptation Plan Strategy at a multi-stakeholder meeting
- Undertake specific assessments of vulnerabilities and risks identified during the adaptation planning process in the Libreville and Port-Gentil regions in the context of climate change
- Meeting with local governments (governorate, town hall, county council, prefecture, provincial administration services), the private sector, and public, community and international institutions, civil society
- Field visits to critical sites
- Assess the structural, infrastructural capacities of local and coastal communities to prepare their adaptation to climate change
- Discuss ways to implement and finance the relocation of activities and assets
- Assess coastal protection techniques carried out by the various actors in the coastal sector
- Inventory and prioritise the investments needed to adapt the coastal area

The main results of this national institutional consultation, which are expected by the end of 2020, are:

- Institutional actors are considered in the inventory of adaptation scenarios
- The advisory work of the study area is integrated into the process of developing the National Strategy for Adaptation to Climate Change
- The scientific and technical institutions of the region are strengthened in climate and environmental issues
- Coastal communities are trained in climate change adaptation strategies
- International and national consultants have incorporated the results of their respective meetings in their reports
- Local coastal vulnerability management committees for the exchange and sharing of climate information are established
- Ownership of documents and workshops related to adaptation to climate change is shared by participants during the consultation

4.4.2 Implemented actions

To fight against the floods in Libreville, the watersheds of Gué-Gué, IAI, Terre Nouvelles are being developed through the Bassins Versants project. This program should continue in Port-Gentil. No practical action has been taken since the project on Gabon's second national communication on climate change, which focused on the vulnerability and adaptation of Mandji Island to the effects of climate change. This choice of location was justified by the importance of the socio-economic stakes implemented in the low-lying 50 km long sandy Mandji Island. Numerical modelling were carried out and the effects of biophysical impacts on socio-economic aspects identified and analysed. The results obtained have made it possible to propose adaptation measures as well as implementation strategies to fight coastal erosion and floods, monitor freshwater salinisation, update the legislative framework and relocate the town of Port-Gentil between Gongué and Mpilapé. Unfortunately, to date, the proposals set out have not been considered.

4.4.3 Potential actions

Several actions have been identified to reduce the risks associated with various coastal hazards in Gabon:

- **Rainfall floods:** improving the rainfall drainage system and regulating land-use in vulnerable areas
- **Coastal erosion:** ending uncontrolled sand mining in the coastline and regulating it at sea
- **Coastal floods:** developing coastal defences and raising the level of low-lying areas. Relocating certain vulnerable activities, particularly in Port-Gentil
- **Water salinisation:** moving the freshwater pumping stations that supply drinking water to the city of Port-Gentil beyond the limit of the saltwater wedge in the Ogooué River
- **Climate change:** Adapting habitat types to produce more resilient cities

4.4.4 Intervention portfolios

In Gabon, intervention portfolios are described in a comprehensive and strategic reflection on Gabon's climate change investment priorities for the next five years. Such programme also defines its funding by national resources but also by the various multilateral and bilateral partners, depending on their added value. The programme is also based on the Emerging Gabon Strategic Plan, which has guided the implementation of a National Land-Use Plan developed to ensure land-use within the framework of provisions on the prevention of the consequences of climate change and the obligation to preserve ecosystems. This program includes the construction of coastal protection infrastructures to protect roads and other buildings, the establishment of a legal, institutional and coastal zone management framework, and support for the restoration and conservation of mangroves. The objective of this entire program is to make the Gabonese coast resilient to climate change and its associated risks.

4.4.5 Adaptation paths

The measures taken to date in the context of adaptation in Gabon have focused on building physical barriers, which are often very costly and, in many cases, aggravate the problem rather than resolve it. Within the three main adaptation measures (protection, accommodation and withdrawal), appropriate adaptation may require a variety of integrated measures depending on location, targets and time.

Coastal erosion is a matter of concern to industrial companies located in coastal areas, particularly the oil company Total Gabon, in Port-Gentil. Since 1957, studies and works have been undertaken to control the erosion in the northern part of Cape Lopez. Based on the studies carried out and the work undertaken to protect Mandji Island from coastal erosion, it appears that these actions have not really stopped shoreline retreat. The area of Cape Lopez, where the Total Gabon's oil terminal is located, suffers a substantial loss of land estimated at 4.6 m per year.

As for rainfall flooding, still in the region of Port-Gentil, the main adaptation measure was the construction of a network of canals in the 1980s as part of a plan called Philippin. These infrastructures are currently limited and poorly maintained.

For better adaptation, new measures need to be explored in Gabon. It requires a collective awareness on the long-term evolution of coastal erosion, whose effects can have significant impacts in the country. The work undertaken under the National Adaptation Plan proposes the establishment of a Coastal Management Steering Committee whose tasks will include:

- Inspection of the protective structures carried out,
- Validation of the technical works to be carried out,
- Control of sand and gravel quarries around Mandji Island,
- Implementation of a shoreline monitoring program to:
    - quantify the effect of defence structures,
    - determine the consequences of storms at specific points,
    - assess long-term coastal evolutionary trends.

Flood-related adaptations should lead to the establishment of a land-use and planning policy. This policy should provide a mesh of occupation and non-occupation zones along the coastal areas. This should be combined with the construction of new coastal engineering works and the maintenance of existing ones.

On the risk of salinisation of freshwaters, the adaptation would consist on finding new water pumping stations in Port-Gentil, beyond Mandorové. It is also strongly recommended that the Gabonese Government considers the partial relocation of the town of Port-Gentil from the southwest of the Wonga Wongué plain in front of Mandji Island. The legislative and regulatory component should not be left out. It is recommended an update of the various official laws and regulations related to the marine and coastal environment.

4.5 Final remarks

As expected for most of the planet, in Gabon climate change will aggravate the impacts of coastal hazards, such as coastal erosion, coastal flooding, saline intrusion, occurrence of extreme weather events, loss of biodiversity, etc. In general, the concrete response to climate change is focused on mitigation. However, this approach will not influence the effects of the changes underway. Adaptation must therefore be a priority. The main objective of adaptation is to reduce the vulnerability of habitats, ecosystems and infrastructures. This approach is the preferred one in Gabon. Adaptation strategies in the country should therefore include impact assessment, monitoring, development of early-warning systems, planning of ecosystem uses, and modernisation of infrastructures located in vulnerable coastal areas.

Adaptation measures should not only focus on physical investments, but should also include institutional, regulatory and legal reforms that would help improve resilience to climate change. At the top of the immediate priorities, Gabon needs to revise its laws and regulations that address the main management matters dealing with coastal zone management.

Acronyms and abbreviations

AASECNA	Agency for the Security of Air Navigation in Africa and Madagascar
AGEOS	Gabonese Agency for Space Studies and Observation
BSRI	Brazilian Space Research Institute
DGFA	Directorate-General of Fisheries
EEZ	Exclusive Economic Zone
EGSP	Emerging Gabon Strategic Plan
GASSO	Gabonese Agency for Space Studies and Observation
GCOS	Global Climate Observing System
GDAE	General-Directorate of Aquatic Ecosystems
GDENP	General-Directorate of Environment and Nature Protection
GHG	Greenhouse gas
IAEA	International Atomic Energy Agency
IOC-UNESCO	Intergovernmental Oceanographic Commission of UNESCO
IMCME	Integrated Management of Coastal and Marine Environments
IMSG	Integrated Maritime Strategy of Gabon
INDC	Intended Nationally Determined Contribution
IRD	Research Institute for Development
IUCN	International Union for the Conservation of Nature
NACESTRE	National Centre for Scientific and Technological Research
NANP	National Agency of National Parks
NAP	National Adaptation Plan
NCC	National Climate Council
NCODI	National Centre for Oceanographic Data and Information
NCS	National Council of the Sea
NGO	Non-Governmental Organisation
NMA	National Meteorological Agency
OPRAG	Gabon Ports and Harbours Office
ODINAFRICA	Oceanographic Data Exchange Network for Africa
SEEG	Gabon Society for Energy and Water
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
LSPANATE	Laboratory of Space Analysis and Tropical Environments of the Omar Bongo University
WMO	World Meteorological Organization

The sun sets over the Atlantic Ocean in a beach near Libreville, Gabon.

5. The case of Ghana

Coastal landscape near Cape Coast, Ghana.

Author: Kwadwo Osei Hwedie

5.1 Ghana and its coastal zone

Ghana is almost at the centre of the Gulf of Guinea on longitudes 3°15′W and 1°12′E, and latitude 4°44′ and 11°15′N in West Africa (Figure 5.1), borded by Côte d'Ivoire, Burkina Faso and Togo to the west, north and east respectively, and to the south by the Gulf of Guinea. It has a total land area of 238,533 km^2 with a coastline spanning a distance of approximately 550 km (Boateng, 2006a).

Ghana's shoreline is highly dynamic with features that have evolved in response to waves, currents, tides and winds (Boateng, 2012). The sandy beaches are built up by ocean wave energy and backed by wetlands forming barrier beaches. The coast of Ghana spans four administrative and political regions: Western, Central, Greater Accra and Volta region. Six out of the ten most populous cities in the country are located along the coast: Accra, the nation's capital, Tema, Ashiaman and Teshie all in the Greater Accra region; the twin cities of Sekondi-Takoradi in the Western region; and Cape Coast, the former colonial capital in the Central region (GSS, 2013; World Population Review, 2020). Most of the country's major rivers drain into the sea, forming estuaries and lagoons along the shore, providing habitat for many plants and animals, including migratory birds and many types of fish.

Figure 5.1 Location map of Ghana.
© UNESCO-IOC.

Ghana defines its coastal zone as the area below the 30 m contour above sea-level (Dadson, Owusu and Adams, 2016). The zone represents about 7% of the country's total land area, is home to 25% of the nation's population (Boateng, 2006b) and harbours over 60% of Ghana's major industries (manufacturing, refinery, mining, port and harbour, textile and smelting), businesses and conservation sites (Amlalo, 2006). The coastal zone has been a key driver of economic growth in the country, contributing about USD 922 million to the Gross Domestic Product (GDP) (USAID, 2014). Demographic data available indicates that 51.5% of Ghana's coastal zone is urbanised compared to the national figure of 35.4% (Boateng, 2006b).

Coastal lagoon and coastal barrier in Bojo Beach near Accra, Ghana.
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The Cape Coast castle in Ghana is one of about forty "slave castles", or large commercial forts, built on the Gold Coast of West Africa.
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Ghana's coast is sub-divided into three zones, namely Western, Central and Eastern based on the geomorphology (*e.g.,* Ly, 1980; Wellens-Mensah *et al.*, 2002). The Eastern coast is an approximately 149 km long high-energy coast stretching from Aflao, Ghana's border with Togo in the east, to the west of Prampram. The East coast is predominantly sandy with barrier lagoons and spits. The sediment particle sizes range from medium to coarse sand with beaches of about 2 m above sea-level in elevation (Boateng, 2012). The Central Coast is more developed than the other two coasts and is known for its moderate energy. It is also the most elongate strip among the three zones with a distance stretch of about 321 km extending from west of Prampram to Cape Three Points. This zone is in the embayed contour of rocky headlands, sandbars and spits enclosing coastal lagoons (Alves *et al.*, 2020). The West Coast is the smallest with 95 km of shoreline from the estuary of the Ankobra River to the border with Côte d'Ivoire. The West coast comprises flat but wide gentle beaches, bordered by lagoons and characterised by low energy events. Coastal erosion occurs to varying extent along the entire coastline of Ghana (Alves *et al.*, 2020)




Various aspects of the coast of Ghana exhibiting coastal lagoons (Butre, top left), low-lying rocky cliffs (Elmina, top right), desert sandy beaches (Axim, bottom left) and moderately occupied areas (bottom right).

The vegetation types of the coast from east to west reflect the rainfall gradient of the area. The vegetation types are strand and mangrove, rain forest, southern marginal moist-semi deciduous forest to the east of Sekondi, guinea savanna and coastal scrub and grassland. The coastal zone and the whole country are under the influence of the tropical humid climatic conditions and experiences two major seasons, namely the rainy season and dry season. The mean minimum rainfall is 900 mm per year occurring around the south-eastern part of Ghana (Accra-Aflao) while the mean maximum rainfall is about 2,000 mm per year, occurring in the south-western portions (Axim) (Tamakloe, 2000).

Fishing is the primary activity of the coastal zone of Ghana (Figure 5.2). Other activities of economic importance that occur in the coastal zone are agriculture, transportation, salt production, oil and gas exploration, sand and stone winning, recreational and industrial developments. Ghana's coastal zone is well-endowed with coconut palms and other resources which are exploited by different sectors of the economy.

Figure 5.2 Aerial view of fishing boats moored together in the port of Tema, Greater Accra, Ghana.
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The coastal zone is well-known internationally for the provision of feeding, roosting and nesting sites for thousands of birds, mostly migratory species. In addition to its importance for biodiversity, the Ghanaian coast is marked by important historical monuments designated as UNESCO World Heritage sites. These sites are significant for both domestic and international tourism due to their rich and significant history.

Ghana's coast faces several challenges, including coastal flooding, coastal erosion, overexploitation of natural resources, marine and coastal pollution, loss of ecosystem services, severe weather, illegal sand mining, rapid urbanisation and unsustainable land use (Boateng, 2012). These challenges degrade the coast, endanger the coastal ecosystems, put human livelihoods and well-being at risk, increase coastal risk and vulnerability to natural hazards, as well as undermine economic potential. The country loses about 2.7 million m^2 of its shore every year, with 80% of the shoreline actively eroding (Appeaning Addo, Walkden and Mills, 2008). The threats posed by these hazards, its effects and impact are expected to further increase due to rapid population growth and sea-level rise in Ghana. Low-lying sandy coastal areas, especially in the eastern coast, could be profoundly affected and, in turn, impact the coastal habitats, biodiversity and socio-economic activities. These hazards are a threat to life, properties and development along the coast, including Ghana's rich heritage of historical coastal sites.

5.2 Coastal hazards in Ghana

5.2.1 Sea-level rise

As global warming expands the ocean's upper layer due to increases in temperature, coastal communities are expected to experience increasing coastal impacts of sea-level rise (IPCC, 2018). Consistent with global increases, sea-level rise in Ghana conforms with the world trend at a historical rate of 2 mm per year and an estimated average local subsidence rate of ≤ -1 mm per year (Boateng, Wiafe and Jayson-Quashigah, 2016).

Ghana's coastal lowlands are expected to be impacted tremendously by rising sea-level as most barrier beaches are retreating at a rate of about 1 m per year in recent decades (Boateng, Wiafe and Jayson-Quashigah, 2016). The rising sea level will aggravate sea incursions resulting in overwash, coastal flooding, land loss and shoreline retreat. The alarming rate of urbanisation and human-induced activities on the coast makes the situation even worse. The problem has placed humans and properties on the backshore in a more vulnerable position to future storms and sea-level rise. A clear example is the Anlo beach, where the whole settlement has been under threat from sea-level rise for some years now. Twice a year, the community is flooded for several weeks by seawater destroying properties and obstructing economic activities. Similar incidence exists in other coastal communities with varying impacts based on the elevations above sea level. Attempts are being made to control shoreline retreat in some areas using gabions and boulders; however, current trends indicate that these measures have not been adequate in addressing the issue.

Globally, it has been accepted that the coastline can cause an horizontal retreat 50 to 100 times the vertical sea-level rise (IPCC, 2007). Hence, the predicted global sea-level rise would cause a shoreline retreat of sandy beaches of 4.5 to 88 m by 2100 in many places around the world (IPCC, 2007). Several of the anticipated impacts of accelerated sea-level rise identified by the IPCC have been experienced in Ghana already (GEPA 2000). This rise will accelerate the disappearance of trees in future decades, which will accelerate erosion and result in the degradation of mangroves and several ecosystems and habitats. Hundreds of species of birds, reptiles and amphibians depend on these freshwater areas. If sea level rises 50 cm in Ghana, these freshwater wetlands will become saltier, and their habitats will be destroyed.

A projected sea-level rise of 1 m by 2100 could see the loss of over 1,000 km^2 of land, with 132,000 people likely to be affected. The east coast is particularly vulnerable to flooding and shoreline retreat. In Ghana, some places in and around Accra are projected to be inundated between the years 2035 and 2065 due to the sea-level rise (Appeaning Addo, 2015). Additionally, a significant proportion of Ghana's infrastructure, such as transportation and communication networks, are located around coastal population centres. Coastal inundation is likely to damage structures and disruption of coastal services.

Fishing village flooded in Ghana.
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5.2.2 Coastal erosion

Coastal erosion and its associated shoreline retreat problems are a serious threat to life, safety, property, economic development and livelihoods of some Ghanaians, as over 70% of the major industries, urban settlements, tourism, heritage and conservation sites are located in the coastal zone (World Bank, 2020). The coast of Ghana is predominantly composed of sandy beaches with fewer rocky areas (Alves *et al*., 2020). High energy waves on this open coast result in favourable conditions for coastal erosion (Appeaning Addo, Walkden and Mills, 2008). Despite coastal erosion being a natural phenomenon, its trends in Ghana have mainly been aggravated by human-induced factors such as beach sand mining or "winning" for building purposes (Boateng, 2012; Jonah *et al*., 2015; Jonah *et al*., 2016), which is illegal (Figure 5.3). The very high vulnerability areas of erosion cover the Cape Coast municipality in the Central region, Jomoro district in the Western region and three coastal districts (Dangme East, Keta and Ketu) on the eastern coast where human settlements, roads and recreational resources are constantly threatened (Figure 5.4). The problem is more severe on the east coast with shoreline retreat rates between 3.4 and 3.9 m per year (Boateng, 2012). These areas under high coastal erosion represent about 15% of Ghana's coastline (Boateng, Wiafe and Jayson-Quashigah, 2016). With no active management, sea-level rise alone could contribute to the movement of Ghana's eastern shoreline, approximately 50-250 m landward over the next 50 years in different locations (Boateng, 2012).

Figure 5.3 Coastal sand mining activities identified in Elmina and Accra coastline: (A) is an example of people actively doing illegal sand mining at the beach, (B) is an example of a blocks mould from beach sand mined.

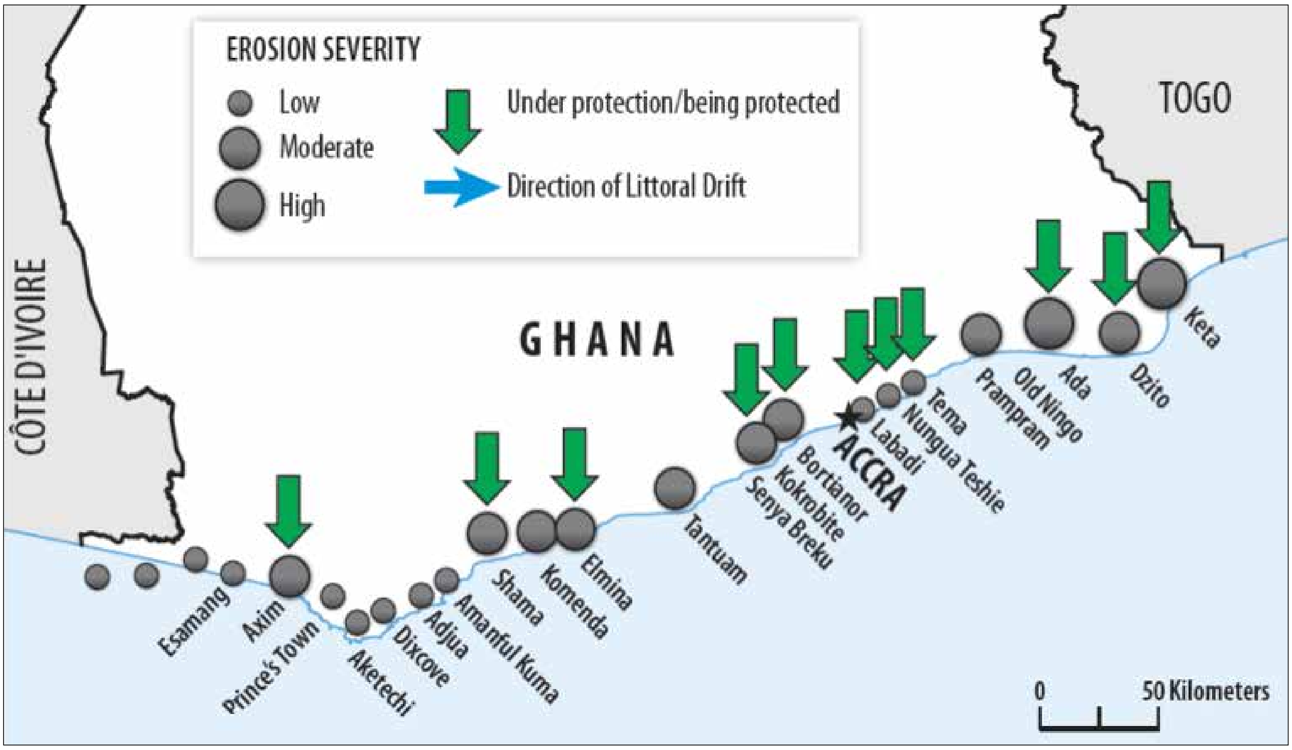

Figure 5.4 Coastal erosion hotspot in Ghana.
Source: Angnuureng *et al.* (2013)

Several major coastal defence projects have been undertaken by the central government along the most affected communities to protect infrastructure and assets of national interests (Jonah *et al.*, 2016). Other small-scale coastal defence projects have also been carried out by property owners along many sections of the country's coast with the view to protect their investments (Jonah *et al.* 2015).

Currently, Ghana has no holistic policy or integrated plan for the management of coastal erosion (Boateng, 2006a), although the National Environmental Policy recognizes the need to manage the marine and coastal zone, the policy does not include clear cut action plans. This considerable gap has caused coastal erosion management to remain traditional, reactive, site-specific, and dominated by hard engineering approaches, which are fraught with their peculiar problems to the coastal environment in response to short-term erosion events that usually threaten facilities located close to the coastal zone.

Climate change and sea-level rise events are expected to increase in the coming years (IPCC, 2018). The persistent impact of sea-level rise, changes in the frequency and intensity of climate conditions and water infiltrating the soil will inevitably accelerate coastal erosion process. The pressure and weathering process on this sensitive environment will only intensify as contemporary coastal urbanisation, population growth and activities continue. Apart from the loss of valuable sensitive ecosystems, socio-economic implications will be severe, as key industries, major residential settlements, poorer tourism dependent communities, conservation sites, UNESCO heritage and historical monument are all located at less than 200 m from the shoreline of Ghana (Boateng, 2012). According to Campbell (2006), 17 coastal inhabitants have lost their homes to coastal erosion over 26 years in the western section of the Accra coast. This indicates on average of approximately 0.7 homes eroded annually in the western section which is significantly high and thus results in displacement of families.

Coastal erosion on Sankofa Beach near Accra, Ghana.

5.2.3 Salinization of surface and ground water

The location of the freshwater–saltwater interface along the coast is an essential factor in the ecological and socio-economic dynamics of coastal communities. However, the movement of saline water into freshwater aquifers, which leads to groundwater quality degradation, is one of the main problems in the coastal regions of Ghana.

The country's natural soil processes are mostly found within the coastal savanna zone (east and central coast) (EPA, 2003). The western coast, where annual rainfall is about 2,000 mm, is also oddly filled with acid sulphate clay soils and salt-affected soils (EPA, 2003). These degraded soils cover over 10,000 km^2 (Gulzar, 2014). Apart from their high salt content and high acidity, most of these soils are heavy-textured, poorly drained with columnar structures (Amisigo, McCluskey and Swanson, 2015).

Recorded cases of salinization occurrence on Ghana's coast calls for primary concern because most of the country's population is concentrated within this zone, and the urbanisation rate is also alarming. Additionally, most of these coastal regions rely on groundwater as their primary source of freshwater for industrial and agricultural purposes. For instance, the Accra Plains contains the main industrial establishments of Ghana and provides one of the wealthiest arable lands for large-scale agriculture to the city of Accra, Tema and nearby towns because of the production of crops using groundwater (Kortatsi, 1994). However, lack of surface water resources and salinisation is depriving the Accra Plains of full utilization for agricultural purposes and reduce it to only backyard farming.

The intrusion of seawater in the soil threatens biodiversity along with crop yields, and the leaching of salts from areas affected by these processes would increase the salinity of water bodies nearby, destroy infrastructure and the economy in the long run. Over the coming decades, changing climate, growing coastal population and increased sea-level rise will raise the salinity of the coastal zone aquifers of Ghana, affecting in various ways its population.

5.2.4 Wetlands change and loss, dry land loss

Ghana's coastal wetland is home to some of the most ecologically valuable and diverse wetlands providing feeding, roosting and nesting sites for thousands of migratory and resident birds, marine turtles, and many species of fish. Such habitats are also a source of plant genetic materials for research and a major source of income, especially for poor communities dependent on agricultural activities, salt mining and other economic activities (Kumi, Kumi and Apraku, 2015). The wetlands of Ghana are characterised by salt marshes, mangrove swamps, tidal flats and various lagoons and estuaries, emphasising the strong influence of tidal actions along the Gulf of Guinea. Five of numerous wetlands along Ghana coast – Keta Lagoon Complex, Songhor, Sakumono, Muni Lagoons and the Densu Delta - have been designated as Ramsar sites for protection (Anderson, 2010).

In recent times, Ghana's coastal wetlands have become an easy target and threatened by human and natural factors due to neglect, urbanisation, unsustainable human activities, and population growth coupled with high rate of migration to coastal urban centres (Kumi, Kumi and Apraku, 2015). The downside of this urbanisation is limited residential facilities to accommodate the population, resulting in rapid conversion of wetlands for housing development, rapid development of slums, mining, harvesting of mangrove as fuel wood, fishing with chemicals, and marine pollution with less regard for the environment (Agyeman, 2019). Aside the country's wetlands being exploited at a much faster rate than ever before, with negative implications for livelihood by urbanisation, natural factors such as saline intrusion, coastal erosion and subsidence are all contributing to this degradation (Davies-Vollum and West, 2015). In most cases, removal of mangrove cover paves the way for dumping of garbage in the wetland areas. This practice does not only reduce the water retention capacity of these systems, but also reduce the abundance of the fishery in these areas by diminishing the nursery grounds, which is a key function of mangroves and their associated estuaries. Consequently, these have led to the frequent flood and storm attack over the few years on communities along the site.

Approximately a quarter of Ghana's wetlands were lost between 1980 and 2006 (Corcoran, Ravilious and Skuja, 2007; Ajonina *et al.*, 2008). While the trends continues with little checks, Ghana was not able to implement its five year "National Wetlands Conservation Strategy and Action Plan" (2007-2012) due to inadequate commitment, lack of resources, and a social climate that favours economic development at almost any cost (Asomani-Boateng, 2019) Presently, the country still lacks an overarching management strategy for this matter. Land use zoning maps that could determine densities and types of development to be pursued or permitted around wetland areas are also lacking. The situation further looks dire due to the lack of scientific data on land uses and land cover types, as well as poor documentation of relevant socio-economic information including anthropogenic stressors around wetlands (Aheto *et al.*, 2011).

Climate change is projected to also have significant impacts on Ghana's wetlands. Although there will be fluctuations in both annual temperatures and precipitation, the trend for temperature over the period 2010-2050 indicates warming in all regions (World Bank, 2010). Continues land-use changes in and around wetlands in Ghana together with the impact of climate change would be disastrous for Ghana's wetlands, the welfare and safety of coastal communities due to its potential effects on property, water, extinction of iconic species, livelihood and food security.

Coastal lagoon and coastal barrier in Bojo Beach near Accra, Ghana.
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5.2.5 Floods

Flooding is one of the most significant hazards that Ghana's coast faces, with wide-ranging social, economic and environmental impacts. Fifty percent of the 540 km shoreline of the central and the eastern coasts are exposed, vulnerable and susceptible to flooding due to their low-lying nature, geomorphology, coastal elevation, geology, local subsidence, sea-level rise, shoreline change rates, tidal range, wave climate, and population density of the coastal areas (Boateng, Wiafe and Jayson-Quashigah, 2016). The frequency of flooding has been on the ascendancy in coastal areas of Ghana since 1995 (Douglas *et al.,* 2008). The effects of flooding in the coastal area of Ghana are further exacerbated by human activities, like building in flood-prone areas, encroachment on wetlands and poor enforcement of development control (Mensah and Ahadzie, 2020).

Floods constitutes one of the major natural hazards that affect the coast with devastating experiences in 1973, 1986, 1995, 1999, 2001, 2002, 2010 and 2011. According to the report on natural hazards in Ghana, floods is second after epidemics with regard to the loss of lives (EM-DAT, 2015). About 409 lives were lost between 1968 and 2014 because of flood events. Between 1900 and 2014, the economic loss as a result of flooding to Ghana was approximately USD 780,500,000 (EM-DAT, 2015). Areas prone to recurring coastal floods include the Accra plains along the coast, the Shama District (Pra River, Ankobra River basins) (Karley, 2009; Coastal Resources Centre, 2013), Sekondi-Takoradi Metropolis (Daily Graphic, 2009) and Keta Municipality (World Bank, 2007). Common causes of flooding are intense rainfall run-off, dam-burst, storm surge (Karley, 2009), poor urban planning (Tasantab, 2019), flaws in the drainage network (Mensah, 1997), poor disposal of waste resulting in blocking of drains and drainage systems and climate variability and change (Appeaning Addo and Adeyemi, 2013)

Flooding along the coast of Ghana, especially in Accra, has become more and more prominent over the years with a 20% chance of flooding in any given year (Asumadu-Sarkodie, Owusu and Rufangura, 2015) with an estimate of more than 172,000 slum residents at risk per year (Rain *et al.*, 2011). This proportion keeps increasing with longstanding rapid rural-urban migration. For instance, the October 2011 flood event affected 43,000 people, killed 14, and displaced 17,000 others in a day (UNEP/OCHA, 2011). After the incident, 100 cases of cholera were reported (UNEP/OCHA, 2011). On 3 June 2015, a heavy downpour in Accra claimed over 152 lives as a GOIL Fuel Station exploded at the Kwame Nkrumah Circle (Shaban, 2016). The blast is thought to have been caused by hours of torrential rain, from which many of the victims were sheltering. The flood destroyed houses, bridges, electricity, washed away roads, among others, to the extent of disrupting the educational, health, water and sanitation sectors.

The government of Ghana has inaugurated statutory supervisory agencies such as the Ministry of Works and Housing (MWH), Ministry of Health (MoH), Ministry of Local Government and Rural Development (MLGRD), City Engineers and Urban Planners to prevent and mitigate the socio-economic effect of flood on human lives and properties (Frick-Trzebitzky and Bruns, 2017). However, these agencies' management strategies, both past and present, include hard-engineered seawalls, groins, breakwaters, drain construction, waterways dredging, and educational campaigns, have not been enough in tackling the underlying causes. Consequently, new areas periodically experience floods. A major setback to these agencies in performing their duties is the lack the financial capacity to embark on flood prevention activities. Funds for flood prevention are instead spent on perpetual cycles of recovery (Tasantab *et al.*, 2018) leading to an increase in relief expenditure and health control by government.

A USAID report from 2010 estimates that about 1,842,000 people in Ghana live in coastal zone areas situated below an elevation of 20 m (World Bank, 2017b) and are potentially at risk from storm surges and coastal inundation. Seventy percent of these people are urban poor residents in Accra (Rain *et al.*, 2011). This figure is expected to increase to more than 3 million by the year 2050 (USAID, 2014) with slums emerging along major river banks within the coastal zone (Karley, 2009). Projections by IPCC (2012) for West Africa and Ghana indicates that annual rainfall during the wet season tends towards increase, suggesting that torrential rain is likely to become more intense, increasing flood risk from surface water and ordinary watercourses, as well as rivers. Sea-level rise is also projected to reach 5.8 cm, 16.5 cm and 34.5 cm by 2020, 2050, and 2080, respectively. Indeed, Meehl *et al.*, (2007) suggest that flood-prone coastal area in Ghana is likely to be further affected by sea-level rise and storm surges by the end of this century.

With much of Ghana's infrastructure concentrated in the coastal zone (Amlalo, 2006), frequent and increasing extreme floods will bring a huge number of risks to the coastal zone of the country, which could have consequences on essential services and on the national economy. Industries and business dependent on access to or use of the coastal zone need to prepare for the impacts of climate change and flooding. Many industries are made up of small size to medium-sized operators that have less capacity to adapt to these hazards.

Urban coastal landscape in Ghana's Gold Coast.
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5.2.6 Droughts

Ghana is vulnerable to drought although the phenomenon is more frequent in the northern part of the country than the coastal south. Drought occurrence is defined by two main factors: reduction in the amount and frequency of rainfall and reduction in streamflow (EPA, 2015). The variability of mean annual rainfall in the coast is between 750 mm per year in the coastal savannah, to approximately 2,200 mm the western coast (Owusu and Waylen, 2009; Kranjac-Berisavljevic *et al.,* 2014). Notwithstanding average variability in rainfall being relatively moderate, rainfall totals turn to change dramatically across years (Ghana Meteorological Agency, 2008; Tan and Rockmore, 2018). As an example, annual rainfall in Accra have historically varied between 1,197 mm and 275 mm (Ofori-Sarpong, 1986).

While Ghana has experienced droughts and prolonged dry spells throughout its history, causing serious hydrological imbalances that adversely affected the land resources production systems, fresh water supplies, vegetation and crops, leading to diseases' outbreak and social unrest. The 1983 drought was particularly intense in the coastal areas, with Accra recording its second lowest annual total rainfall (58% of the average amount) and other regions recording their lowest annual total rainfall (Ofori-Sarpong, 1986). The effect of the drought was shortages in food production, domestic price increases, lowered family income and a general decline in human livelihood (Tan and Rockmore, 2018). The fiscal situation of the country was further complicated by the substantial drop in cocoa production, the main export crop and source of government revenue from an average of more than 450,000 tons per year to a low of 159,000 tons in 1983-1984 (Mulangu, Miranda and Maiga, 2015). Since the 1983 drought, other intermittent droughts have occurred in 1993, 2003, 2006 and 2007 which affected Ghana's hydroelectric infrastructure with huge socio-economic burden on the country (Bekoe and Logah, 2013).

Ghana has recently transitioned to an industrial and service sectors led economy; however, agriculture still plays a crucial role in the economy by contributing to 21% of the country's GDP, employing 45% of the country's workforce, and supplying over 70% of the country's food (Ministry of Foreign Affairs of the Netherlands, 2018). The agricultural sector is believed to have the potential to grow at rates as high as 6% (Breisinger *et al.,* 2008). However, the agriculture system in Ghana is predominantly rain-fed, making it highly vulnerable and sensitive to drought events, especially in the eastern coast and Volta Basin, where prolonged dry seasons have replaced shorter dry spells (Pinto *et al.*, 2012).

In the last decade, an increase on the incidences of drought across the country with decline in food production was observed (National Development Planning Commission, 2015a). Studies by Gbangou *et al.* (2020) and rainfall statistics from the Ghana Meteorological Agency (GMA) between 1961 and 2010 reveal an overall decline in average annual rainfall and an increase in the dry spell frequency along the coastal savannah of Ghana.

Whilst uncertainties remain on future estimates of rainfall and temperature changes, the IPCC's projections on climate change suggests trends of increased inter-annual variability of rainfall with increased drought intensity and frequency (IPCC, 2007). Mean minimum temperatures over the coastal zone of Ghana is also projected to rise by 1.1 °C, 2.5 °C, 1.9 °C, by 2040, 2060 and 2080 respectively, whilst rainfall across the country has been projected to decrease by 2.9% in the near future (EPA, 2015). Because of these scenarios, dryness and drought is likely to be more regular and more extended in duration.

Food security in Ghana is expected to be placed under severe considerable stress due to climate change, and variability (FAO, 2010) as most food production systems are generally rain-fed. While the data is not available, the vulnerable and the poor also face increased disease risks resulting from large-scale cholera and malaria outbreaks because of drought. Ultimately, the coast, especially the eastern coast, could become more marginal and unproductive during the periods of low precipitation, with seawater intrusion into the groundwater aquifers and profound effect on agriculture and drinking water supplies.

Goats hoping for rain in Ghana.

5.2.7 Marine pollution and water quality change

Many areas along the coast of Ghana lack adequate wastewater and solid waste management systems causing large volumes of untreated sewage and solid waste being dumped into nature, polluting aquatic ecosystems. The untreated waste mainly comes from communities, agricultural, and industrial activities. Although little information and data are available, the primary sources of pollution are waste products from coconut oil extraction, discharge of human wastewater, waste from shipping operations, oil spills, inadequate ballast water management, dredging and deposition of solid waste, especially plastics, into streams, wetlands and the sea (World Bank, 2013).

Miezah *et al.* (2015) suggest that about 12,710 tons of waste is generated every day in Ghana. Based on the current population of 30 million, of which 25% live in the coastal zone, urbanisation is likely to increase waste generated and the volume of untreated sewage entering the marine environment.

Along the beaches of Ghana, debris and rubbish are all too familiar after rains, as some coastal communities practice burying of plastic and waste in the sand at the beaches (Ackon-Mensah, 2018). With time, waves erode the sand and expose the rubbish to the sea and degrade the quality of the water (Figure 5.5).

The collection, transportation, and treatment of wastewater from onsite systems are so limited that most of the sludge from these systems end up in roadside drains and storm drains before being discharged into the ocean or other bodies (World Bank, 2012). Besides faecal deposits in aquatic biodiversity being too common in poor coastal communities (slums), trucks dump untreated domestic effluent into the ocean every day, which poses a severe health risk to both the users of the beach and sea. For instance, 250,000 gallons of domestic effluent from Accra is discharged into the ocean daily when the city's wastewater treatment plant breaks down (Goodier and Fairbabugh, 2016).

Moreover, studies have shown that Ghana's five river basins and other small streams which used to be source of drinking water have now been impacted by illegal small-scale gold mining (Owusu *et al.*, 2016). Aside illegal mining activities of gold, sand winning in and around the beaches and water bodies is also polluting water bodies, enhancing coastal erosion and disrupting aquatic life (World Bank, 2012).

Figure 5.5 Waste management is a serious environmental issue in Ghana as clearly visible in many of the country's beaches closer to urban centres.
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5.2.8 Changes in the distribution and abundance of coastal and marine species

Ghana's fishing industry is based on resources from the marine, inland sectors and coastal lagoons and endowed with significant and valuable stocks of fish, producing 430,000 tonnes of catch annually (Afoakwah, Osei and Effah, 2018). However, available scientific evidence has repeatedly pointed to the undisputed fact that Ghana's marine fisheries are in crisis, with fish landings gradually decreasing over the last decade (Lazar *et al.*, 2016). While fishing effort continues to increase and landings are declining, the catch per unit of effort is getting lower, and sizes of landed fish are diminishing, suggesting overfishing (Lazar *et al.*, 2016).

Production from marine fisheries has been declining since 1999, from almost 420,000 tonnes to 202,000 tonnes in 2014 (FAO, 2016). Small pelagic landings have dominated marine fish production in Ghana over last 25 years; however, landings in recent times have dropped to 20% of the total marine landings (Lazar *et al*., 2016). Averagely, 135,000 metric tons were produced annually between 1980-2014. The whole small pelagic species catch in 2014 represented 24% of the average landings from 1980 to 2014, and only 12% of the maximum landings catch in 1996 (Lazar *et al*., 2016).

Too many vessels are exploiting the current resources. Industrial fishing vessels mainly bottom trawler players, semi-industrial vessels made up of large and smaller vessels typically wooden vessels and artisanal fishing vessels have all increased significantly in numbers and capacity over the last 10 years (MFAD, 2015). The situation is further worsened with all fishing fleets – except the tuna fleet – operating within the exclusive inshore zone (MFAD, 2015), which is invariably the spawning ground for most fish species. Additionally, illegal fishing practices, inadequate scientific information on the biology and current biomass levels of the main commercial species and not enough punitive deterrent measures are hugely contributing to the gradual dwindling fish stock in Ghana (Afoakwah, Osei and Effah, 2018).

The declining fish landings have significant disastrous consequences implication to Ghana's economy, livelihoods and food security. Fish forms more than 60% of animal protein intake by the Ghanaian population and generates over USD 1 billion in revenue each year (MFAD, 2015). The sector further accounts for at least 4.5% of Ghana GDP and provides a livelihood for an estimated 10% of the population, including their dependents (MFAD, 2015).

Crowded beach with market, football field and numerous fishing boats in Accra, Ghana.
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The national demand for fish is estimated at over 950,000 metric tons of fish annually (Lazar *et al.,* 2018), but approximately 40% is produced locally due to declining stocks leaving a supply deficit of 60%, filled in by fish imports worth more than USD 135 million (Allotey, 2017). Aquaculture production currently cannot narrow this gap either, given that a significant share of the population relies upon fish and fish products (MFAD, 2015). The situation has resulted in Ghana becoming a net importer of about 40% of its fish requirements. This Figure is likely to increase in the coming years due to the current population growth rate, combined with the continuous increase in fishing capacity and efficiency and dwindling trend in fish landings.

5.2.9 Coastal livelihood, urban sprawl and infrastructure development

The coastal zone of Ghana serves as home to many people. The zone represents about 7% of the country's total land area, home to about 25% of the nation's total population and 70% of its industries and businesses (World Bank, 2020). The presence of diverse natural resources, industrial installations and employment opportunities pulls people of different social backgrounds to the coastal areas of Ghana. The net effect of these pull factors has resulted in the faster growth of coastal urban areas than those in non-coastal areas.

The urbanization of Ghana's coastal areas has been momentous, relying largely on industrial development. For example, two large coastal mega-cities, Tema and Takoradi, as port cities have attracted a lot of industrial development. Additionally, following the discovery of oil in 2007 and commercial production in 2010-2011, there has been significant oil and gas infrastructure development in coastal areas of Ghana. The results of this increased industrial development have led to massive growth and expansion of coastal urban areas, resulting in both intensifications of densities and sprawling into peri-urban areas as well as high concentration of settlements within a short distance from the coastline (Appeaning-Addo, 2014).

Weak enforcement of planning standards and building codes has resulted in many of the peripheral villages and towns being engulfed by the conversion of agricultural land, pastures and mangroves into urban land-uses, with slums developing along major riverbanks and drains especially in Accra (World Bank, 2020). The continuous unplanned sprawl of coastal urban areas in the country (Figure 5.6) has made the coastal zone vulnerable and prone to floods by reducing the infiltration capacities of the basin surfaces for the amount of water that enters the soil before runoff occurs (World Bank, 2020).

Figure 5.6 Unplanned sprawl of coastal urban areas in Accra: (A) Residential houses in flood-prone areas, (B) Upcoming residential building in flood-prone areas along the beach.
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Poor urban planning and poor infrastructure delivery, primarily hydraulic, solid waste management, and transport infrastructure has exacerbated Ghana's vulnerability to coastal flooding, compounded by inadequate solid waste management that obstructs the natural runoff, sea-level rise, tides, and storm surges, with downstream effects on cultural heritage, biodiversity and livelihoods, among others.

With the recent oil and gas find in the region, coastal wetlands are increasingly being encroached upon for different purposes, notably agriculture, aquaculture, beach sand winning, residential housing development, and economic and social infrastructural development. The net effect is the degradation of the coastal environment, including wetlands.

5.3 Coastal risk management in Ghana

The 1992 Constitution of Ghana provides the basis for environmental laws, which enshrines commitment to a sound environment. Chapter Six of the constitution, "Directive Principles of State Policy", assigns the responsibility of ensuring sustainable use of Ghana's natural resources to both Government and citizens. Article 36(9) pronounces that "the State shall take appropriate steps needed to protect and safeguard the national environment for posterity; and shall seek cooperation with other states and bodies for purposes of protecting the wider international environment for mankind." Notwithstanding the provision in the constitution, Ghana currently has no national legislations or policies that specifically target issues of integrated coastal zone management (Wiafe, Boateng and Appeaning Addo, 2013; World Bank, 2020); however, the country has numerous existing environmental policies and strategies that protect the country's coastal zones. According to Amlalo (2006), the main thrust and orientation of these existing national policies and legislations on the protection and management of the marine and coastal environment is hinged on three major areas: coastal zone management and sustainable development, marine environmental protection, both from land-based activities and from sea-based activities, and sustainable use and conservation of marine living resources.

The promulgation of the numerous existing environmental policies gave way to specific plans, education and awareness creation programmes and management strategies to ensure prudent management of the marine and coastal environment. Past and existing coastal risk management strategies have largely focused on provision of hard protection at specific locations where risk levels to life and economic assets are high. There has been little commitment to the concepts of integration of management interventions with wider natural processes and longer-term sustainability. In most cases, such ad hoc management interventions classically tend to stabilise the shoreline at the protected section and aggravate the situation elsewhere along the shoreline (Wiafe, Boateng and Appeaning Addo, 2013).

Ghana's coastal zone management plans and strategies

National Environmental Action Plan (1994)

The National Environmental Action Plan (NEAP) of 1994 was developed in reaction to a host of environmental problems that had arisen from the exploitation of Ghana's abundant natural resources to meet socio-economic needs. The plan defined a set of policy actions, related investments, institutional mandates and strengthening activities to make Ghana's utilisation of its natural resources environmentally sustainable. The adoption of NEAP led to development of different management resources in major areas including land management, water management, marine and coastal ecosystems.

Coastal Zone Management Indicative Plan (1990)

The Coastal Zone Indicative Management Plan (CZIMP) has demarcated the landward extension of the coastal zone of Ghana as the "line joining the landward limits of lagoons, lagoon depressions, marshes and estuarine swamps, together with intervening interfluve areas" (Armah & Amlalo, 1998).

National Oil Spill Contingency Plan with specific reference to the marine environment (2002)

The Oil Spill Contingency Plan outlines the national arrangements for responding to oil spills in the environment, with the aim of protecting it from oil pollution or, where this is not possible, to minimise its effects. The plan also ensures that adequate protection is provided for public health and welfare and the marine and inland environment (Environmental Protection Agency, 2019). The plan provides the framework for co-ordination of an integrated response by government agencies and relevant stakeholders to protect the environment from the deleterious effects of pollution from spillage of oil substances. It is intended to promote the development of local plans for ports, inland waterways, oil pipelines, oil installations, and all other storage and transport facilities for oil to respond to such incidents.

Environmental Sensitivity Map of the coastal areas of Ghana (1999 and 2004)

The Environmental Sensitivity Map is a GIS-based environmental planning tool for the coastal zone management planning and implementation on the response to coastal risk. The maps contain 96 maps (scale 1:20,000) covering the entire coastline of Ghana illustrating geological, ecological and human use features relevant in coastal zone management and in oil spill combat (Environmental Protection Agency, 2004). Each map sheet includes a short description of the main features and indicates the ranking of the coastline in terms of sensitivity to oil spills. The maps focus on coastal environmental features within a coastal corridor of 4-5 km being the most sensitive area with respect to oil spills and containing focal issues in coastal zone management.

5.3.1 Governance

Coastal zone management in Ghana is under two spheres of government: central and local.

National Government

The national level is headed by the Presidential cabinet which takes national decisions on environmental and natural resource management policies and planning. Just below that level, by its mandate the Environmental Protection Agency (EPA) provides an inter-sectoral forum to discuss environmental issues prior to making recommendations to be considered at the national level. Sectoral agencies have responsibility to prepare and implement sectoral development plans. The EPA also serves as a technical secretariat, interfacing with sectoral agencies and acts as a clearinghouse through several inter-sectoral networks. At the base of the system are District Assemblies (DAs) and community authorities that together manage environmental resources through mechanisms that facilitate community participation and are underpinned by local by-laws.

Local Authorities

In Ghana, the metropolitan, municipal and DAs are the political and administrative local authorities responsible for the day-to-day development, improvement and management of coastal zones, human settlements and the environment as decreed in Section 12(3)(e) of the Local Government Act, 2016 (Act 936) and the National Decentralization Policy Framework 2015 – 2019 with the support of the community. This responsibility is exercised subject to policy directives, guidance, planning evaluation, and monitoring responsibilities of central government and its agencies.

5.3.2 Academia

The academic and education communities provide the basis for new and sustainable approaches, solutions and technologies to support the government in meeting the challenges of coastal management in Ghana. The role of science in the implementation of the United Nations Sustainable Development Goals (SDGs) on water (SDG 6) will be particularly important, as tackling water challenges requires both sound policies, supported with adequate resources, and new scientific approaches to deploy sustainable solutions and appropriate technologies. The contribution of science to the achievement of water-related Millennium Development Goals (MDGs) targets has already been significant, notably to providing access to safe drinking water, reducing deaths caused by water-borne diseases, and improving hygiene to reduce health risks related to unsafe drinking water and lack of sanitation. This important contribution of science to the attainment of the MDG target on access to water and sanitation has laid a solid foundation on which to build and continue efforts for the implementation of SDG 6. Indeed, the latter's proposed targets build on the unfinished agenda on access to water and sanitation and furthermore link it to water resources management issues such as improving water quality and wastewater management, increasing water efficiency, promoting integrated water resources management and reducing water-related risks. UNESCO strongly believes that science and education is also a key contributor to reducing inequalities and poverty by bequeathing the conditions and generating the opportunities for better, sustainable lives.

The scientific community provides significant contributions to setting of meaningful and feasible goals, supported by scientific evidence, during the consultation processes with the government and its agencies. The contribution of the academic community is central in developing sustainable solutions to address water challenges through advancing water sciences. In addition, academia (Department of Marine Sciences at the University of Ghana-Legon, and Department of Fisheries and Aquatic Sciences/Centre for Coastal Management at the University of Cape Coast) as centres of excellence, engages in teaching and research to train high level professionals with the needed technical and scientific competencies to manage marine and coastal zones.

5.3.3 Society

Civil society and Non-Governmental Organizations (NGOs) in Ghana partner with the central and local governments in planning and management of coastal resources. They are mostly representatives of communities and are in constant touch with the needs and priorities of the communities. They operate at the grassroots level, and support government to carry out projects that have been identified by the communities in achieving its development objectives of poverty reduction, food security, sustainable fisheries management and biodiversity conservation. Moreover, they have local knowledge of natural resources and their (sustainable) uses and bring experiences from other parts of the world to assist government project.

5.4. Coastal adaptation and risk mitigation in Ghana

Coastal hazards are a major threat to the development and progress of Ghana. The coastal population is large and growing because of the booming oil and gas industry, and large urban centres and much of the country's economic activity are located along the coast. The Government therefore seriously considers coastal risk management to be vital within the national development: in recognition of the risks, vulnerabilities and challenges along the coast of the country, the Government and the donor community have begun to determine adaptation priorities, and to integrate this knowledge into development and sectoral planning. A few government adaptation priorities remain in the early stages or are still unaddressed, including mainstreaming adaptation into national, sector-specific and local-level planning, strengthening the capacity of the local authorities, and expanding investment in a coastal risk project that reduces risk and better targets the adaptation efforts.

5.4.1 National level

To protect functional coastal ecosystems and reducing vulnerabilities to existing coastal hazards which are being influenced and worsened by climate change, the Government of Ghana has already initiated national policies and strategies on climate change and adaptation. These policies and strategies also meet international commitments to provide a targeted approach for decreasing vulnerability and increasing resilience of communities, positioning the country for accessing funds to meet national adaptation needs, while also raising stakeholders' awareness. The policies form the basis for coastal zone management towards national development and environmental sustainability and facilitate coastal risk reduction (World Bank, 2020). The key national adaptation policy framework is the National Adaptation Plan Framework (NAP) of 2018 (Antwi-Agyei, 2018), National Climate Change Adaptation Strategy (NCCAS), 2012, and the National Climate Change Policy (NCCP), 2014 (Mensah, Anderson and Nelson, 2016). The strategies of the two key national adaptation policies describe the prioritised interventions for adaptation focused on reducing vulnerabilities and innovative adaptation measures, such as: the improvement of the quality and access to information, increase of the resilience of both built and natural infrastructures, improvement of water supply and quality, improvement of the resilience of agricultural systems, and improvement of the social support for vulnerable groups (Mensah, Anderson and Nelson, 2016).

There are also a few other national policies and plans that also provide complementary actions within the coastal infrastructure and management plan, such as the Medium-Term Development Plan (MTDP) prepared every four years (National Development Planning Commission, 2018). The strategy and actions provided in these national development frameworks gives detail actions to coastal zone management to collaborate the NCCAS and NCCP with action measures for adaptation and mitigation for effective groundwater management, coastal infrastructure, coastal land zoning, entrepreneurship promotion, sustainable tourism, effective utilisation of available resources with knowledge management, and social communication (National Development Planning Commission, 2015b). The current development framework in place "An Agenda for Jobs: Creating Prosperity and Equal Opportunity for All (first step) 2018-2021" presents measures to enhance coastal zone management and its resources exploitation with adaptation (National Development Planning Commission, 2020). In addition to national adaptation strategies and policies, the Government of Ghana has setup a Coastal Development Authority (CODA) to lead the process of providing infrastructure support for poverty alleviation and inclusive growth in the coastal zone.

In summary, Ghana does not have one-in-all adaptation measures and plan for dealing with climate change in the coastal zone. However, different specific national policies and strategies together with the different national plans (Table 5.1) give the needed and necessary measures for coastal zone management.

Table 5.1 National policies, strategies, and measures for enhancing coastal community adaptation to coastal risk and mitigation of vulnerabilities.

Policy/Plan	Strategies	Measures
Medium-Term National Development Policy Framework (2018-2021)	Ensure sustainable development and management of aquatic fisheries resources Promote sustainable water resources development Reduce coastal erosion Conserve marine areas	Provide adequate economic incentives to stimulate private sector investment in aquaculture development Promote marine conservation and protection in a sustainable manner Map and assign conservation status to wetlands Enforce appropriate legislation to protect wetlands Strengthen involvement of local communities in management of wetlands Promote investment in hard control structures including gabions and boulders Promote mangrove forest replanting and planting of other vegetative cover to contain erosion Control sand mining along beaches Strengthen the participation of local communities in sustainable coastal management practices Prepare and implement an Integrated Coastal Zone Management (ICZM) Plan Enact appropriate legislation to protect mangrove forests, wetlands and marine areas from degradation Establish a Coastal Zone Commission with strong stakeholder participation Regulate harvesting and eliminate illegal, unreported, unregulated, destructive fishing practices Promote efficient solid and liquid waste management in coastal communities Strengthen institutional capacity for research, monitoring and enforcement of legislation and byelaws Promote efficient solid and liquid waste management in coastal communities
National Climate Change Adaptation Strategy (NCCAS) (2010 to 2020)	Improve society's awareness of and preparedness for future climate change Enhance the mainstreaming of climate change into national development to reduce climate change risks Increase the robustness of infrastructure development and long-term investments Increase the flexibility and resilience of vulnerable ecological and social systems to enhance their adaptive capacity Foster competitiveness and promote technological innovation	Promote fish farming Sustain livelihoods through enhanced fisheries resource management Design and implement programmes on fisheries management and disease control Identify and enhance early warning systems Minimize impacts of climate change for the poor and vulnerable Enhance national capacity to adapt to climate change through improved land use management Adapt to climate change through enhanced research and awareness creation Manage water resources as climate change adaptation to enhance productivity and livelihoods Minimize climate change impacts on socio-economic development through agricultural diversification Develop and implement of environmental sanitation strategies to adapt to climate change
National Adaptation Plan Framework (2018)	Engage the private sector in climate change adaptation Ecosystem-based approach to management Community-based adaptation (CBA) approach to reduce risk	Leverage the private sector in climate change adaptation Include private commercial banks, microfinance institutions and private insurance companies for financing for the implementation of climate actions Place local communities at the centre of adaptation planning Harness the traditional authority structure in Ghana to promote climate change adaptation

Policy/Plan	Strategies	Measures
National Climate Change Policy (2014)	Climate-resilient agriculture and food security systems Disaster preparedness and response Natural resource management Equitable social development Energy, industrial and infrastructural development	Develop and promote climate-resilient cropping systems Support to adaptation in the fisheries sub-sector Support to water conservation and irrigation systems Risk transfer and alternative livelihood systems Build capacity to design climate-resilient infrastructure Climate-resilient sectoral and local development planning Ensure that existing key infrastructure is climate proof Flood prevention activities Develop climate-resilient infrastructure for key services Protect coastal resources and communities Rapid response and disaster management Ecosystem-based adaptation Water and land management Social protection for migrant poor Comprehensive wastes (solid, liquid and human) management
Disaster Risk Management Country Plan (2014)	Advocacy and capacity building for disaster risk reduction Improve flood forecasting Communicate flood risk information	Develop a training agenda and material to address disaster risk reduction and preparedness Organize high level public events to raise awareness to disaster risk reduction and management Enhance data sharing among relevant institutions for more accurate flood forecasting and real time information provision Make flood risk information available to the district assemblies
National Urban Policy Framework (2012) National Urban Policy Action Plan (2012)	Promote climate change adaptation and mitigation mechanisms	Intensify public information and awareness campaigns on energy conservation, climate change and mitigation strategies Encourage progressive reduction of hazardous substances by industry Promote settlement structure plans designed to achieve a high level of amenity as well as the prevention of effluent and refuse pollution Promote and strengthen cooperation of adjoining Metropolitan, Municipal and District Assemblies (MMDAs) in collaboration with traditional authorities and other relevant stakeholders in management of water bodies and other natural resources Avoid coastal zone development which affects ecologically sensitive areas Impose and enforce more effective coastal zone and wetlands management regulations Strengthen the capacities of agencies that are charged with promoting environmental standards Generate public awareness on climate change and mitigation strategies through mass media educational campaigns

5.4.2 Sub-national level

At the sub-national level, municipalities and districts are the main bodies mandated for development planning, implementation and monitoring. Government-led adaptation initiatives, within the framework of coastal zone management, are implemented primarily by actors at the local level, led by the Metropolitan, Municipal and District Assemblies (MMDAs) through their environmental and planning committees (National Development Planning Commission, 2015a). MMDAs rely on national adaptation policies, plans, programs and strategies to formulate their plans and actions. Planning at this level is guided by the NDPC guidelines for medium-term development planning at the district and municipal level (National Development Planning Commission, 2015a). In 2014, these guidelines were updated to explicitly address climate change issues, among other cross-cutting themes (Adaptation Learning Program [ALP], 2014; Sova *et al.*, 2014).

While the national adaptation strategies mostly deal with largescale and structural protection of the coastal zone, the MMDAs deal with the day-to-day activities, livelihood, social construction and immediate response to risk and disaster in the coastal zone. The MMDAs collaborate with the decentralised representatives of different sectoral ministries, as well as NGOs, CBAs, traditional authorities, and the private sector to develop adaptation and disaster risk management plans, incorporating actions identified in community-level adaptation plans (Table 5.2). However, Kankam *et al.* (2013), makes the point that MMDAs and coastal communities in Ghana have limited adaptive capacity to respond to emergencies generated by natural hazards. The limited capacity forces some sections of the communities to find their own alternatives short term adaptation measures such as moving in with family and friends, re-enforcing their homes during disasters.

At the community-level, adaptation options are often straightforward, simple, with practical actions that counter or reduce impacts (Yaro, 2010). Dominant adaptation strategies deployed by households at the community level in response to coastal risk and variability include livelihood diversification, crop diversification, migration, planting drought-tolerant crops, cultivation of upland crops, constructions of wells, boreholes, and water harvesting (Adodoadji-Dogbe, 2018). Local adaptation practice is often based on indigenous knowledge (Gyampoh and Asante, 2011), varies from zone to zone, (Gyampoh and Asante, 2011; Yaro, 2010) as well as according to the asset's holding level and the livelihood group (World Bank, 2020). Although individuals and communities have shown the ability to adapt to coastal risk and variability in the past, their ability to adapt effectively to current and future climate change will be influenced largely by the institutional and economic environment. Institutional and economic parameters affect the vulnerability and adaptive capacity of societies.

Table 5.2 Summary of adaptation/coping strategies at the local and community level.

Issues	Hazard	Community Coping Strategies	Community Adaptation Strategies
Fishing	Depletion of fish stock	Reduce fish catches	Some coastal communities and households are diversifying fishing and engaging in alternative livelihood to fishing (Antwi-Agyei *et al.,* 2013)
Farming	Drought and erratic rainfall	Irrigation Crop diversification	Some households capture and store rainwater to irrigate their farms and thus grow crops all year round (Adodoadji-Dogbe, 2018) Grow drought-resistant varieties (Adodoadji-Dogbe, 2018) Some coastal communities and households are diversifying and engaging in alternative livelihood to coastal farming (Antwi-Agyei *et al.,* 2013)
Rise in sea-levels	Inundation and wetland flooding from tides and storms	Construct sea defence structure Build resilient housing	Construct embankments (Tasantab *et al.,* 2019; Kankam, 2013) Some households build structures that have been elevated to reduce the impacts of tides and storm surges (Adodoadji-Dogbe, 2018)
Floods	Inundation and flooding of communities and farmlands	Construct temporary drainage channels (at home and on farms) Move to secure places before the start of rains Relocate temporarily to live with family and friends	Construct drains and dredging silt from major drains to improve drainage and avoid excess moisture (Mensah and Ahadzie, 2020) Construct embankments and sandbags in front of houses to prevent flood waters from entering their homes and shops (Adodoadji-Dogbe, 2018; Mensah and Ahadzie, 2020) Some households and settlement relocate their settlements and economic activities from flood-prone areas (Mensah and Ahadzie, 2020)

5.3.4 Evaluation of adaptation and mitigation strategies in Ghana

Ghana has initiated several policies and strategies with the aim of reducing risks and vulnerability in the coastal areas with the support of DAs (Coastal Resources Centre, 2013). Adaptation responses generally have been mostly incremental and short-term as compared to long-term transformative responses. The National Climate Change Policy acknowledges the challenge of uncertainties and states that to address this challenge, policy decisions should be robust enough to withstand many different climate change scenarios (Antwi-Agyei, 2018). Although stated on paper, this is often not achieved in practise. Regrettably, most of these efforts has been given little or no attention by coastal dwellers. Considering the increased rate and magnitude of disaster, risk, vulnerability and climate change impacts in the country, broader transformation will be required to addressed them in a more substantively and robustly way.

To address the impacts of coastal risk and vulnerabilities analytically and effectively, there is the need to put in place a comprehensive framework or policy such as ICZM. It would provide a context and guidance for implementing specific measures, which can also be a source of adaptation. ICZM also provides an opportunity to introduce measures that can effectively address anticipated impacts. Effective ICZM policies are likely to strengthen adaptive capacity, build resilience and reduce vulnerability to the impacts of climate change at various levels in the society.

With the development of the National Climate Change Policy Framework and its accompanying National Climate Change Adaptation Strategy in 2010, a foundation was laid for the development of the substantive National Climate Change Policy in 2013. Whilst these strategies and activities has helped to shape poverty reduction strategies within vulnerable communities, it did not influence a broader incorporation of integrated coastal zone management (Gyampoh and Asante, 2011).

5.5 Final remarks

In Ghana, coastal zone management remains traditional, reactive, site-specific, and dominated by hard-engineering approaches. The current shoreline management regime is not sustainable given the global perspective of climate change and associated sea-level rise. Hence, there is much reason for concern on the need for a holistic shoreline management plan that is sustainable and can stand future pressures of sea-level rise, climate change and economic development. Like many other nations with a long history of coastal zone management interventions, in an accelerated sea-level rise context, Ghana cannot opt anymore for measures that are expected to cause unsustainable impacts and to increase risk levels along the coast.

Moreover, the mandate of Ghana's multitude of coordinating bodies remains fixed at the central level, despite the local nature of many adaptation responses. Projects and programmes that work directly with rural communities at the district- and village-level are not captured by the central-level coordination units and are thus not reflected in Ghana's adaptation portfolio nor get to be implemented. The country's new composite budget has theoretically fortified the DAs' central planning and coordinating role by transferring funds directly through the MMDAs for subsequent distribution to agencies falling under the purview of the Assembly (Mensah, 2005). Yet, significant delays in the release of central-level funds to the DAs and their limited capacity to produce internally generated funds through local taxation have challenged the confidence in the system. The evidenced shows that the MMDAs, due to insufficient financing, have hardly implemented the medium-term development plans, constituting a waste of the scarce funds, time and energy (Mensah, 2005).

There is the need for public policy to create the right environment for the implementation of appropriate adaptation measures to climate change, which will require:

- Improved data relating the physical, natural and human environments of Ghana's coastal zone
- Improved communication and collaboration between government agencies, local administrations and landowners and other interested parties
- Awareness raising and limited legislation to encourage engagement and facilitate planning
- Modest funding to establish the processes of integrated coastal management

The coast of Ghana is prone to multiple hazards like coastal erosion, coastal flooding, storm surges and sea-level rise, among others. The continuous urbanisation and development of the coast makes it more exposed to these multiple hazards, jeopardising the country's goal of becoming a middle-income country and the well-being of its population. The extent to which these hazards occur is likely to increase under the scenarios of climate change. While the sea level rises, the continuous influx of people into the coastal zone to work and live in flood-prone areas poses a huge risk and challenges to coastal risk management in Ghana. The assessment of coastal risk and vulnerability must not only include physical aspects of the coast, but also its human components and economic livelihood. Importantly, the unique assets of the coastal zone and its ecological values should be duly considered when necessary measures are planned, designed and executed.

However, continuous efforts are needed to address the underlying factors of multi-dimensional poverty, population growth, gender inequality, and resource degradation that leave many Ghanaian coastal residents vulnerable to the impacts of coastal hazards and climate change. This requires close cooperation in-between authorities responsible for the coastal flood defence, nature conservation, marine spatial planning and coastal zone management. NGOs that manage sites in the coastal zone are also an important partner in coastal risk management.

Finally, the knowledge and experiences about coastal risk management in Ghana should be shared through academic, policy and practical levels. This will help to ensure safety as well as to create a viable environment for working and living.

Acronyms and abbreviations

CBA	Community-Based Adaptation
CODA	Coastal Development Authority
CZIMP	Coastal Zone Indicative Management Plan
DAs	District Assemblies
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GMA	Ghana Meteorological Agency
GSS	Ghana Statistical Service
ICZM	Integrated Coastal Zone Management
IPCC	Intergovernmental Panel on Climate Change MDGs
MDGs	United Nations Millennium Development Goals
MFAD	Ministry of Fisheries and Aquaculture Development
MLGRD	Ministry of Local Government and Rural Development
MMDAs	Metropolitan, Municipal and District Assemblies
MoH	Ministry of Health
MTDP	Medium-Term Development Plan
MWH	Ministry of Works and Housing
NAP	National Adaptation Plan Framework
NUP	National Urban Policy Framework
NCCAS	National Climate Change Adaptation Strategy
NCCP	National Climate Change Policy
NEAP	National Environmental Action Plan
NGOs	Non-Governmental Organisations
SGDs	United Nations Sustainable Development Goals
UNEP/OCHA	UN Environment Programme/UN Office for the Coordination of Humanitarian Affairs

Sunset over the palm trees on the beach in Almina, Ghana.

6. The case of Lebanon

The sea, the city and the mountains in Tripoli, Lebanon.
© Eva Mont/Shutterstock.com

Author: Vera Noon

6.1 Lebanon and its coastal zone

The East Mediterranean, with its strategic geopolitical setting connecting three continents and two major sea basins, as well as its high prospects for hydrocarbons exploitation, is grabbing plenty of international attention. Particularly, the Levantine coast is exposed to several hazards of natural and anthropogenic nature, both exacerbated by climate change effects.

Lebanon is a small country named after its snowy mountain peaks, with demographics dictated by its rugged topography, and a lifestyle shaped by the temperate climatic conditions. The Lebanese coastal zone hosts over two thirds of the total country's population, harbouring its main economic activities and infrastructure facilities.

Tarnished by regional geopolitical struggles, Lebanon's modern history has been anything but stable. Further exacerbating this pressure on the coast is the – seemingly periodic – influx of refugees from nearby countries, seeking refuge in a once hospitable land. Palestinian camps and Syrian informal settlements are home to some 1.5 million individuals, adding even more pressure on scarce resources (MOE/EU/UNDP, 2014).

Lebanon today is at a crossroads: as political, financial, economic, pandemic, and humanitarian crises cripple some 6.8 million people living in this small part of the world (Worldometers, 2020a), the environmental crisis – which is just as real – is often overlooked, even though environmental degradation increases coastal communities' vulnerability to hazards.

Figure 6.1 Location map of Lebanon.
© UNESCO-IOC.

Building on experts' interviews and literature review, this report is divided into four main sections:

- Describing the coastal area's natural, socio-economic, and political characteristics
- Assessing communities' vulnerability to risks based on previous studies and forecasts
- Prioritising current and future risks from local stakeholders' perspectives
- Identifying coastal risks adaptation measures

The country's coastal characteristics will be addressed from an environmental point of view (geomorphology, climate and oceanography, biodiversity), from a socio-economic point of view (demography, land use and maritime sectors) and from a political point of view (administrative and institutional frameworks).

6.1.1 Geomorphology

The coastal zone of Lebanon stretches over 240 km in length from north to south, with an average width of 500 m. It incorporates the foothills of Mount Lebanon, the narrow coastal plain, the shoreline and continental shelf, and rises to 250 m (CDR, Ecodit and IAURIF, 1997). The coastal area is traversed by many rivers and streams and is dotted with both coastal and marine freshwater springs that amplify the marine diversity (SPA/RAC, 2015; Shaban *et al.*, 2016).

Table 6.1 The five geomorphological regions of Lebanon and percentage of total territory.

Geomorphological region	Percentage of total territory
Coastal zone	13%
Mount Lebanon mountain chain	47%
Bekaa Plateau	14%
Anti-Lebanon mountain chain	19%
South Lebanon Plateau	7%

Source: CDR, Ecodit and IAURIF (1997)

6.1.2 Climatic and oceanographic settings

Lebanon's Mediterranean climate is characterised by hot and dry summers (Jun-Sep) and cool-rainy winters (Dec-Mar). Average temperatures in the coastal zone range from 5-10 °C in January, to over 35 °C in August (MoE/UNDP/GEF, 2015b). However, estimates based on previous years and IPCC reports reveal an increase in temperature: 1.15 °C by 2040, and 4.15 °C by 2080 (MoE/UNDP/GEF, 2016).

The coastal areas of Lebanon receive between 600-800 mm per year of rainfall (MoE/UNDP/ECODIT, 2011); however, this value is projected to decrease by 10-20% by 2040, and by 25-45% by the year 2090. The drought periods, over the whole country, will become 9 days longer by 2040 and 18 days longer by 2090 (MoE/UNDP/GEF, 2011).

In terms of wave climate, November through March record the highest waves, with waves reaching up to 9 m in the Gulf of Beirut. Tripoli and Beirut both experience some swell waves occurrences (Kabbara, 2005). A major south-north current runs along the coast, although some north-south currents are also detected (Abou Ibrahim and El Fadel, 2004).

In Lebanon, the mean monthly variation of sea surface temperature (SST) between 2000 and 2012 ranged from a minimum of 17.8 °C in March and a maximum of 27.7 °C in August (Abboud Abi Saab *et al.*, 2013). However, studies between the period 1996-2006 revealed a general increase in SST trends in the Levantine Sea basin (Samuel-Rhoads *et al.*, 2009). In fact, the Mediterranean SST is expected to gradually increase due to climate change. A 2-3 °C increase might extend the tourist season but is most likely to affect marine biodiversity (MoE/UNDP/GEF, 2011).

The Eastern Mediterranean is characterised by high salinity levels, with deep water salinity averaging 38.7‰. Anthropogenic factors such as the construction of the Aswan Dam in Egypt (limiting freshwater influx to the East Mediterranean) and the opening of the Suez Canal (the Red Sea salinity reaches 41‰ at the Gulf of Aqaba) exacerbated the salinisation of the Levantine sea basin (Skliris *et al.*, 2018; Mohamed and Sweet, 2019) . Salinity levels in Lebanon based on 2001 sampling vary between 38.87‰ and 39.57‰ (Abboud Abi Saab *et al.*, 2004). Studies showed an increase of salinity in the period of 1950-2010, likely due to a decrease in precipitation levels and an increase in evaporation trends (Skliris *et al.*, 2018).

6.1.3 Biodiversity status of the coastal zone

The Lebanese coastline is mostly characterized by rocky headlands, small bays and stretches of sandy beaches. Various other coastal morphologies exist along in Lebanon, such as gravel beaches, rocky cliffs, and artificially reclaimed land (MoE/UNDP/GEF, 2011).

The key sensitive coastal ecosystems that characterize the Lebanese coastline are vermetid reefs (which are listed as vulnerable in the IUCN Red List), coralligenous assemblages, as well as brown seaweeds, namely *Cystoseira* forests. Direct anthropogenic effects such as habitat destruction linked to coastal developments and pollution, as well as climate change effects such as increased seawater temperatures and ocean acidification (Badreddine, 2018) threaten these ecosystems.

Sea turtles represent the most important fauna directly depending on the good condition of the coast and sandy beaches. The main species that regularly nest in Lebanon are the loggerhead (*Caretta caretta*) and the green turtle (*Chelonia mydas*). Although the main nesting habitats are in the south of Lebanon (Al Mansouri, Al Abbasieh and Al Addousieh beaches), the north of Lebanon also hosts a site with moderate frequency, the Palm Islands Nature Reserve. Sea turtles are also threatened by anthropogenic factors such as urbanisation of the coast, biodiversity loss, plastic pollution, and ghost gear (SPA/RAC, 2020). Today, three existing official Marine Protected Areas contribute to the protection of the marine biodiversity in Lebanon (Table 6.2).

The coast off Tyre, Lebanon.

Moreover, there are three coastal wetland areas located in the coastal zone, designated by the Ramsar Convention (Ramsar, 2016). These wetlands attract many migratory birds, mainly coming from Africa and heading towards Europe (Shaban *et al.*, 2016) (Table 6.3 and Figure 6.2).

Table 6.2 List of existing Marine Protected Areas in Lebanon.

Name	Legal reference	Year established
Palm Islands Nature Reserve (PINR)	Law 121	1992
Tyre Coast Nature Reserve	Law 708	1998
Abbassieh Coast Nature Reserve	Law 170	2020

Source: UNESCO-IOC/Vera Noon based on SPA/RAC and MedPAN (2019)

Table 6.3 Ramsar designated coastal wetlands in Lebanon.

Name and year designated	Area (km^2)	Description
Palm Islands Nature Reserve (2001)	4.1	Three islands almost covered by saline water, notably among the karstic ponds. There are also small freshwater pools on the largest one of the islands (MoE/UNDP/LU, 2004)
Deir el Nouriyeh cliffs of Ras Chekaa (1999)	0.85	Joint cliffs of carbonate rocks adjacent to the sea (50-600 m altitude) • Several clusters of saline water occur along the shorelines • Water seepage showing along the bedding planes of the limestone and dolomite rocks
Tyre Coast Nature Reserve (1999)	3.8	Elongated watercourse occurring from several artesian springs running to the coast (Ras Al Khaimah). The water sources are: • Three water wells • Three springs • Two ponds • Two major conveying channels • A few small artificial tributaries

Source: UNESCO-IOC/Vera Noon based on Shaban *et al.* (2016), UNEP-MAP/UNESCO-IHP/CNRS-L (2015)

6.1.4 Demographics

The culture of Lebanon is a mosaic of various civilisations overlapping for thousands of years, resulting in diverse populations, religions, and traditions. Lebanese are identified by traditional family values and religious norms. However, sectarianism is the dominant social, economic, and political reality in Lebanese society (Baytiyeh, 2017). The last official census in Lebanon was done in 1932, since then all demographic data were based on estimations from multiple sources, barely reflecting the distribution of populations across the territory (Verdeil and Dewailly, 2019).

Forced displacements have marked the lives of most residents of Lebanon: Palestinian refugees (since the 1948 Palestinian exodus), Lebanese residents (1975-1990 during the Lebanese Civil War) and recently the Syrian refugees (since the 2011 Syrian Civil War). The heavy influx of Syrian refugees has exceeded 1.2 million and further exacerbated the environmental and economic pressures, as the real/ estimated number exceeds that of the officially registered at UNHCR (Balanche and Verdeil, 2019; Dionigi, 2016). Since 2011, hundreds of informal settlements have appeared along the coast, particularly in the coastal plains of Akkar and in the southern governorates. The latest estimations reveal that one over four residents in Lebanon is a displaced person (GOL and UN, 2014). In fact, most internal migrations are directed towards the urban areas, namely along the coastal strip. The coastal zone hosts around 70% of the total population (MoE, 2002) with an average density of 1,549 persons per km^2 while the average national population density is 364 persons per km^2 (ELARD and ALEM & Associates, 2007) (Figure 6.3).

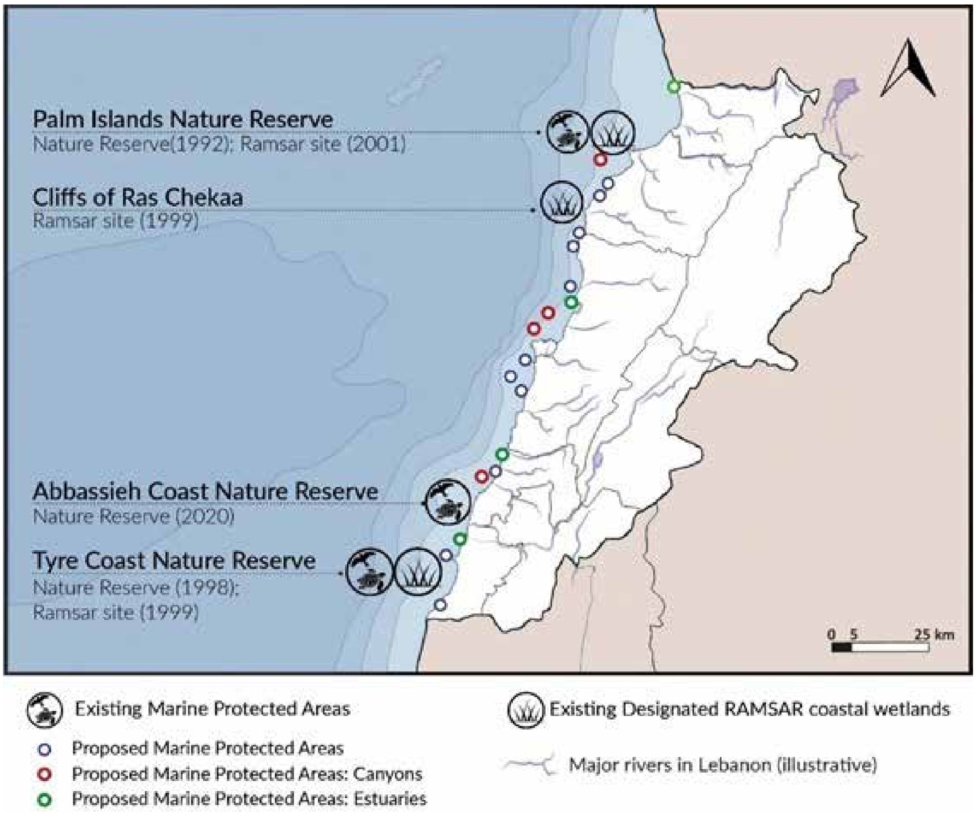

Figure 6.2 Map of existing and proposed Marine Protected Areas in Lebanon, as well as Ramsar designated coastal wetlands.
Source: UNESCO-IOC/Vera Noon based on SPA/RAC and MedPAN (2019)

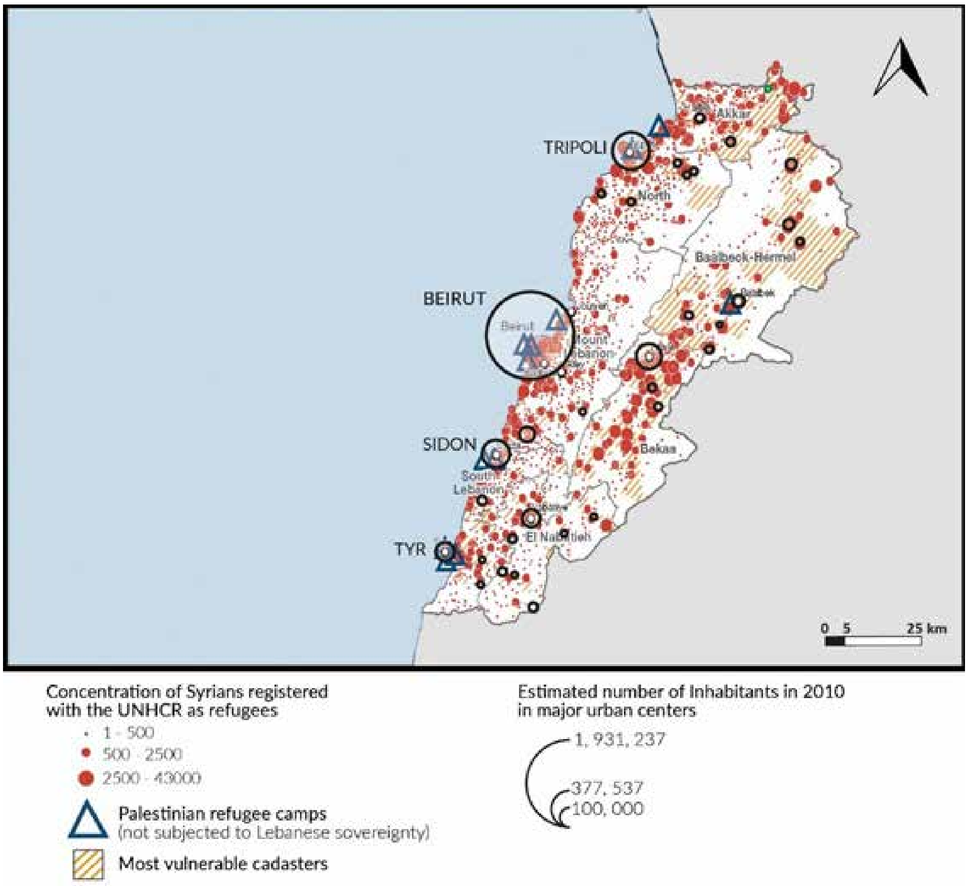

Figure 6.3 Demographic map illustrating major urban centers' estimated population as well as major Syrian and Palestinian refugees' settlements.
Source: UNESCO-IOC/Vera Noon based on Verdeil and Dewailly (2019), Dionigi (2016)

6.1.5 Land use and maritime sectors

Lebanon's largest four cities by population are located along the coast (Beirut, Tripoli, Saida and Tyre) making Lebanon's economic activity largely concentrated in the coastal zone, contributing to more than 73% of the national GDP (MoE, 2002; PAP/RAC and MoE, 2010). The main coastal activities are commercial shipping, agriculture, fishing, tourism, military, and industrial zones Additional notable uses are traditional extractive activities such as the salt ponds in Anfeh and Akkar areas (Kanbar, 2015) and cultural heritage sites (Figure 6.4).

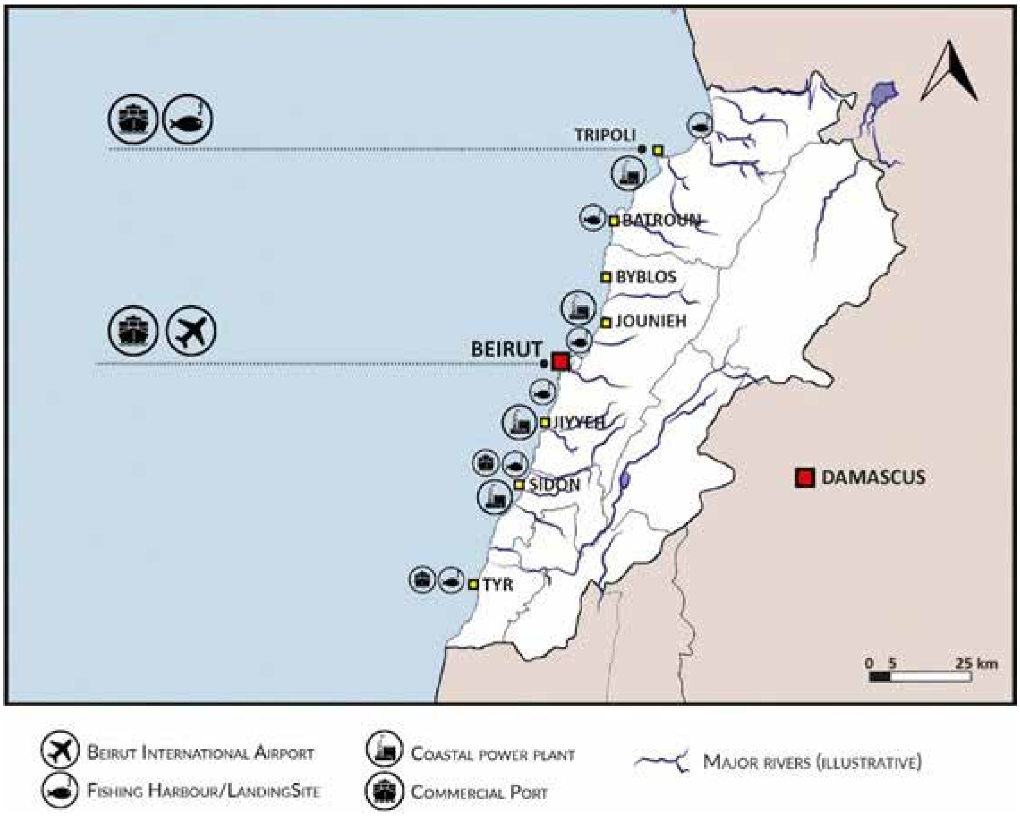

Figure 6.4 Indicative location of main coastal infrastructure and facilities in Lebanon.
Source: UNESCO-IOC/Vera Noon based on Kanbar (2015), PAP/RAC and MOE (2010), Majdalani (2005)

The country's main infrastructure and service facilities are located within the coastal zone:

- The main highway connecting the North-South borders
- Beirut Rafic Hariri International Airport: the only operating passenger airport in Lebanon
- Power plants: four coastal thermal power generation plants (Deir Ammar, Zouk, Zahrani and Tyre)
- Industrial facilities: Chekka, Selaata, Zouk, Dora, Ghadir River, Ghazieh are the main industrial hotspots (PAP/RAC and MOE, 2010).
- Commercial ports: four main commercial ports; and 13 private marinas for leisure boating (Kanbar, 2015)
- Fishing harbours: around 44 Fishing harbours/landing sites (Majdalani, 2005)
- Landfills: five main coastal dumpsites
- Sewage treatment plants (eight completed, four operational) (Shaban, 2008)
- Extractive industries: salt extraction ponds, quarries, etc.

Port areas and touristic resorts occupy most of the coast's urban infrastructure, with nearly 27% for each sector, followed by non-built up areas (mineral extraction sites, dumpsites, landfills, urban extension and/or construction sites etc.) with around 18%, urban fabric forming around 15% and industrial/commercial areas up to 11% (Lichaa-El Khoury & Bakhos, 2003) (Figure 6.5).

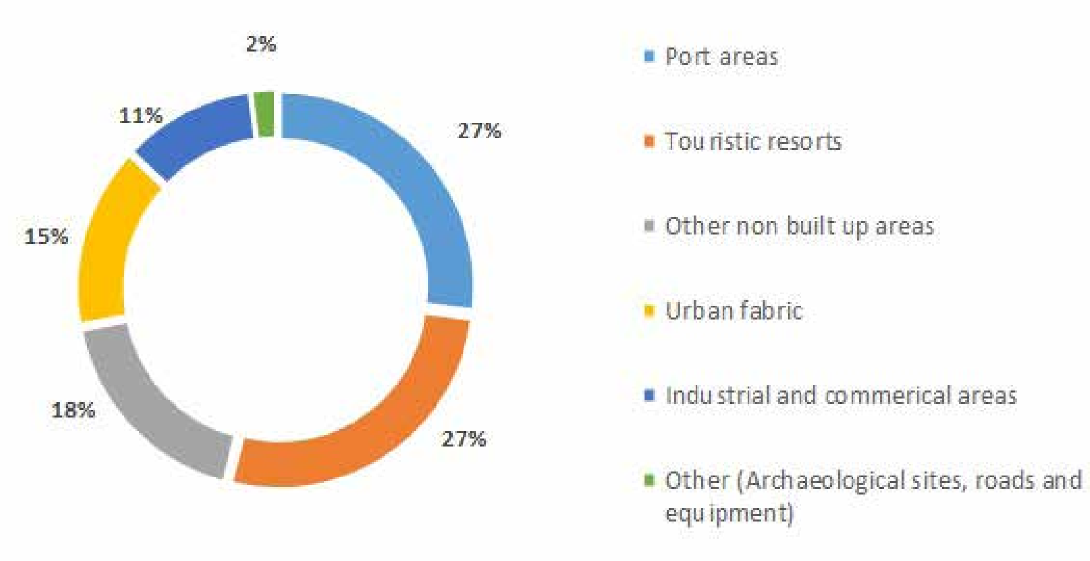

Figure 6.5 Distribution of urban development structures along the coastline as a percentage of total coastal length.
Source: UNESCO-IOC/Vera Noon based on Lichaa-El Khoury and Bakhos (2003)

6.1.6 Administrative divisions

The Lebanese territory is divided into Governorates, Districts and Municipalities (descending order of hierarchy). The governor is appointed by decree by the council of the ministers and is subordinate to the Minister of Interior. Several municipalities created federations/unions of municipalities, allowing them to undertake projects exceeding the financial possibility of a municipality (such as major urban works, firefighting, waste management, sewage systems development). Federations/unions enjoy a legal status with financial and administrative autonomy (Localiban, 2020) (Figure 6.6).

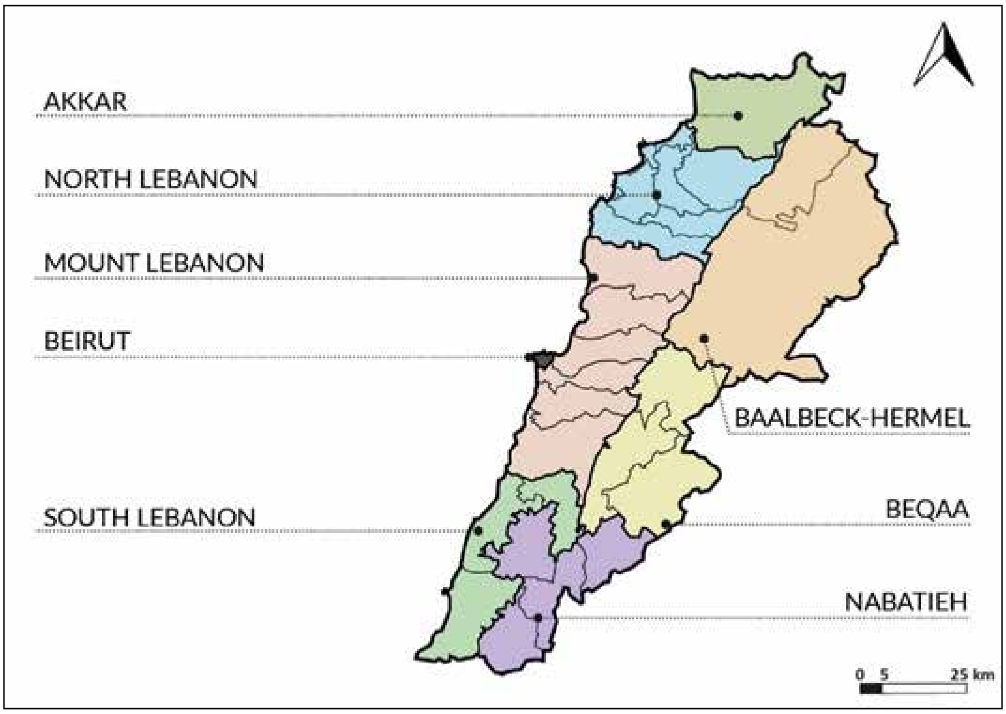

Figure 6.6 Administrative divisions of the Lebanese territory.
Source: UNESCO-IOC/Vera Noon based on Localiban (2020)

6.1.7 Institutional framework

On an international level, Lebanon ratified several conventions related to the marine environment, cultural and natural heritage, climate change and air quality. As such, Lebanon acquired a mandatory force of law implying major commitments and obligations for the protection of the coastal zone, such as environmental assessment and monitoring, adopting proper economic financial and fiscal instruments, prevention from natural hazards or risks affecting the coastal zone, emergencies, climate change and natural hazards, adopting national coastal strategies, plans and programs.

Despite these obligations, compliance has proved to be limited, particularly in the law enforcement domain. Moreover, several assessments revealed an overlap in the mandates of ministries and public institutions. The global institutional framework and the different public institutions that play a role in coastal zone management are summarised in the table below (MRCZM-IOE-UOB, 2014) (Table 6.4).

Table 6.4 Global institutional framework for coastal zone management in Lebanon.

	Planning	Water Resources Management	Ports and Marine Transport	Urban Planning & Zoning	Standards & Legislation	Enforcement	Project Financing & Execution	Cultural Heritage	Biodiversity/ Marine Environmental Protection	Wastewater Discharge	Awareness & Guidance	Solid Waste Management	Sampling & Monitoring	Forests	Hazardous Waste Management	Issuing Permits	Public Maritime Domain
M. of Environment	X	X		X	X	X	X		X	X	X	X	X	X	X	X	
M. of Public Works & Transport	X		X	X		X	X	X		X		X		X		X	X
Port of Tripoli/ Port of Beirut			X				X										
M. of Industry				X	X		X			X			X			X	
M. of Energy & Water		X					X			X			X				
M. of Interior & Municipalities				X		X	X			X		X	X			X	X
Municipalities	X			X		X	X	X	X	X	X	X	X	X		X	X
Council for the Development & Reconstruction	X	X		X			X			X		X					
M. of Public Health		X			X								X			X	
M. of Agriculture	X				X	X			X		X			X			
M. of Tourism							X	X	X		X					X	
M. of Culture							X	X									

Source: UNESCO-IOC/Vera Noon based on MRCZM-IOE-UOB (2014)

6.2 Coastal hazards in Lebanon

6.2.1 Sea-level rise

Most of Lebanon's residents live in urban areas concentrated along a coastline that is vulnerable to sea-level rise, which is expected to reach 30-60 cm over the next 30 years (MoE/UNDP/GEF, 2016). Coastal slums and informal settlements that exist around major cities are particularly vulnerable to this hazard. Such is the case of Ouzaii slums in the southern suburb of Beirut, and Syrian informal settlements in the Akkar plain. Agricultural fields along the coastal plains of Akkar and Tyre are also at high risk from sea-level rise (MoE/UNDP/GEF, 2011).

6.2.2 Storm surge and wave action

High tides and storm surges in the winter season occasionally cause the closure of coastal roads and bridges as they are threatened by inundation. Coastal landfills are also threatened with collapse into the sea. These surges, coupled with a high frequency and intensity of storms can also disrupt the operations at the Beirut International Airport (MoE/UNDP/GEF, 2011). In fact, every year, damage to coastal infrastructure is reported following heavy storms impacts (Naji, 2019). The Beirut Municipality, for instance, has repeatedly repaired its coastal promenade structure following devastating wave impact.

Storm on the sea in Beirut, Lebanon.
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6.2.3 Coastal erosion

Coastlines are prone to erosion due to natural factors such as strong storms and littoral drift, in addition to different anthropogenic factors which act as pressures on coastal ecosystems. Sensitivity is higher in low-lying coastal areas which are more exposed to tides (MoE/UNDP/GEF, 2011). Sandy beaches are more prone to coastal erosion as opposed to gravel beaches (Bou Kheir, Cerdan and Abdallah, 2006). For instance, between 1962 and 2003, satellite imagery and aerial photographs revealed a shoreline retreat of up to 150 m in Akkar (Figure 6.7), where waves flooded coastal wetlands and previously productive agricultural lands (Faour and Rizk, 2008).

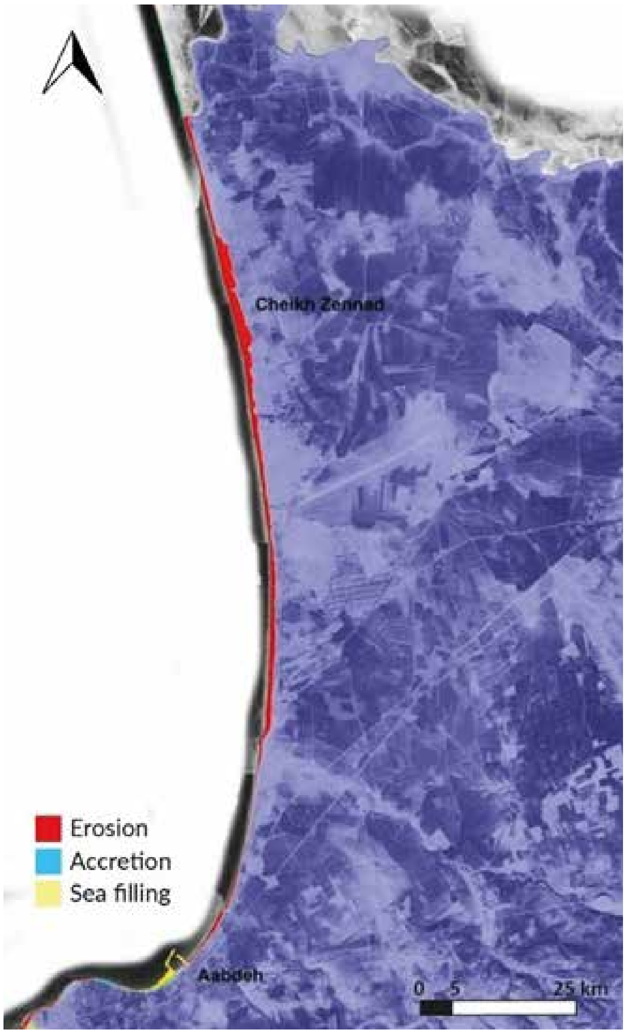

Figure 6.7 Akkar coastline evolution (1962-2010).
Source: MCR-IOE-UOB (2017)

Coastal erosion is also impacting coastal infrastructure, such the existing (abandoned) railway, which undermines the potential of reviving the train track in Lebanon (Verdeil, 2019). Besides being a threat to the built environment, coastal erosion also puts at risk the cultural heritage. Many maritime archaeological sites across the Lebanese coast are being impacted by coastal erosion. This is being exacerbated by torrential rains, heavy storms, quarrying and sand/gravel extraction (Semaan, 2019), landslides, earthquakes, and weathering (Nicu, 2019).

6.2.4 Earthquakes

Lebanon is located over the 1,200 km Levant Fault, stretching from the Gulf of Aqaba to Turkey, and is characterized by a presence of major faults, but low to moderate seismicity. These conditions have led to several historically devastating earthquakes, namely the 551 earthquake and tsunami (with epicentre at sea over the Mount Lebanon Thrust), and the 1202 earthquake (with epicentre over the Yammouneh fault). Recent years revealed only moderate seismicity. However, studies have shown that the Yammouneh and Mount Lebanon Thrust faults may rupture again (Figure 6.8).

The highly urbanised coastal strip, particularly Beirut that houses 40% of the Lebanese population, makes it particularly exposed to seismic risks. Moreover, the city's urban fabric is a mosaic of historic buildings and glass skyscrapers, all prone to severe damage from potential earthquakes (ANR Libris, 2019).

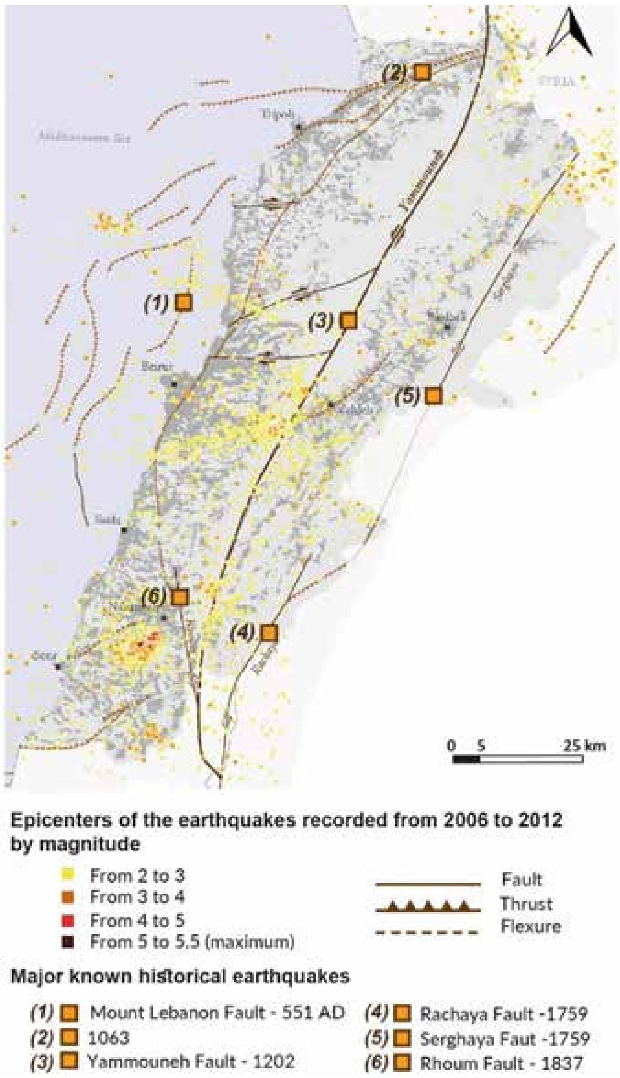

Figure 6.8 Historical and recent seismicity map.

Source: UNESCO-IOC/Vera Noon based on ANR Libris (2019), Elias *et. al.* (2012)

6.2.5 Tsunamis

Although the coastal zone in Lebanon is at medium risk for tsunamis (10% chance that a potentially damaging tsunami might occur in the next 50 years), this risk might increase with time due to the sea-level rise effect (Peters, Eltinay and Holloway, 2019). Coastal infrastructure, such as the Beirut International Airport, may be at risk as its barrier can protect against 4 m waves only, while higher waves have been reported in that area. Ports, electric power plants and oil refineries require due attention as well (GOL/UNDP/GRIP, 2010).

6.2.6 Landslides

There has not been a national level mapping of mass movements in Lebanon, however several studies reported over 3,500 landslides and 6,000 block, rock and debris falls in 2010 only. On average, they may cause financial losses approximately amounting to USD 10 to 15 million per year. Landslides may be caused by natural factors such as earthquakes or torrential rains but are exacerbated by human action such as quarrying and construction of roads and irrigation systems (Abdallah and Gillette, 2019). Reconstruction efforts may take a long time due to lack of funds and political deadlock, such as the case of the Ras-Chekka landslide which lead to the collapse of one of the road's protective concrete walls (Elias *et al.*, 2019).

6.2.7 Floods

Increased urbanisation, deforestation and the increased frequency of torrential rains are leading to a heightened level of flood risks. Loss in agricultural areas, construction, refugees' tents, and infrastructure damages reach millions of dollars (CNRS, 2013). Situated near rivers and located by the coast, the major coastal towns and cities of Beirut, Tripoli and Saida are at risk from flooding (Sene, Houghton-Carr and Hachache, 2001). Similarly, the low-lying agricultural plains of Akkar, Damour, Saida and Tyre are vulnerable to flooding (Figure 6.9).

Aerial photo of the Beirut International Airport in Lebanon, located in a low-lying area in contact with the Mediterranean Sea.

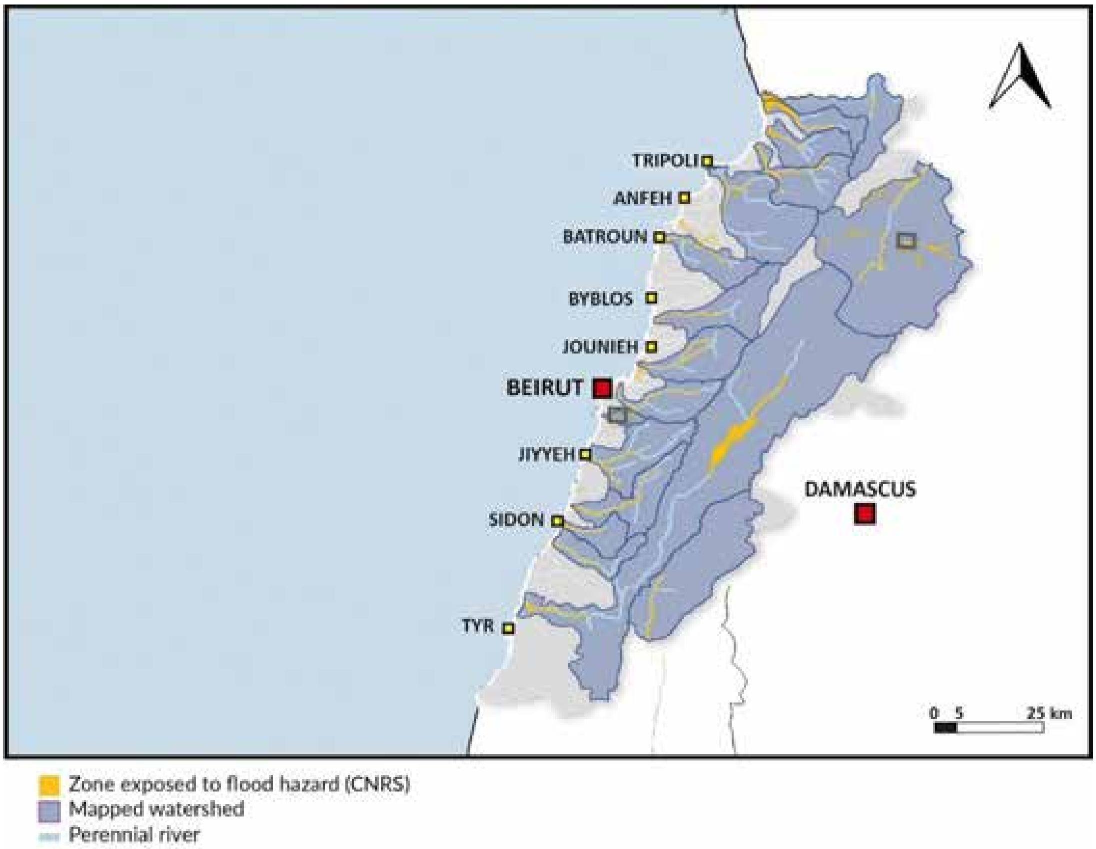

Figure 6.9 Flood hazard and risk areas in Lebanon.
Source: Abdallah (2019)

6.2.8 Environmental degradation

Wastewater management remains one of the most problematic sectors in Lebanon. Satellite imagery show anomalous features in the marine environment, and coupled with field surveys and water sample analysis, 82 pollution hotspots along the Lebanese coast are identified. Seventy-three percent of these pollution sources are discharges from wastewater, cooling water, chemicals, and oil residues from land-based activities. Waters near industrial complexes show high levels of heavy metals and are often warmer than the sea temperature. Rivers and streams often play the role of transport routes to polluting of land based manmade wastes to the sea: most rivers in Lebanon revealed unacceptable levels of raw sewage based on *E. Coli* counts (Shaban, 2008; MoE/UNDP/ECODIT, 2011) (Figure 6.10).

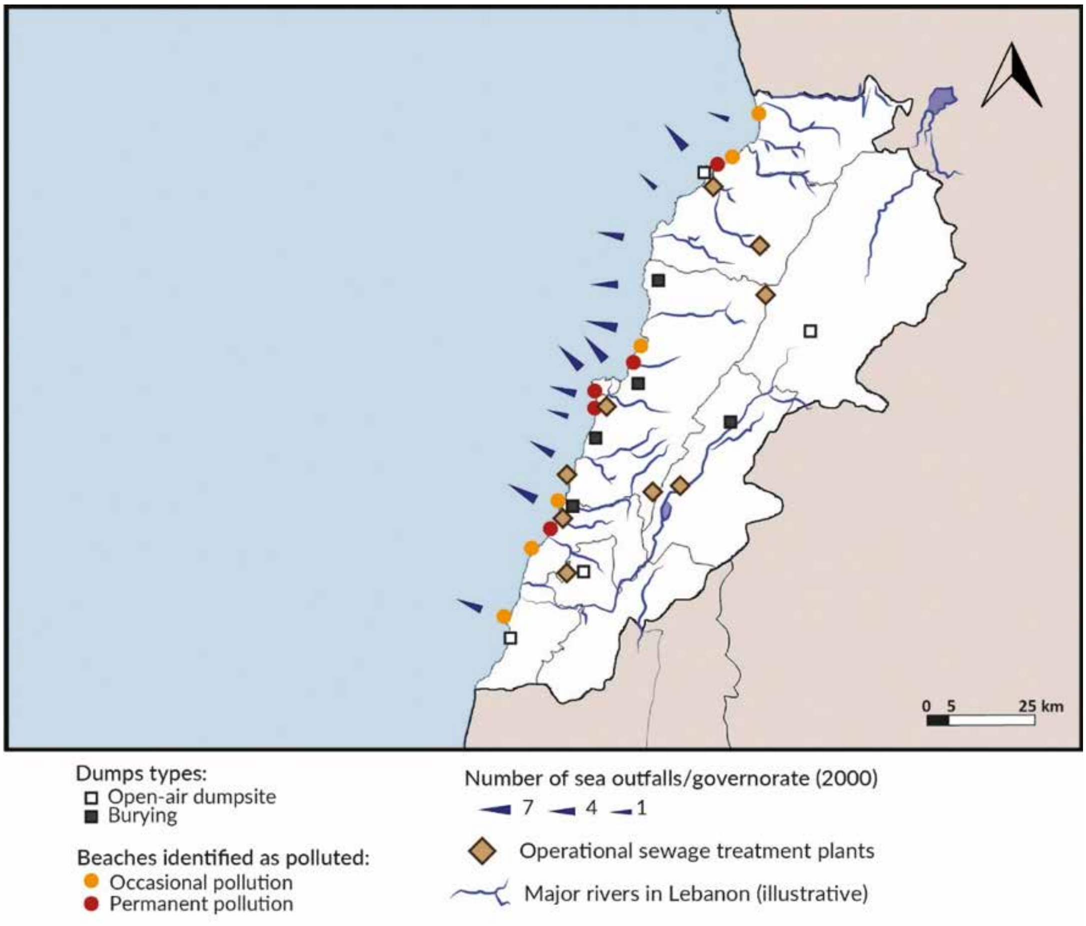

Figure 6.10 Sources of land-based pollution going into the sea of Lebanon and main dumpsites.
Source: UNESCO-IOC/Vera Noon based on Farah and Verdeil (2019), Alles (2019b)

Environmental degradation is mainly linked to anthropogenic intervention: gravel extraction from riverbeds and sand extraction from river mouths is exacerbating environmental degradation and reducing its attractiveness to tourists and locals alike (MRCZM-IOE-UOB, 2012). Likewise, coastal quarries have proven to reduce land value by 16-71%. As a result, cost of environmental degradation in Lebanon is quite high: in the north of Lebanon, the costs of the coastal zone degradation are estimated at USD 102 million per year. In Beirut, the cost imposed by Ramlet El Bayda beach's poor bathing water quality is estimated at USD 343,200 per year, from additional medical expenses linked to gastrointestinal diseases and acute febrile respiratory illness (Kanbar, 2015).

In July 2006, a new month-long war erupted in Lebanon, renewing the conflict with Israel. One of the coastal power plants in Jiyyeh, some 30 km south of Beirut, was targeted by airstrike missiles, releasing over 30,000 tons of heavy fuel oil from damaged tanks into the sea. The 10 km wide oil slick drifted along the coast reaching Turkish, Syrian, and Cypriot beaches (Figure 6.11). The environmental impact was heavy: beaches and harbours were covered in thick black smudge for weeks. Oil sediments sunk to the seabed. Fish, sea turtles and sea birds were contaminated (Hill, 2010).

Figure 6.11 Black sands. Oil from the bombed power plant of Jieh (south Lebanon) contaminating the beaches of Beirut - August 2006.
© ZeNahla, https://commons.wikimedia.org/wiki/

Figure 6.12 Thousand of packed garbage bags in Jdeideh, a northern suburb of Beirut, Lebanon, Feb. 23, 2016.
© Hasan Shaaban / Reuters

Lebanon at the time did not have experience in handling such ecological disasters, so funding and specialised help came from all over the world, and a coalition of environmental groups worked to help clean both the land and the sea (Hill, 2010). The cost of this war's environmental degradation was estimated at USD 729 million (Das and Davidson, 2011). However, the fisheries sector received financial support from the United Nations Development Programme (UNDP) (USD 1.1 million) to help repaire damages and get the fishermen back on track, while other international assistance helped assess the effect of the spill on the ecosystem (MoE/GEF/UNDP, 2009).

In July 2015, the Naameh landfill (opened in 1998 as a government emergency response plan) was closed following protests by residents and activists (Shaaban, 2015). Solid waste management failure is not new to the Lebanese government, but this time this event led to the piling up of tons of uncollected garbage in the streets of the capital Beirut and Mount Lebanon. Finding no other solution, some locals resorted to open air burning of the waste, especially in the poorest areas, leading to serious health risks (Human Rights Watch, 2017) (Figure 6.12).

An updated master plan for the closure and rehabilitation of uncontrolled dumpsites was elaborated, seeking to pinpoint main areas of concern, prioritise dumpsites for closure and propose rehabilitation options (MoE/UNDP/ELARD, 2017). In 2017, 47% of the Beirut Municipality's budget was allocated to the solid waste management sector. One of the proposed solutions was the establishment of waste to energy power plants within the capital (Beirut Municipal Council, 2018). However, that solution was not met positively among the environmental activists and civil society, and to this day, no concrete and sustainable waste management strategy has been put to action yet, despite some sporadic efforts.

On 4 August 2020, a massive explosion shook the city of Beirut and its suburbs. Since 2013, almost three thousand tons of ammonium nitrate, alongside kerosene, hydrochloric acid, and fireworks, had been stored in Hangar 12 within the Beirut Port Authority premises. Hundreds of thousands of people live within one kilometre of the site, and the result of that disaster was hence catastrophic:

- Over 200 people killed, 6,000 people injured and 300,000 displaced.
- A pressure wave travelled the city, causing physical damage to buildings located up to five kilometres away. The massive amount of rubble still being picked up created yet another solid waste problem, especially that asbestos-filled materials are omnipresent in the old heritage buildings.
- The grain silos building, where most of the nation's wheat is stored, was destroyed, raising issues of food security.
- The orange and black smoke raised alarms over the toxicity of the stored material spreading across the coastal area, which even travelled across the country.
- The 140 m wide crater in the port's structure as well as the sunken ships alerted environmentalists over the impact such explosion may have on the marine environment, namely water quality, seabed, and on marine species such as fish and marine mammals.
- Major healthcare and educational institutions concentrated in the nearby neighbourhoods sustained severe damage and will still require restoration and rehabilitation efforts to be able to operate.

This explosion revealed a major weakness in response measures and exacerbated the socio-economic vulnerability of the Lebanese capital (Hubbard *et. al*, 2020; Reliefweb, 2020a; UNOCHA, 2020) (Figure 6.13).

Figure 6.13 Beirut Port explosion's aftermath: aerial view of the grain silos. August 5th, 2020.
© Nicolas Tawk

6.2.9 Biodiversity loss and invasive species

The main aspects of biodiversity loss are linked to environmental degradation due to anthropogenic causes: habitat loss due to urbanisation; decrease in fish stocks due to overfishing and destructive fishing methods; and the pollution of marine and river aquatic systems due to domestic, agricultural and industrial runoff. Fisheries are among the main maritime sectors affected. Climate change impacts and ocean warming are also threatening biodiversity: for instance, marine turtles nesting will be affected by climate change, posing major challenges to environmental conservationists (AFED, 2009).

Located on the East Mediterranean coast, Lebanon is at the frontline of the Lessepian migration: the Suez Canal opening has led to an increase in invasive species migrating from the Red Sea to Lebanese waters. Deterioration of the seawater quality and the destruction of habitats has weakened the marine ecosystem, rendering it more prone to invasive species, particularly the ones coming from harsh conditions (high salinity and higher temperatures) (MoE/UNDP/GEF, 2015a). The *Lagocephalus sceleratus* (or commonly referred to as pufferfish) is one species that has established thriving populations and causing serious damage to the fisheries sector (Boustany, Indary and Nader, 2015). The Lebanese Ministry of the Environment has imposed restrictions on the fishing of the pufferfish due to its poisonous characteristics, which may have contributed to its proliferation.

Another fish population expanding at an alarming rate is the *Pterois Miles*, or the lionfish, first recorded in 1991, but rapidly growing since its second recording incident in 2012 (Bariche, Torres and Azzurro, 2013; Bariche *et al.*, 2017). However, several entities are proposing adaptation methods to deal with the lionfish invasion issues. (Pers. Comm. J. Talj; H. Naccour; M. Nader). Some macro flora has also been detected as well and marked as potentially invasive (Bitar *et al.*, 2017).

6.2.10 Droughts, water salinisation and wildfires

The increase in global temperatures, the reduction of snow cover's spatial extent and the decline in the volume of water from several sources (up to 60% in some rivers and springs) will ultimately lead to more frequent incidence of droughts (Shaban, 2011; IPCC, 2014). Reduced rainfall and high evapotranspiration will lead to decreased soil moisture and increased aridity, affecting agricultural yields and decreasing productivity of crops and fruit trees (MoE/UNDP/GEF, 2011). In fact, water sources monitoring such as the coastal wetland of Ras El Chaqaa, indicated that the coastal plain is no longer witnessing soil saturation like the past few decades' trends (UNEP-MAP/UNESCO-IHP/CNRS-L, 2015). As water demand is continuously rising, proportionally to population growth, water shortages may become a problematic risk in the future, particularly in dense cities (MoE/UNDP/ECODIT, 2011).

Groundwater accounts for 50% of the agricultural sector needs and 80% of the drinking water needs in Lebanon. However, the uncontrolled exploitation of this resource has led to major intrusions of salted seawater in coastal areas, including in densely populated areas (Alles, 2019a). The karstic nature of the geological formations and the narrow steep valleys make it difficult to efficiently store surface water, placing additional pressure to groundwater reserves (PAP/RAC and MOE, 2010). Acute water shortages in recent years coupled with recurrent periods of drought, have led to many illegal wells being dug that contribute to saline intrusion along the coast, rendering the total dissolved solids levels of many sampled wells in Beirut to those of seawater (~37,500 mg/L) (Saadeh and Wakim, 2017). However, a local authorities' representative indicated that many illegal wells have been put out of operations over the course of the recent years.

According to an estimate produced by the National Centre for Scientific Research (NCSR or *CNRS*), an average of 1,200 hectares are burnt yearly, amounting to 0.1% of the Lebanese territory. The most affected areas according to exposure mapping are in the periphery of the Beirut and Tripoli urban areas (Abdallah and Gillette, 2019). The massive wildfires that spread during October 2019 revealed a failure to respond by local and national authorities due to a lack of proper equipment and infrastructure, to the extent that foreign intervention was required to assist in putting out the fires (Zoheiry, 2019).

A nearly dried-out section of the Beirut River in Lebanon.
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6.3 Coastal risk management in Lebanon

6.3.1 Local authorities

For this chapter, the mayors of two major Lebanese coastal cities were interviewed: Mr. Itani, the Mayor of Beirut, and Mr. Dbouk, the Mayor of Tyre. The two cities present different environmental, demographic and economic characteristics, yet share a few common ones: they both host vulnerable social groups (Ouzai coastal slums south of Beirut and Tyre's Rachidieh coastal Palestinian refugee camp southwards) and have long stretches of sandy beaches (Ramlet el Bayda public beach in Beirut and Tyre's public beach).

Both mayors expressed concerns linked to pollution in public spaces, namely in public beaches, caused by marine litter left by beach goers. In fact, they have both recalled neglecting behaviours by residents of their municipalities, which in turn reflects negatively on economic activities, such as tourism, and recreation.

Seawater quality status in these two areas differs radically: the coast extending from Naqoura to Tyre has little to no human activity, and a sewage treatment plant has been operating in the north of the city, reducing the amount of untreated sewage disposed in the vicinities of Tyre city. Moreover, Tyre is surrounded by natural protected areas, so the beach dunes are somewhat preserved and direct human pressure is mainly concentrated in the city centre. Beirut on the other hand has no protected areas, a highly urbanised coast, a higher population density, no operating sewage treatment plants, and informal settlements in its southern suburbs with sewage outfalls being transported northwards by dominant currents. Mr. Itani highlighted that the separation of raw sewage from rain runoff upstream of the sewage treatment plants is part of a plan aiming at the reduction of marine pollution.

Both mayors also voiced fears about future water scarcity issues. In Beirut, rapid population growth has increased pressure on freshwater resources, and the city has suffered over the years from illegal digging of wells due to deficiency in water supply, leading to deterioration of water quality and threats to public health. Meanwhile, Tyre relies on historic freshwater ponds located in Ras El Ain, which are in turn threatened by seismic activity that may lead to diversion of water supply.

The priorities expressed by both mayors are linked to institutional bottlenecks, which hamper the implementation processes and funds allocation. Decentralisation of power and granting autonomy to local authorities was a common recommendation. Central government was urged to provide further financial and human resources to follow up on law enforcement and environmental compliance.

From a social lens, both municipalities' experiences differed drastically. Beirut municipality was often faced with civil disdain, particularly concerning solid waste management issues. In fact, Beirut's proposed "waste to energy" power plant was suspended until further notice following pressure from the civil society that deemed it unsustainable (Kaouri and Safieddine, 2019). Similarly, the public opinion following the 2020 Beirut explosion judged the government's delays in Disaster Risk Management (DRM) response. The municipality eventually provided personnel for assisting the reconstruction efforts and guarding neighbourhood areas prone to thefts. It is also collaborating with local NGOs on channelling humanitarian assistance as the army took charge following the declaration of emergency state.

On the other hand, Tyre recorded a successful experience of DRM activities. In 2010, the Union of Tyre municipalities established the first municipal level DRM Rapid Response Unit in Lebanon, in collaboration with local associations, public institutions and the support of the Swiss government (Peters, Eltinay and Holloway, 2019). Additionally, Tyre's Union of municipalities connected with religious-political associations, an act that proved successful on the Disaster Risk Reduction (DRR) level (list of local community associations available on the Tyre Municipality website (Tyremunicipality, 2017).

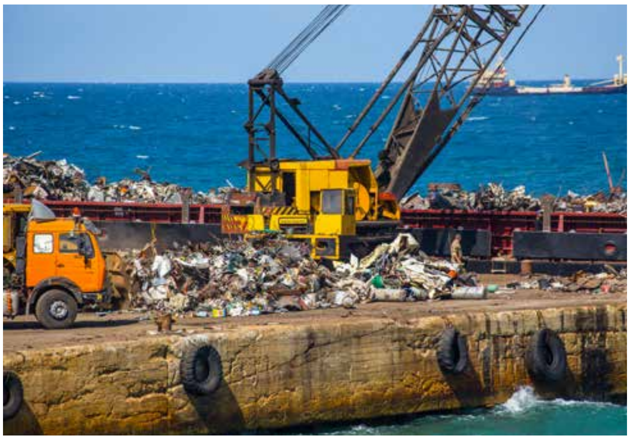
Plastic pollution on a pebbles beach in Lebanon.
© Eliane Haykal/Shutterstock.com

6.3.2 Maritime sectors

Interviewed experts from maritime sectors come from backgrounds such as shipping and logistics, marine engineering, chemical engineering, fisheries, environmental conservation and maritime cultural heritage. The most common concern expressed by most of the experts was related to infrastructure: experts from environmental conservation and engineering backgrounds highlighted the urgent need to repair and maintain existing sewage treatment plants and proceed with their operation as soon as possible. Whereas the maritime cultural heritage and marine engineering experts expressed fears about ancient heritage structures and modern infrastructure being impacted by coastal erosion, the effects of extreme storms, sea-level rise, ocean acidification and sea warming. Experts from sectors requiring access to the sea, such as fishing and shipping, exhibited safety concerns linked to infrastructure efficiency facing stormy weather (particularly from December to March). Among the many landing sites and fishing harbours, only the Beirut and Tripoli fishing harbours were deemed safe during winter seasons. Moreover, geophysical parameters changes such as sedimentation processes within commercial and fishing harbours will affect safe access of ships/boats.

Another cross-cutting issue is related to illegal activities and maritime security at sea, where proper accountability and law enforcement is still lacking. Dynamite fishing for example, is harmful to fisheries, to marine and benthic ecosystems, to maritime archaeology and to submarine cables and pipelines. It is worth mentioning that this practice is often reportedly linked to Palestinian camps such as Rachidieh Camp in Tyre or Badawi Camp in Tripoli. This raises the issue of governance as Palestinian camps in Lebanon are under the jurisdiction of the United Nations Relief and Works Agency for Palestine Refugees in the Near East (UNRWA), and local authorities have no power within those premises (International Crisis Group, 2012).

Recommendations from the private sectors' representatives are twofold: firstly, to regularly monitor, maintain, support, and rehabilitate existing marine structures and facilities (including sewage treatment plants) to help protect against extreme weather events and pollution. Secondly, to elaborate innovative engineering solutions for mildly exposed areas. Examples like sand-filled geo-bags were proposed, which can serve as sustainable eco-friendly breakwaters for low-lying areas. As for the activities at sea, experts required the enforcement of the installation of AIS/VHF technologies on board all fishing boats, to help monitor all vessels movements, which in return will ensure proper law enforcement and security at sea, even beyond the 12 NM.



Garbage processing in the port of Saida, Lebanon.
© Sun_Shine/Shutterstock.com

6.3.3 Scientists

The scientists that were interviewed work in different fields related to the marine environment: oceanography, biodiversity conservation, ecosystem restoration, environmental economics, and environmental planning. The common consensus among scientists was prioritising protection over restoration efforts, be it the protection of one specific coastal habitat or the adoption of a nationwide protection strategy, scientists highly value the existing/remaining sensitive habitats (previously highlighted). The two locations in urgent need for protection are the Naqoura's coastal cliffs and vermetid reefs (southernmost point in Lebanon), and the Palm Island Nature Reserve's beaches and vermetid reefs in Tripoli. Threats to these ecosystems from habitat destruction stem from urbanisation, trampling, wastewater pollution and climate change. These ecosystems have also proven to contribute in return to the protection of coasts from effects of extreme events. Integrated planning, economic valuation and investment in human capital are main tools proposed to help reach this target.

Additionally, the upcoming oil and gas sector seemed to be a threat looming for both the environmental and social scientists. Both regional and national exploration/extraction activities, raised fears of a potential oil spill hazard and its impact on the Lebanese coastal and marine environment, especially given the currents and waves trends in the Levant. The previously mentioned failed DRM experiences revealed how unprepared the Lebanese government still is to face major disasters, but also to govern such a – supposedly – lucrative extractive industry.

Recommendations from scientists revolved around two axes: firstly, to establish a national guiding and integrated master plan for the Lebanese coast, starting by the activation of an ICZM Unit which serves as an implementing entity (MRCZM-IOE-UOB, 2015). Experts noted that scientific studies, draft laws, and expertise are available, only awaiting the right resource allocations and action plans. Secondly, the need to bridge the data gap by connecting various experts across disciplines. Several experts highlighted the need to include retired scientists involved as their long-term expertise is crucial in DRR, while also employing freelance researchers on more specific short-term tasks. Sharing technical expertise such as knowledge in certain software or online platforms among the different sectors, or even underwater exploration methodologies, can help create synergies and save valuable time.

Once a popular bathing spot, the Saint Simon beach in Beirut suffers nowadays from solid waste and wastewater pollution from raw sewage disposal into the sea.
© Sirio Carnevalino/Shutterstock.com

6.3.4 Civil society

The civil society interviewees cover a wide array of activities, such as advocacy for public maritime domain rights, humanitarian response, environmental management and planning, education, and awareness. The initial priority that was raised, not surprisingly as the interviews took place shortly after the catastrophic explosion in the port of Beirut, was regarding the government's role in emergency response, which seemed to have let down the civil society and local communities. Criticism of the failure to respond and to organise rapid recovery interventions, in addition to the delays and sometimes obstruction of reconstruction efforts, have led to a collective feeling of discontent, as hundreds of NGOs, mainly youth volunteers, have been deployed in the streets from day one to cover recovery and reconstruction efforts that the government failed to do. Despite the USD 2 million resiliency plan of the Beirut Municipality, and despite the presence of the Higher Relief Council Committee, as well as the DRR drills performed in the past years (Beirut Municipal Council, 2018), localised actions on the ground were mainly being implemented by civil society: local and International NGOs, professional syndicates, activists and freshly sprouted initiatives. The Lebanese Army took charge eventually two weeks after the blast, yet their role was ultimately the assessment of damage and the channelling of compensation (Fawaz and Harb, 2020).

Another issue topping activists' agenda, particularly around the capital, is the illegal occupation of the maritime public domain, which is directly linked to the rapid urbanisation and illegal construction that proliferated during and after the civil war. Restoring public access to the beach and its continuity across the coastal strip was among the main targets sought.

Changing behavioural patterns by promoting ecotourism over traditional built-up spaces, using valuation techniques and promoting competition through environmental labels are all tools recommended to help recuperate lost natural spaces that serve both as an escape for the residents and a protective buffer from natural seaborne hazard risks.

Modern and historic human occupation and near the seashore in Tyre, Lebanon.
© Eva Mont/Shutterstock.com

6.4 Adaptation measures

Risk adaptation to coastal hazards can take different forms, and there is a myriad of ways to categorise them. The CoastAdapt project and the RISC-KIT were used as reference for the following section.

The RISC-KIT Toolkit, an output of the EU funded project "Resilience Increasing Strategies for Coasts – toolKIT", separates structural from non-structural adaptation measures to reduce risk and increase resilience to low-frequency, high-impact hydro-meteorological events. Structural measures include ecosystem-based approach (habitat restoration) in addition to what is referred to as "grey infrastructure" (hard engineering), while non-structural measures refer to planning, policy making, public awareness raising, training and education (Ecologic, 2019).

The "CoastAdapt" project is a national decision-support tool developed for Australia's coast and elaborates further by dividing the non-structural adaptation measures into planning, social, community, and education (NCCARF, 2017).

Based on experts' interviews and literature review, this chapter collates a list of previous and current projects and initiatives that can play a role in the DRR and DRM cycle in Lebanon (Table 6.5 and 6.6).

The lists of initiatives below is non exhaustive and aims to shed light on the diversity of potential activities that can be undertaken, as well as the important role that international collaboration has in the area.

6.4.1 Implemented projects and initiatives

Table 6.5 Past projects and initiatives that contributed to Disaster Risk Management and Disaster Risk Reduction in Lebanon.

Title	Lead partners	Time frame	Sector
INTERNATIONAL			
Hyogo Framework for Action: "Building the resilience of Nations and communities to Disasters"	GoL-UNDP	2005-2015	DRM
Climate Change, Sustainable Agriculture and Food Security (CCSAFS) MSc program	Erasmus	2016-2019	Climate change and education
REGIONAL			
MedWetCoast: Project for the Conservation of Wetlands and Coastal Ecosystems in the Mediterranean region	MEDWET-MOE	2002-2006	Environmental conservation
Coastal Area Management Program (CAMP) Thematic activity: Integrated Coastal Area Management (ICAM)	UNEP MAP PAP/RAC	2002-2005	Planning and management
Integrated Management of East Mediterranean Coastlines project (IMAP)	UOB	2006-2009	Planning (ICZM)
Reorient University Curricula to Address Sustainability (RUCAS) TEMPUS Higher education program	EU-NDU	2010	Sustainability
Ecosystem Approach (EcAp) MEDI/II projects	Plan Bleu	2012-2015 & 2015-2019	Environmental conservation
NATIONAL			
National Action Program to Combat Desertification	GoL (MoA)	2003	Forestry
National Master Plan for the Lebanese Territory (NMPLT)	GoL – CDR	2005	Urban Planning
National Strategy for Forest Fire Management in Lebanon	GoL (MOE)	2009	Forestry – Wildfires
Strengthening Disaster Risk Management Capabilities in Lebanon project	UNDP	2009	DRR-DRM
Making Cities Resilient campaign	UNISDR	2010-2018	DRR
ANR Libris	CNRS-USJ-AUB	2010-2014	DRR – Seismic risks
Earthquake Model of the Middle East (EMME project)	EFEHR	2010-2014	DRR – Seismic risks
Earthquake Engineering Center (EEC)	UOB	2014	DRR – Seismic risks
Earthquake Preparedness Initiative (EPI)	AUB	2014	DRR – Seismic risks
Environmental Resources Monitoring in Lebanon (ERML)	IOE-UOB	2009-2013	Environmental conservation
State of the Environment Reports (SOER)	GolL (MoE) UNDP EcoDIT	2010-2012	Environmental conservation
Regional Governance and Knowledge Generation project (ReGoKo)	Plan Bleu	2013	Economics; Education
Enhancing Adaptive Capacity of the Rural Communities in Lebanon (AGRICAL project)	GoL (MoE) – IFAD-Green Plan- (LARI)	2015-2019	Agriculture
Ecosystem Approach to Fisheries (EAF)	IOE	2016	Fisheries
The economy and the beach: Valuation of public beaches	Nahnoo	2019	Economics

Title	Lead partners	Time frame	Sector
LOCAL			
Artificial Reef Installation (Aabde)	IOE-UOB	2012	Fisheries
MedPAN small project: PINR /TCNR Legal and technical support for the development of ecotourism	MedPAN (AUB/ UNDP/IUCN/GEF/ MOE)	2014-2016	Ecotourism – Economics
ELME Project (Evaluation of the Lebanese Marine Environment)	IUCN	2018-2020	Fisheries

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6.4.2 Ongoing projects and initiatives

Table 6.6 Current projects and initiatives that contribute to Disaster Risk Management and Disaster Risk Reduction in Lebanon.

Title	Lead partners	Time frame	Sector
INTERNATIONAL			
UN Framework Convention on Climate Change (UNFCCC)	GoL (MoE) – UNDP – GEF	1994-Ongoing	Climate change
Sendai convention (UNDRR Disaster Risk Reduction)	GoL – UNDP	2016-Ongoing	DRR – Prevention
CLIMAte change and Sustainability Policy TEMPUS (CLIMASP) interdisciplinary program	Erasmus	2019-Ongoing	Climate Change and Education
REGIONAL			
Reducing Earthquake Losses in the Eastern Mediterranean Region programme (RELEMR)	CNRS – UNESCO – United States Geological Survey (USGS)	1993-Ongoing	Seismic risks – Forestry
Strategic Action Programme for the Conservation of Biological Diversity in the Mediterranean Region (SAP BIO)	GoL (MoE) – SPA/RAC	2003-Ongoing	Environmental conservation
Education, practical activity bursaries, research, and exploration methods	Honor Frost Foundation	2011-Ongoing	Maritime Cultural heritage
GOA-On Ocean acidification Mediterranean network	CNRS	Ongoing	Oceanography
NATIONAL			
National Emergency Reconstruction Program (NERP)	Beirut municipality	1990-Ongoing	Wastewater management
Fish Landing Operational Utility for Catch Assessment database (FLOUCA) Web portal	GoL (MoE) – FAO	2006-Ongoing	Fisheries
CANA Project (Establishing Monitoring and Sustainable Development of the Lebanese Sea)	CNRS (funds from Italian Ministry of Foreign Affairs / Italian Cooperation)	2009-Ongoing	Marine Environment monitoring
Litani River Basin Management System	Litani River Authority-USAID	2009-Ongoing	Watershed & Wastewater management

Title	Lead partners	Time frame	Sector
Lebanon Reforestation initiative	USFS (International Program of the US Forest Service)	2011-Ongoing	Forestry
National Marine Protected Areas Strategy	GoL (MoE), IUCN	2012	Environmental conservation
National Water Sector Strategy (NWSS)	GoL (MoEW)	2012-On going	Watershed & Wastewater management
Strategic Environmental Assessment (SEA) -Environmental Impact Assessment (EIA) Decrees	MoE	2012	Planning
National Afforestation and Reforestation Plan (40 Million Tree Campaign)	GoL (MoAgriculture) – FAO	2012	Forestry
SuNaR (Sustainable Natural Resources Management Platform and Early warning)	CNRS – UNDP (LU-USJ-NDU)	2014-Ongoing	DRR – Early warning systems
National Reforestation plan	GoL (MoE) – UNDP	2015-2025	Forestry
National Oil Spill Contingency Plan in the Lebanese Waters	GoL	2017	DRR
Enhancing socio-ecological climate change resilience of marine and coastal systems in Lebanon	IUCN – Norwegian funds (NRC)	2018-2021	Climate Change and Biodiversity
National Lebanon Crisis Response Plan (LCR)	GoL – UN	2018-2020	DRM-Response
Lionfish targeted campaign to commercialize the invasive lionfish consumption	Diaries of the Ocean	2018-Ongoing	Fisheries
National firefighting strategy	GoL	2019	DRM – Wildfires
Bahr Bala Plastic (Plastic free Ocean)	Lebanon Eco Movement-Lebanon Environment Forum (LEM & LEF)	2019-Ongoing	Solid waste management (Marine debris)
Beirut Relief Coalition	Coalition of 22 NGOs	2020-Ongoing	DRM -Response & Recovery
LOCAL			
Awareness campaigns, fishing competitions, reporting	Fishing in Lebanon	2011-Ongoing	Fisheries
Getting Airports Ready for Disasters program (GARD)	GoL	2015	DRR – Prevention
Landslide Risk Index mapping	LAU	2015	Landslides risks – mapping
LiveLoveRecycle APP	LiveLove	2015-Ongoing	Solid waste management (Marine debris)

6.5 Final remarks

This chapter summarises the situation of the Lebanese coast's vulnerability to hazards in 2020 based on a combination of literature review and expert interviews. It sought to highlight lessons learnt from previous experiences in adaptation strategies to coastal hazards, to better inform plans and policies. Although mostly focused on climate change impacts, coastal zone management and coastal hazards, this chapter tried to combine the analysis with various social, political and environmental hazards that are currently relevant in Lebanon.

Casually stretching on the East Mediterranean coastline, Lebanon is home to sensitive marine and coastal habitats, with beaches and intertidal zones shelter valuable flora and fauna. With many economic activities, such as shipping, fishing, agriculture, tourism, and various industries competing over the coastline, pressure has been exerted on these sensitive ecosystems.

Being an intrinsic part of the Mediterranean Sea, Lebanon is also prone to potentially severe climate change impacts such as sea-level rise, increasing water and atmospheric temperatures, and decreasing rainfall. Coupled with coastal hazards, climate change serves as a risk multiplier, threatening millions of people. Combining socio-political factors, physical conditions, environmental factors and economic considerations, this chapter presents a vulnerability assessment, highlighting hotspots along the coast for each main hazard category.

Hydrological and meteorological hazards are likely to affect key coastal infrastructures such as the Beirut airport, the commercial ports and power plants. Additionally, poverty-stricken populations around major cities, like Tripoli and Beirut, as well as informal Syrian refugee settlements and coastal Palestinian camps are highly vulnerable. Climatological hazards will mainly affect the agricultural sector in coastal plains and will put the peripheries of Tripoli and Beirut at high risk.

Geological and geophysical hazards such as earthquakes are less frequent yet more destructive, particularly in old historic city centres such as Beirut (and most major coastal cities). Controlling coastal erosion is a time-consuming process whose effects require long-term monitoring to be discerned. However, both hazards pose a major threat on valuable historic cities infrastructure and cultural heritage in Lebanon, particularly in low-lying areas.

Environmental hazards will have tremendous impacts on public health first and foremost, namely due to overall environmental degradation, river runoff, and salinisation of freshwater resources. Sea-level rise and biodiversity loss will also affect the agricultural sector and low-lying vulnerable communities, threatening food security of communities relying on natural resources for subsistence, such as fishers that live by and from the sea.

Biological hazards are among the most difficult to control, both on a national and global scale, and solutions are yet to be found for invasive species that are adapted to extreme water conditions, or for the global pandemic that has left an entire planet crippled.

Technological and explosion hazards are by far the most devastating and require years of continuous investments in human and financial capital to recover. The examples of the 2006 oil spill, the 2015 garbage crisis and the 2020 Beirut port explosion revealed the extent of damage to property and human lives that can occur within a very short period, sometimes seconds. Additionally, a hazard that goes hand in hand with the Lebanese history is the recurrent armed conflicts and civil unrest, which is slowly being considered in environmental planning.

The Lebanese experts interviewed helped to underline the main priority areas for intervention and set the stage for a thorough compilation of multi-scalar adaptation strategies and initiatives.

Local authorities' main concerns were marine litter and water scarcity. Their recommendations revolved around decentralising power to provide more autonomy to municipalities. Private sectors on the other hand focused their attention on coastal infrastructure maintenance and upgrading, as well as safety considerations. Scientists' recommendations were about increasing protected areas to adopt nature-based coastal defence and sharing data across disciplines and institutions. Finally, civil societies exhibited understandable frustration from central governments' response to disasters and crisis, all whilst advocating for a continuous stretch of accessible public maritime domain. The single common recommendation received by a vast majority of the experts was the need for a national-scale integrated master plan for the coastal zone, incorporating emergency response and recovery strategies, following a vision set through a participatory approach.

The compilation of existing, ongoing and future and potential measures were categorized in four main intervention pathways, sorted by scale of intervention and lead stakeholder. International conventions often set the stage for national strategies, creating an incentive for governments to push forward. As a result, most of the projects were funded/supported by international organisations. Public institutions often proved to have little power, with a few exceptions, such as the CNRS whose role is intrinsic to the development of maps and surveys, early warning systems, monitoring and forecasting parameters, which are crucial decision support tools for planning and policy making. The role of NGOs has also been incontestable, especially as the youth involved help to bring innovative solutions to the decision-making processes.

Unlikely findings were the importance of also incorporating religious-political organisations in Disaster Risk Reduction and Management strategies. As antithetical as it sounds to secularist parties, this social capital, if set in the right direction, can generate mass mobilisation reaching the most secluded communities (Baytiyeh, 2017).

Modern communication tools, such as mobile apps, social media platforms and influential storytelling, have proved to be alternative ways for data collection and public outreach. Mimicking the UN Goodwill Ambassadors concept in a virtual way, influencers can help to raise awareness in the wider public about responsible behaviours that lead to the reduction of risk and may also lead to more sustainable livelihoods.

Proper hazard management and adaptation to potentially devastating natural phenomena require a long-term vision and significant investments, both of which are absent in the Lebanese context (Riebe, 2011). However, extreme situations require a shift in mindset from temporary isolated fixes to permanent holistic solutions.

Lebanon's once thriving coast has taken one too many hits, and room for hope has become quite small; yet it still exists among the debris of the nation.

Acronyms and abbreviations

AUB	American University of Beirut
CAMP	Coastal Area Management Program
CDR	Council for Development and Reconstruction
CNRS	*Centre National de la Recherche Scientifique* (in English, view NCSR)
COED	Cost of Environmental Degradation
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
EcAp	Ecosystem Approach (particularly of the Barcelona Convention's strategy)
EIA	Environmental Impact Assessment
ERML	Environmental Resources Monitoring in Lebanon
FAO	United Nations Food and Agriculture Organization
GDP	Gross Domestic Product
GEF	Global Environment Facility
GoL	Government of Lebanon
HFF	Honor Frost Foundation
IAURIF	Institut d'Aménagement et d'Urbanisme de la Région Ile-de-France
ICAM	Integrated Management of Eastern Mediterranean Coastlines
ICM	Integrated Coastal Management
ICZM	Integrated Coastal Zone Management
IFAD	International Fund for Agricultural Development
IMP	Integrated Marine Policy
IOC	Intergovernmental Oceanographic Commission of UNESCO
IOE	Institute of the Environment
IPCC	Intergovernmental Panel on Climate Change
IRC	International Red Cross
IUCN	International Union for Conservation of Nature
LAEC	Lebanese Atomic Energy Commission
LAF	Lebanese Armed Forces
LARI	Lebanese Agriculture Research Institute
LAU	Lebanese American University
LOGI	Lebanese Oil and Gas Initiative
LRC	Lebanese Red Cross
LRI	Lebanese Reforestation Initiative
LSI	Land Sea Interaction
LU	Lebanese University
MoA	Ministry of Agriculture
MoE	Ministry of the Environment
MoEW	Ministry of Energy and Water
MoI	Ministry of Industry
MoIM	Ministry of Interior and Municipalities
MoPWT	Ministry of Public Works and Transport
MoT	Ministry of Tourism
MRCZM	Marine Resources and Coastal Zone Management Programme
MSP	Maritime Spatial Planning
NCG	National Centre for Geophysics
NCMS	National Centre for Marine Sciences
NCRS	National Centre for Remote Sensing
NCSR	National Council for Scientific Research (in French, view *CNRS*)
NPMPLT	National Physical Master Plan of the Lebanese Territory
OECD	Organization for Economic Co-operation and Development
PAP/RAC	Priority Actions Programme Regional Activity Centre (UN Environmental Program – Mediterranean Action Plan)
PINR	Palm Islands Nature Reserve
PLO	Palestinian Liberation Organization
PoB	Port of Beirut
PoT	Port of Tripoli
RoL	Republic of Lebanon
SDG	Sustainable Development Goals
SEA	Strategic Environmental Assessment
SPA/RAC	Specially Protected Areas Regional Activity Centre (UN Environmental Program – Mediterranean Action Plan)
SST	Sea Surface Temperature
STP	Sewage Treatment Plant
TNCR	Tyre Coast Nature Reserve
UNDG	United Nations Development Group
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFPA	United Nations Fund for Population Activities
UNHCR	United Nations High Commissioner for Refugees
UNISDR	United Nations Office for Disaster Risk Reduction
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNRWA	United Nations for Relief and Works Agency for Palestine Refugees in the Near East
UoB	University of Balamand
UNDRR	United Nations Office for Disaster Risk Reduction
WHO	World Health Organization

The famous Pigeon Rocks in Beirut, Lebanon.

7. The case of Myanmar

Myeik City in Pahtaw Pahtet Island, Myanmar.

Author: Thet Oo Mon

7.1 Myanmar and its coastal areas

7.1.1 Geographical setting

Myanmar is the second largest country in mainland Southeast Asia, located between 9°32' and 28°31' N latitude and 92°10' and 101°11' E longitude. It stretches around 2,000 kilometres from north to south and the land area is approximately 676,577 km^2. The country is bounded by the Bay of Bengal to the west and to the south by the Andaman Sea, bordered by Bangladesh, India and China in the north and Laos and Thailand in the southeast (Figure 7.1). It has a structurally complex and diverse topography, with steep mountain ranges, plateaus, hills, and valleys in the east, north and northwest. The central dry zone is surrounded by the western coastal range and lowland deltaic region in the lower part of the country and by a narrow coastal strip, further south establishes the connection with the peninsular Thailand.

The coastline stretches approximately up to 3,000 km, including the islands known to be the most intact coastline in all of mainland Southeast Asia. The country possesses a large and unprotected and mostly unregulated marine territory covering about 486,000 km^2 (WCS, 2016). The coastal zones of Myanmar can be subdivided into three major geographical zones, namely the Rakhine Coast, Ayeyarwady Delta, and Tanintharyi Coast. The Rakhine

Coast (with about 740 km from the mouth of the Nat River in the north to Mawtin Point), the Ayeyarwady Delta region (with about 460 km from Mawtin Point to the Gulf of Mottama) and the Tanintharyi Coast (with about 1,200 km from the Gulf of Mottama to the mouth of the Pakchan River in the very south close to Kawthaung), plus the coastlines of several islands of the Myeik (Mergui) Archipelago, which possess some of the world's most important marine biodiversity (Holmes *et al.*, 2014). The Myeik Archipelago contains a network of more than 800 islands covering an area of about 34,340 km^2 and extends up to 140 km offshore (FAO, 2019). Major rivers that flow into the coastal zones include: the Mayu and Kaladan rivers in the Rakhine coastal area; the Ayeyarwady, Sittaung and Thanlwin (Salween) rivers in Ayeyarwady Delta coastal area; and the Ye, Dawei, Tanintharyi and Lenya rivers in the Tanintharyi coastal area.

The Rakhine coastal plain forms a narrow strip, mostly between 5 and 20 km wide, but up to 60 km wide in some places, bounded by the Rakhine Yoma mountain range that lies parallel to the coast in the east. The Ayeyarwady Delta and its adjacent coastal plains form an expanse of fertile alluvial land with a network of small rivers and streams (Zöckler *et al.*, 2013). The Tanintharyi coastal plain in the south, similar to the Rakhine plain, is narrow and gradually rises towards the east to become the Tanintharyi Yoma, with mountain ranges as 2,073 m high (Myint Pe, 2002).

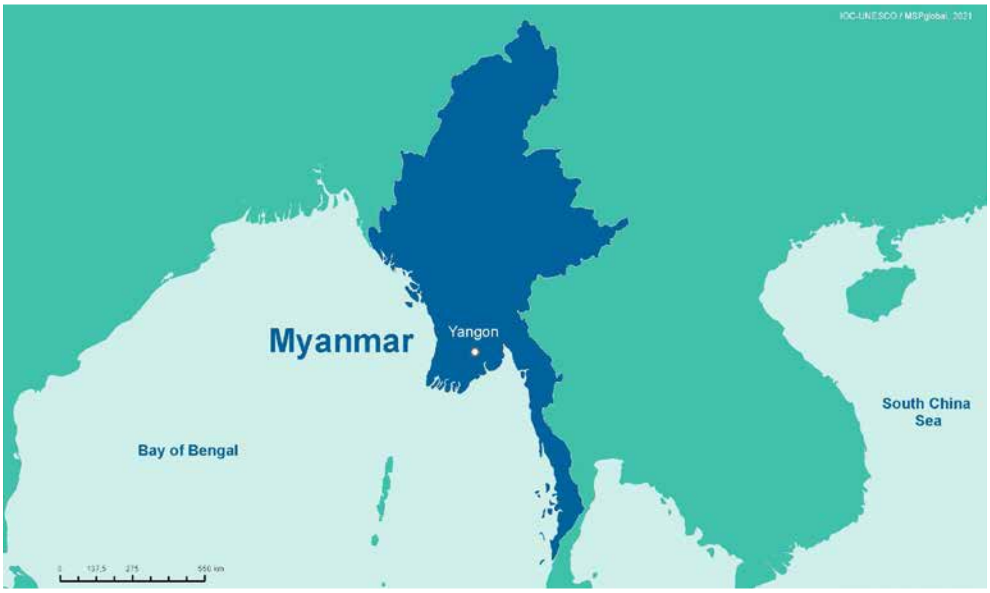

Figure 7.1 Location map of Myanmar.
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7.1.2 Administrative setting

Generally, the three coastal zones share the administrative boundaries among six coastal states or regions : the Rakhine coast mainly in the Rakhine State (capital: Sittwe); the Ayeyarwady coastal zone within the Ayeyarwady Region (capital: Pathien); Yangon Region (capital: Yangon); Bago Region (capital: Bago) and Mon State (capital: Mawlamyine); and Thanintharyi coastline in the Thanintharyi Region (capital: Dawei) and partly in Mon State.

7.1.3 Climate

Myanmar has a tropical climate with three seasons: the dry or summer season (from March to May), the rainy or monsoon season (from June to October) and the winter (from November to February). Seasonally, the temperature ranges in most parts of the country between 32 °C and 38 °C during the dry season, 25 °C and 35 °C during the rainy season and 10 °C and 25 °C during the cold season (FAO, 2019). Annual rainfall can be as high as 6,000 mm along the coastal reaches, and in the mountains of Rakhine and Tanintharyi, with intermediate rainfall up to 3,000 mm in the Ayeyarwady Delta area (NAPA (2012); RIMES, n.d.; WWF (2017); Zöckler *et al.*, 2013). The southwest monsoon from the Bay of Bengal and Indian Ocean lasts from May to October with two cyclone seasons of around a month each from April to May and then again in October to November (Akester, 2019).

7.1.4 Ecosystems

The intact nature of marine biodiversity in the coastal regions of Myanmar is normally presumed, with few assessments to quantitatively determine the status of marine species and habitats. Efforts to increase understanding of critical marine life and ecosystems are increasing (*e.g.,* Myanmar Marine Biodiversity Atlas (Birch *et al.*, 2016; BOBLME, 2015; FFI, 2018; Murray *et al.*, 2020), together with many conservation activities is on its way are to be consolidated (Holmes *et al.*, 2014).

The mangrove areas in Myanmar is the second largest in Southeast Asia, extending across Rakhine, Ayeyarwady and Tanintharyi regions, with Tanintharyi Region one of the least disturbed mangrove areas in the country (May Ei, 2020). Myanmar's nearshore areas and offshore islands provide habitat for populations of globally threatened marine turtles. In Rakhine State, vast seagrass beds and large portion of Southeast Asia's remaining mangrove forests provide critical habitat for a range of species, while the southern waters of the Myeik Archipelago are noted for their rich coral reefs (Zöckler *et al.*, 2014). In addition to mangroves, coral reefs, sea grass beds and sandy beaches, there are many intertidal mudflats, which are home to many globally threatened water bird species and located mainly of the Gulf of Mottama and in the adjacent Ayeyarwady Delta. More than 150,000 wintering and migrating water birds of 80 different species are depending on those intertidal areas (Zöckler *et al.*, 2014). The Myanmar coastal zone is also important for fish stocks which support artisanal fishery, and other livelihoods for local people, with more than 442 species of fish, prawn, shrimp and lobster (Akester, 2019).

7.1.5 Socio-economic conditions

Major economic activities of coastal communities include small-scale agriculture, aquaculture, and fishing, though there might be some variations in the crops or types of fisheries. The Ayeyarwady region was the rice bowl of the country due to its major production of rice across the country and agriculture is in fact the principal livelihood in the rural delta, with a maximum number of people engaged (Delta Alliance, 2015). Fisheries support the dominant livelihoods in many of these coastal regions, raising concerns about sustainability matters.

Beach, lagoon and mangrove forest on an island of the Mergui Archipelago, Myanmar.

7.2 Coastal hazards in Myanmar

It is challenging to understand and summarize all the factors contributing to various types of risks threatening the coastal communities as the institutional setup and socio-economic dynamics involved can be complex and varying in many contexts (Barbesgaard, 2019). Major coastal risks in Myanmar comprise many physical processes and affect various societal groups. A summary is presented below based on the available literature, interviews with relevant stakeholders (locals, government institutions and scientists) and understanding of the system and local conditions. This report is aimed to serve as a critical step in encouraging a dialogue among important actors and to understand the dynamics behind these issues so that it can lead to measurable steps towards managing coastal risks in the coastal regions of Myanmar.

7.2.1 Coastal floods (sea-level rise, extreme waves, storm surges)

According to a regional risk assessment by UN ESCAP (2019), Myanmar is one of the countries with the highest flood risk in the Southeast Asia region. Most frequent and disastrous floods contributing to this number are monsoon rainfall floods (and, in some places, landslides) and economic damages resulting from them, including some cities of the coastal regions (Ei Shwe Sin, 2018). In addition, rainfall projections in most of the major observation stations in Rakhine and Mon States, Ayeyarwady and Yangon regions suggest an increasing tendency in annual and wet season rainfall (RIMES, n.d.).

Storm surges affecting Myanmar are to some extent less disastrous compared to other parts of the Indian Ocean, such as Bangladesh and India. Notable storm surges affected the Myanmar area in the past five decades, namely in 1975, Pathein; 1982, Gwa; 1992, Thandwe; 1994, Sittwe; 2006, Mala; 2008, Ayeyarwady (Nargis); and 2010, Rakhine (Giri) cyclones, implying higher occurrences in the Ayeyarwady Region and Rakhine State. Despite the relatively lower cyclone frequencies and risk, the impacts can be devastating due to low preparedness and high vulnerability of the coastal communities. The Nargis Cyclone in 2008 is a very prominent example of this (Disasterscharter, 2008; Lai *et al.,* 2017). During Nargis (category 4 on the Saffir-Simpson Hurricane Scale, SSHS) which made landfall on 2 May 2008, the official death toll estimates exceeded 138,000 fatalities, making it one of the deadliest cyclones ever recorded worldwide to date (Fritz *et al.*, 2009). In addition to the numerous human casualties, Nargis resulted in severe socio-economic damage in the densely populated Ayeyarwady Delta, which is already subject to large-scale deforestation and mangrove removal (Besset *et al.*, 2017). The impacts of Cyclone Nargis is reported to be much higher than a comparable cyclone of the same magnitude, due to the lack of an established early-warning system and lack of cyclone awareness, preparedness, and evacuation plans.

Various parts of the Myanmar coast are being impacted by sea-level rise.
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Considering Myanmar's higher vulnerability to flood hazards, the indirect losses need to be studied in further details, as they can also act as a very severe drag on the economic development (Groot, 2017; UN ESCAP, 2019).

Published works focusing on vulnerability assessments or future projections for sea-level rise and storm surges are not widely available in Myanmar except for a regional study by GERICS (n.d.) and the Deltares global platform Blue Earth Data, which offers global water- and subsoil-related data.

7.2.2 Coastal erosion

Severe coastal erosion has been reported in recent years, displacing many villages in the Bago Region near the Sittaung river mouth. Changes in the river erosion and sedimentation patterns are frequent with anecdotal evidence reporting the repeated erosion cycle each 10 to 15 years (Helvetas Myanmar, 2018). The river banks' erosion has forced entire villages to retreat and to abandon their homes, causing severe disruptions on education and socio-economy activities (Rozanna Latiff, 2020). Livelihood patterns of farmers and fishers are adversely affected, forcing most of the inhabitants to migrate to cities or other foreign countries. The issue is difficult to manage as it involves land issues and due to the lack of validated property records. Helvetas Myanmar (2018) has carried out a study on this matter including an assessment of various management options. A combination of monitoring and managed retreat is suggested as most of the displaced areas, especially in the Gulf of Mottama, are extremely difficult to access (Zöckler *et al.*, 2014). Whether the erosion has been mostly caused by sea-level rise or the natural cycle of the river system needs to be studied in details (Helvetas Myanmar, 2018). The media tends to highlight sea-level rise; however, it is difficult to conclude this since there are no local sea-level studies in the area.

Ayeyarwady Delta is also under the influence of rapidly changing shoreline dynamics, governed largely by reduction of the sediment supply and change in hydrological regime through the construction of dams, deforestation, and mining activities upstream. Most of the western coastline areas (42% of its shoreline) are subject to erosion, whereas the eastern delta front accreted with an average shoreline change rate of 10.4 m per year from 1974 to 2018 (Chen *et al.*, 2020). This advancement around the eastern side is affirmed by locals in nearby villages, such as Letkhokekone.

7.2.3 Tsunamis

The coast of Myanmar is relatively less prone to tsunamis compared to other coastlines in the Asia-Pacific region, which was the case during the 2004 Indian Ocean tsunami (MAPDRR, 2012). However, studies indicate that there is an active subduction zone in the Bay of Bengal, with higher earthquake risk in the northern part that must be better studied by additional scientific research (Gramling, 2007). Shyu *et al.* (2018) also pointed out potential tsunami risks, which can result from earthquake events produced solely by the rupture of upper-plate splay faults. Though smaller in magnitude, these events could still produce significant damages for local coastal communities due to its high vulnerability and low preparedness.

A monsoon storm hits the coast of Myanmar.

7.2.4 Salinisation of surface and groundwater

In the Ayeyarwady Delta, 60% of households use groundwater for drinking and domestic water supplies. Groundwater use is high (more than 80%) in townships of the upper parts of the delta in Hinthada and Tharawaddy districts, and much lower (less than 20%) in the lower delta in townships of Pyapon and Labutta districts. The number of wells in the Ayeyarwady Region is estimated to reach 5,000 to 7,500. The recharge and discharge processes of groundwater in coastal aquifers have a close interaction with mangrove systems and degradation of mangrove forests. Combined with potential sea-level rise, it may have caused more saline intrusion into the aquifers (Thein *et al.*, 2020) although no quantitative study has been carried out to monitor this phenomena. However, an indicative location of the salinity front line has been proposed by Chen *et al.* (2020).

7.2.5 Potential subsidence in delta areas

According to a SAR interferometry study in several townships in Yangon (Van Der Horst, 2017), subsidence velocity reaches up to 9 cm per year, and may be related to the excess groundwater extraction. In the Dagon Myothit townships, which are the most severly hit subsiding area, there is the possibility that a more complex phenomena than the linear relation between groundwater extraction and subsidence might need to be considered. This unmonitored issue can lead to irreversible impacts on groundwater aquifers and consequently on the local population and economic activities that are also contributing to subsidence (including industrial use) in Yangon.

7.2.6 Wetlands change and loss

Various land-based economic activities, such as aquaculture and agriculture, lead to the deforestation of mangrove areas throughout mainland Southeast Asia (Zöckler *et al.*, 2014). Mangrove ecosystems are being lost in Myanmar at the rate as high as 5% per year (Richards and Friess, 2016) and a detailed evaluation of that loss has been assessed by Zöckler and Aung (2019). According to a GIS assessment by ArcCona in Zöckler *et al.* (2013), the original area of mangrove forest in Myanmar was 320,106 ha in the early 20th century, about 275,000 ha in 2001, and probably consisting of only two-thirds of the cover of 2001 by 2013 (Akester, 2019).

The loss of mangroves in Myanmar is also associated with the major drivers identified in developing countries, including agriculture, coastal development, aquaculture, timber and charcoal production, and to improve the access to the ocean (Holmes *et al.*, 2014) mainly in Rakhine and Ayeyarwady regions. Webb *et al.* (2014) listed agriculture expansion for rice production as the main driver for loss in mangrove area, particularly in the Ayeyarwady Delta area, but is also common in the other two coastal regions, more so in the Rakhine Region. Despite the differences in area calculations in the studies (May Ei (2020); Webb *et al.* (2014)), Myanmar's mangrove forests have been considerably depleted and degraded over the last few decades (Holmes *et al.*, 2014). The reasons for loss of mangroves can be due to proximate drivers (*i.e.,* direct human activities) such as aquaculture or agriculture expansion and underlying drivers such as an institutional or socio-economic factor.

7.2.7 Droughts

There are more and more villages with increasing water scarcity reported across the country although the central dry zone is very well-known in terms of severe droughts. UN ESCAP (2019) reported that Myanmar exhibits high vulnerability but low exposure to droughts; however, it must be noted that many of the past events were not widely recorded yet and there is potential for an intensification of the phenomena in the future. Water shortages in coastal areas are majorly associated with the salinisation of groundwater (Thein *et al.*, 2020) and water scarcity driven by dependence on the groundwater and the potential threat of saline intrusion (*e.g.,* Dala Town near Yangon; Groot, 2017); MMtimes, 2020a). Climate change and sea-level rise combined with upstream developments, may cause critical low flow conditions in the Ayeyarwady River tributaries, which are likely to experience stronger saline intrusion in the coastal areas. The existing water sources (for domestic and agricultural use) and the freshwater ecosystem may therefore become more vulnerable (Delta Alliance, 2013). Similar cases are reported in some villages of Yangon and Bago Regions.

Shepherd grazing a gaunt cow through a dry field in Myanmar.

7.2.8 Changes in the distribution and abundance of coastal and marine species

The Myanmar coastal zone is very important for fish stocks, with over 125 fishing grounds offshore (FAO, 2003), which support artisanal fishery and other livelihoods for local people. Rapid and often unsustainable development (Zöckler *et al.* 2013) is beginning to jeopardise the fragile relationship between the crucial habitats of fisheries ground and the livelihoods of rural people (Zöckler *et al.*, 2014).

The fisheries in Ayeyarwady Delta have been severely affected by land use change in the past decades. Large parts of the delta, which used to be a very diverse and rich fishing areas, are now a simplified agro-ecosystem of rice fields, plantations and degraded mangrove areas linked by rivers and canals (Delta Alliance, 2015).

Over-exploitation of fish and marine resources in coastal regions has also become more apparent as excessive unregulated fishing activities got increasingly reported (VOANews, 2020). Illegal fishing by trawling with large fishing boats has been regarded as a major driver for smaller fish populations (Myanmar Ocean Project (2020)). By law, there are regulations in place, such as keeping a certain distance from the islands when fishing and restricted areas for juvenile trawlers, seasonal banning, and prohibition of unsustainable fishing techniques. However, the government's low priority given to the fisheries sector in the national budget weakens the enforcement of the law, namely with regard to monitoring, control and surveillance, as pointed out by Tezzo *et al.*, (2018). Despite the limited resources allocated to fisheries in Myanmar, a large amount of livelihood activities depend on it. The isolation of the some regions and the lack of phone connectivity also affect the enforcement of the law by hindering the efforts of the locals to raise concerns about illegal fishing activities and enforce the Locally Managed Marine Areas (LMMAs) zoning (Myanmar Ocean Project, 2020).

Harmful algae blooms have not been reported in Myanmar yet. In 2013, the occurrence of a "red tide" did not cause any fish mortality. Nevertheless, the potential increase in fishing, associated with the country's economy expansion, is likely to raise impending risks along the Myanmar coast (Su-Myat and Koike, 2013).

Rice fields and rural village near the coast in Myanmar.
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7.2.9 Marine pollution and water quality change

Myanmar has been facing challenges regarding waste management, due to increasing income and consumption levels, expanding urbanisation, and ineffective waste treatment and disposal options. Similar to other countries, a lack of proper waste regulations, together with poor monitoring and enforcement of existing laws, frequently results in both domestic and industrial waste to be dumped in the streets or vacant lands, or into drains, streams or other watercourses, or occasionally burned to minimise the nuisance caused by accumulating piles of waste (UNEP, 2017). It is estimated that 200 tons of waste enter into waterways every day and about 80 millions of plastic bags are used every year in Myanmar (Myanmar Coastal Conservation Lab, 2019). As stated in SOBA (2017), not having a proper sewage treatment nor an urban waste processing infrastructure along the Ayeyarwady Basin causes discharge of pollutants into waterways.

Many coastal villages do not have proper waste management system in place as well. Rubbish is either burnt under or near homes or collected to be dumped further out at sea. Survey from Myanmar Ocean Project (2020) reported increasing amount of plastic waste on the beaches in front of two villages. Water quality monitoring in the marine and coastal environments are non-existent despite the facts above and the impacts that the detected pollutants can have in the delta areas (SOBA, 2017).

Beach covered with rubbish in Myanmar.
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Another major issue falling under the marine pollution is the observation of fishing gear nets along the coasts of the Thanintharyi Region, as reported by the Myanmar Ocean Project (2020). At one of the most severe sites, multiple layers of varying ghost nets were found to be accumulated, killing coral and marine life, and turning a formerly vibrant dive site into a place covered in ghost nets.

7.2.10 Livelihood and socio-economic challenges

Most of the following reflects the major livelihood challenges faced by the coastal community in the Ayeyarwady Region, with similar but less severe situations in other regions. A large proportion of the population in the delta areas comprises landless people and secondary fisheries workers affected by unfavourable socio-economic or political settings that do not allow for a long-term stable livelihood (Delta Alliance, 2015). Some studies also observed that the working conditions of the fisheries workers are well below average, with minimum daily incomes. According to interviews by JICA (2014) on the economic condition of the fisheries workers in some parts of Rakhine State, about 60% of the value of the landing goes to the owner. Belton *et al.*, (2019) stated that there is an urgent need for policy interventions to improve working conditions in Mon's fisheries.

Fishing village in Dawei City, Myanmar.
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Considering the high population growth and lower abundance of natural resources, the ratio of landless farmers or fisheries workers in the deltas are not expected to decrease. At the same time some people lost their right to have both their education and medical expenses covered by their landlord (Delta Alliance, 2015). This lack of viable livelihood means has also forced many inhabitants to migrate to cities such as Yangon, increasing the pressure on urban areas (Groot, 2017; UN-HABITAT, 2020). Some had to migrate to foreign countries in search of a better living. Another challenge is the limited training options due to the lack of investment in capacity building. If no action is taken, the fisheries-based coastal economy may experience a decline (IUCN, 2017).

Understanding the actual vulnerability can be a challenge since reliable data on socio-economy, livelihoods, employment are not available due to the unregistered migration, both into the delta and out of the delta (Delta Alliance, 2013). The livelihood challenges of the community in the rural and coastal areas of the country are also being impacted by climate change as well as by the weak regulation of the market, as evidenced by the volatile prices of crop and fish triggered by unstable and unstandardized market practices.

7.2.11 Infrastructure development impact on livelihoods

Deep-sea ports development

There are nine ports around the coast of Myanmar and Yangon is the principal one, with the Myanmar Port Authority (MPA) acting both as landlord and port operator. The Yangon port (in fact a river port located 32 km from the mouth of the Yangon River, but mostly operating seaborne cargo) handles about 90% of the total cargo of Myanmar

(ADB, 2016). The expansion of Thilawa SEZ (Special Economic Zone) in recent years has also become important for the development of the nation's expanding trade. Now, only small steamers and country boats serve the coasts of the Rakhine and Thanintharyi regions for local transport.

There are new deep-sea port developments being planned for the coastal regions. For the Dawei deep seaport and SEZ in Thanintharyi Region, a Memorandum of Understanding was signed in June 2018 between the Myanmar and Thailand governments. These projects nevertheless remain pending probably because of investment issues. The Kyaukphyu deep-sea port project in Rakhine State, a cooperation between the Myanmar and Chinese governments, was agreed to advance in 2020. The project has not started yet due to land disputes and concerns around its impacts on local business, such as cashew nut growing and production, salt ponds, and fisheries (RFA, 2013; RFA, 2020). Rainforests of globally-threatened species are also reported to be at risk due to road constructions that are part of the Dawei SEZ plan (WWF, 2019).

Urban pressures on the city of Yangon

The capital of the Yangon Region is the major economic centre of the country. It has a recorded population of above 5 million, which is almost one-tenth of the country. A large portion of the population from other states and regions has also migrated to Yangon for more economic opportunities. The large city of Yangon is further expanding rapidly towards the north, west and east. The balance between the increased inhabitants and the facilities that the city can accommodate is also a future concern for the management bodies and inhabitants in Yangon (Groot, 2017).

Oil and gas exploration

Myanmar provides strategic access to the Indian Ocean and Andaman Sea, supported by its moderately rich gas reserves and accessibility to cheaper crude products. This has earned significance and interest from the neighbours China and Thailand, exemplified by the ambitious trans-ASEAN Gas Pipeline project that runs from Kyaukphyu (Rakhine State) to Muse (Shan State) (Hong, 2012). Environmental impact assessments are not widely available to the public, with a reported dispute by the Chinese investor in the Rakhine State (BEWG, 2009). The emerging pressures and tensions require coordinated and informed actions and transparent cooperation with monitoring mechanisms and assessments to foster the generation of a long-term sustainable income and the development of the local community and the protection of the environment.

Yangon with its river harbour that connects to the Bay of Bengal a few kilometres to the south, Myanmar.
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7.3 Adaptation measures to manage coastal risk in Myanmar

In Myanmar, the response measures and management actions around different types of the risks mentioned above will be different in terms of both nature and priority. In recent years, disaster related risks as floods, cyclones, droughts (majorly in the central dry zone) and tsunamis (low occurrences based on previous incidents) and livelihood challenges embedded in the loss of natural resources and degradation of ecosystems are getting more attention at the national level.

Myanmar has committed to a number of new global and regional frameworks, plans and agreements related to disaster, climate and development: the Sustainable Development Goals (SDGs), the Sendai Framework for Disaster Risk Reduction, the Paris Agreement, the Asia Regional Plan for Implementation of the Sendai Framework for Disaster Risk Reduction, and the AADMER Work Programme 2016-2020 (NDMC, 2017). This has led to the development of various national plans and strategies, with increased international attention and support around these issues.

To get an overview on the prioritization level regarding all the above issues is an ambiguous matter. National plans recently adopted or updated from the Government, together with observed community response actions and well-known international project initiatives will be summarized below.

7.3.1 National plans and policies

Table 7.1 Myanmar's national plans and policies affecting the coastal zone.

MSDP (MOPF, 2018)	**Myanmar Sustainable Development Plan**	**2018 – 2030**
The MSDP provides a long-term vision with the objective of giving coherence to the policies and institutions necessary to achieve genuine, inclusive, and transformational economic growth in Myanmar. It is supported by three pillars (peace and stability, prosperity and partnership, people, and planet) which are underpinned by five goals: • Peace, national reconciliation, security, and good governance • Economic stability and strengthened macroeconomic management • Job creation and private sector-led growth • Human resources and social development for a 21st century society • Natural resources and the environment for posterity of the nation, together with strategic action plans for each goal		
NAPA (NAPA, 2012)	**National Adaptation Programme of Action to climate change**	**December 2012**
National Adaptation Programmes of Action (NAPAs) serve as simplified, rapid, and direct channels for Least Developed Countries to identify and communicate priority activities to address their urgent and immediate adaptation needs. It has come up with agriculture, early-warning systems, and forestry as the priority sectors, based on a nationwide overall vulnerability assessment. Regarding the adaptation measures in coastal areas, implementation of ICZM followed by encouraging of community-based mangrove reforestation and aquaculture techniques and biodiversity conservation projects are mentioned as the third priority actions.		
MCCSAP (MoNREC, 2017)	**Myanmar Climate Change Strategy and Action Plan**	**2016 – 2030**
The MCCSAP provides a roadmap to guide Myanmar's strategic responses and actions to climate-related risks and opportunities over the next 15 years and beyond to work towards its vision of a climate-resilient, inclusive nation that can address climate risks and harness the benefits of low-carbon development. The strategy is to be implemented through five pillars: an overarching policy framework, a multi-stakeholder institutional mechanism for coordination across actors and scales, a financial mechanism, a capacity-strengthening framework and a monitoring evaluation and learning framework and across sector-specific outcomes for agriculture, fisheries and livestock, natural resource, energy, transport and industrial systems and low-carbon climate resilient society.		
MAPDRR (NNDC, 2017;renewed update of MAPDRR, 2012)	**Myanmar Action Plan on Disaster Risk Reduction**	**2017 – 2030**
The MAPDRR is a comprehensive and unified action plan for risk reduction and management with prioritized interventions across Myanmar until 2020. In the Action Plan, 32 priority actions have been identified under the four pillars namely Risk information and awareness, Risk Governance, Risk mitigation and Preparedness for response, rehabilitation, and reconstruction (Ei Shwe Sin, 2018). It is built up of three phases designed to align DRR priorities with development priorities: • Phase I until 2020: generation of disaster risk information necessary for undertaking risk reduction programmes, including strengthening and setting up systems and drafting policies and procedures • Phase II until 2025: Application of disaster and climate risk information (by building on the pilot interventions) in development planning and implementation • Phase III until 2030: Institutionalization of the actions and additional measures, based on lessons from phases I and II plus development trajectory and underlying risk drivers		

NBSAP (FD, 2015; revised update of NBSAP, 2011)	National Biodiversity Strategy Action Plan	2015 – 2020
The NBSAP is aimed to establish a strategic planning framework, identify concrete actions, and ensure effective management and conservation of Myanmar's diverse ecosystems, species, and natural resources. The development of national targets is intended to be guided by the flexible framework, built around Aichi Targets, considering both the needs and priorities of the nation and national contributions to the achievement of the global targets.		
MRRP	**Myanmar Rehabilitation and Restoration Programme**	**2017 – 2026**
The MRRP aims to restore over 1.2 million hectares of degraded and deforested land by 2026, through plantations, community forestry, agroforestry, natural forest regeneration. The prioritized actions can differ within regions and a total of 27,738 acres of mangrove protected areas are aimed for plantation on the accreted land in townships in southern Yangon Region in the Gulf of Mottama. (FD, 2017). As a supporting document for MRRP, the Myanmar Restoration Opportunities Assessment Methodology (ROAM) report to identify Forest Landscape Restoration (FLR) opportunities in Myanmar has been undertaken, in which suggested priority areas include mangroves of northern Rakhine State and the Ayeyarwady Delta and the lowland evergreen forest of southern Tanintharyi Region (IUCN, 2019).		
NPOA-IUU (Hosch, 2015)	**National Plan of Action to Combat, Deter and Eliminate Illegal, Unreported and Unregulated Fishing**	**2015**
The NPOA-IUU aims to establish an understanding of the nature, extent, and impact of Unreported and Unregulated Fishing (IUU) fishing in Myanmar's marine and estuarine waters.		

Source: UNESCO-IOC/Thet Oo Mon

The process for developing these national plans has been achieved by forming Union Level Committees such as:

- National Coastal Resource Management Committee (NCRMC)
- National Water Resources Committee (NWRC)
- National Environmental Conservation and Climate Change Central Committee (NECCCCC)
- National Natural Disaster Management Committee (NDMC)
- National Commission for Environmental Affairs (NCEA)
- Wetland Management Committee, Mon State (2016)

It also provided the update or adoption of the following policies and regulations:

- Environmental Conservation Law (March 2012)
- Disaster Management Law (2013)
- Myanmar Water Policy (2014)
- Sendai Framework for Disaster Risk Reduction (2015-2030)
- National Environmental Policy of Myanmar (2019)

The following institutional advancements have been observed:

- Establishment of Protected Areas along Myanmar's coast, Lampi Island as one and only marine national park in Myeik Archipelago and Mainmahla Island, Moscos Island and Thamihla Island as wildlife sanctuaries
- The Department of Marine Science within the University of Mawlamyine to establish an aquaculture research centre
- The Department of Fisheries (DoF) in collaboration with BANCA and FFI plan to establish an MPAs Network System that will incorporate existing MPAs, for example, the Shark Reserves in the Myeik archipelago (Lampi MPA)
- Construction of shelters in high-risk areas to storms and Cyclone Preparedness Pamphlet: MIMU (Ministry of Social Welfare, Relief and Resettlement)
- Township Disaster Management Plans as part of MAPDRR have been developed, which implies the aim to implement measures at multiple levels

7.3.2 Community responses

Most of the adaptation measures, within the capacity of the community itself, exist in the form of scattered individual actions, such as livelihood change or migration in case of low production, or land loss due to flood. It seemed to be working on the surface and for a few people, but now with many other factors like population growth and accelerating hydro-climatic pressures, it is calling for more sustainable long-term visions and recovery needs. For example, in the flood-affected region of Ayeyarwady, the immediate risk to food security is relatively easier to tackle by the support from the public through different mediums as the NGOs and CSOs. Significant decrease in crop production for lower income household has led them to take out loans with high interest rates from moneylenders to buy agricultural inputs (mainly seeds and fertilizers) necessary for subsequent agricultural seasons (NNDC, 2017), which threatens the stability of their livelihood. However, the community-based initiative actions can exist in many forms, such as:

- CSOs to grow mangroves locally
- Actions to bring together scattered voices and actions (*e.g.,* a local media to express the local needs such as TavoyanVoice)
- Coordination support of local NGOs in case of disasters relief
- Independent Local networks/movements based on local knowledge (*e.g.,* BEWG)

7.3.3 Projects and initiatives from international organizations

The support from international development organizations has been important during the formulation process of the national plans, including but not limited to the following initiatives completed or underway:

- Development of data portals such as MIMU and Myanmar National Portal (not specifically to coastal areas)
- BOBLME projects which promotes sustainable marine ecosystem management and sustainable coastal livelihood development and its affiliated knowledge-based programmes
- WorldFish and partners working in the northeast Bay of Bengal (both Bangladesh and Myanmar) to protect the transboundary hilsa fisheries
- IUCN, FFI, WWF, EDF, IIED, WorldFish, bi-lateral and multi-lateral donors under the Myanmar Fisheries Partnership, led by the Department of Fisheries, all working to address the absence of data in the northeast of the Bay of Bengal over the last half century (Akester, 2019)000 km^2. The Myanmar exclusive economic zone (EEZ
- Different agencies and organisations, including JICA, FREDA, and MERN undertaking mangrove and coastal forest restoration efforts following damage from recent cyclones in Myanmar's coastal areas. (NAPA, 2012)
- The Gulf of Mottama Project (GoM), supported by Environmental Defence Fund (EDF), identified three pilot high fisheries dependent sites that could be transformed to high-performing fisheries that model the benefits of reform and serve as proof points and learning laboratories that will inspire replication and scale throughout Myanmar
- Research and initiatives in Myeik to explore the potential of cultivating clams, in cooperation with JICA

7.3.4 Challenges and opportunities

The existing response mechanisms seem to be deviated to more of a reactive approach rather than preventive initiative actions based on assessment, which is understandable for a Least Developed Country (LDC) like Myanmar. In spite of responding to conservation issues on an ad-hoc basic, it is essential to create the enabling working environment for addressing the issues consistently in the long run (NBSAP, 2011).

Management and policy

It is a big initial step to have national plans in place; however, it is critical that these plans are carried out in a way that ensures their enforcement at multiple administrative levels and in accordance with the roadmap, actions and monitoring plan, together with dissemination and engagement of the public. Except for the recently developed frameworks, a well-known issue in management mechanism of Myanmar is the outdated policy and weaknesses in law enforcement. For example, the 1990 Myanmar Marine Fisheries Law is primarily laid out as a licensing and revenue generating mechanism for the State, being silent on fisheries management planning, stakeholder consultations, decision-making, and research (Hosch, 2015). The whole mechanism was designed in favour of either situation a few decades ago, skipping other purposes that would benefit the population. It might therefore be ambitious to expect an immediate change, considering that the country is facing other more pressing and challenging issues in some areas. The ad hoc efforts and willingness to tackle evident problems are evident among various actors, as exemplified by the public and private support during the flood emergencies in 2015. Strong leadership and guidance to bring together the scattered actions from various parties from different sectors can be critical and must be based on inclusive and informed strategies underpinned by long-term sustainable vision. Genuine development will only come to Myanmar if all these plans move harmoniously and coherently under the aegis of a single national strategy (MOPF, 2018).

Another identified challenge is the lack of centralized data records and the insufficient coordination mechanisms and protocols among different governmental departments. The information collected by the Government is not yet centralised in one place although some efforts are ongoing. The information tends to be more commonly shared through workshops, making it hard for the wider public or international bodies to have access.

At the regional level, the announcement of a Ramsar site in the Gulf of Mottama and a potential protected coastal wetland in Nanthar Island, together with the establishment of LMMAs are welcomed by the locals. However, the potential for this action to go hand in hand with the community's understanding and benefits is yet to be explored. While it helps to accelerate actions on conservation, the degrees of awareness and enforcement are still a matter of concern.

Science and research

One of the challenges often pointed out by the scientific community is the lack of baseline studies and limited scope of previous coastal research studies. Most of the existing research outcomes are only in the form of unpublished reports. An example would be the scientific research on Myanmar's marine resources that is only available at the corresponding university. Holmes *et al*. (2014) sets a good example of making proper use of these studies, that many other authors proved it to be of great relevance (FAO, 2019).

Moreover, these long ignored existing resources can serve valuable uses. The scientific community can bridge the gap between the governance sphere and the population, supporting an information-based decision making. For coastal risk management aspects, there is also a potential for interdisciplinary research actions to explore and incorporate the interdependency of political and governance setting and socio-economic conditions of the local people to natural or physical systems. The researchers' willingness to expand the nature of their work and be more engaged in capacity building programmes and international scientific dialogue is also seen as key Holmes *et al*. (2014).

Local communities

The locals have expressed their positive opinion regarding mangrove restoration through livelihood support actions (MERN, 2020) plus the establishment of the LMMAs and its associated outcomes. There are two opposite mindsets: the majority does not know how to claim their rights while a few others use this to their own benefits. It is therefore important to ensure that the development process is fair and transparent and considers and protects the benefits of the vulnerable and/or silent groups.

Lack of access or knowledge about the mandates of the Government or sustainable practices is also observed. For example, sand mining or similar uncoordinated actions as described in Van den Berg (2017) or the issue of fishing gear identified by the Myanmar Ocean Project (2020). Guidance and effective awareness raising actions on these matters will contribute to the development of the rural and coastal areas.

Ongoing project consultants expressed the local communities' willingness to cooperate in knowledge sharing programmes. Despite the lack of experience and capacity in fisheries management, lack of data and information, and the need for community-based fishery management organizations, there is an eagerness among fishers, governmental bodies, and community leaders to set Myanmar on course to recover its fisheries, protect coastal ecosystems, and sustain healthy communities (Foundation Ensemble, n.d.). However, the priority is to promote long-term perspectives among them. It will be a big contribution for the system if the locals have an understanding and bigger picture on the risks they are exposed to. Clear communication among stakeholders and proper guidance is therefore also mandatory regarding sustainable tourism and aquaculture.

Coordination and support

Although many efforts and significant progress have been made on legislative and policy development at the national level, there is still little enthusiasm at local level. To effectively implement sustainable management actions, it is crucial to strengthen the cooperation between the locals, private sectors, authorities, and scientific communities, encouraging information-based decision making.

Regarding international support, Sandford and Adeel (2011) suggested to practice and encourage an alternative governance model, with an adaptive approach which takes local customs into account and develops a model capable of responding to the specific shortcomings of the local institutions so that the legitimacy of the new model will be strengthened from within the country over the current imported models.

Given the increasing accessibility to mobile phones and internet within the wider public, the role of technology and potential for community participation, with the involvement of social science, can be an opportunity worth exploring.

Fishing village of SinMa off the west coast of Myanmar with traditional homes and bags of dried fish for the market.

7.4 Final remarks

With the accelerating pressures at hand, many coastal communities in Myanmar are being more impacted by natural hazards. However, despite their large geographic spread and variations within the country, little assessment and overall understanding exists about such phenomenon. This chapter alone may not provide a complete picture of the complex societal challenges around coastal management nor provide a location-specific assessment. Instead, it offers a glance into the major challenges that the communities in the coastal areas of Myanmar are facing and the viable known solutions, based on the literature available and existing local knowledge.

Pressing issues in coastal areas, including water related hazards, are found to be accelerating in Myanmar due to the combined effects of a changing climate and many unsustainable human actions embedded in the livelihood of most of the population. The impacts of many hazards are evident on the socio-economic sectors of health, education, and livelihoods, resulting in deeper inequalities that are transmitted over generations (Groot, 2017), leading to a vicious cycle of poverty and emergency relief which must be broken to prevent disasters from reversing development actions (UN ESCAP, 2019). At the same time, managing these risks will not be easy and produce immediate results due to the lack of public awareness about coastal risks and the environment as well as, most importantly, the fact that society has been shaped by many years of static management with weak regulations and enforcement.

The Myanmar Sustainable Development Plan pinpoints the need for national planning around developments to have a vision for sustainability and harmonious coordination, to be designed with a holistic view, and to have the welfare of the nation in mind. However, what is most important to change is the will and effort from each of its citizens, as it says:

"*We, all of us, must be strategic in both thought and action if we are to realize our own needs as well as the needs of the nation*" (MOPF, 2018).

An open mind for opportunities will be key to make measurable steps towards a tested and running mechanism for sustainable coastal management. In Myanmar, it is very fundamental that the policies, programmes and actions among all parties – government, development partners, civil society, private sector entities and communities – are fully aligned, harmonised and well-coordinated.

Acronyms and abbreviations

AADMER	ASEAN Agreement on Disaster Management and Emergency Response
ADB	Asian Development Bank
ASEAN	Association of Southeast Asian Nations
BANCA	Biodiversity and Nature Conservation Association
BEWG	Burma Environmental Working Group
BOBLME	Bay of Bengal Large Marine Ecosystem Project
CSO	Civil Society Organizations
DoF	Department of Fisheries, Ministry of Agriculture, Livestock and Irrigation
DRR	Disaster Risk Reduction
EDF	Environmental Defence Fund
FAO	Food and Agriculture Organization
FD	Forest Department, Ministry of National Resources and Environmental Conservation
FFI	Fauna and Flora International
FREDA	Forest Resource Environment Development and Conservation Association
ICZM	Integrated Coastal Zone Management
IIED	International Institute for Environment and Development
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resources Management
JICA	Japan International Cooperation Agency
LDC	Least Developed Countries
LMMA	Locally Managed Marine Areas
MAPDRR	Myanmar Action Plan on Disaster Risk Reduction
MCCSAP	Myanmar Climate Change Strategy and Action Plan
MERN	Myanmar Environment Rehabilitation-conservation Network
MIMU	Myanmar Information Management Unit
MoNREC	Ministry of Natural Resources and Environmental Conservation
MOPF	Ministry of Planning and Finance
MPA	Myanmar Port Authority
MPAs	Marine Protected Areas
MRRP	Myanmar Reforestation and Rehabilitation Programme
MSDP	Myanmar Sustainable Development Plan
NAPA	Myanmar's National Adaptation Programme of Action (NAPA) to Climate Change
NBSAP	National Biodiversity Strategy and Action Plan
NCEA	National Commission for Environmental Affairs
NCRMC	National Coastal Resource Management Committee
NDMC	National Natural Disaster Management Committee
NECCCCC	National Environmental Conservation and Climate Change Central Committee
NGO	Non-governmental Organization
NPOA-IUU	National Plan of Action to Combat, Determine and Eliminate Illegal, Unreported and Unregulated Fishing in Myanmar
NWRC	National Water Resources Committee
RIMES	Regional Integrated Multi-Hazard Early Warning System
RVO	Rijksdienst voor Ondernemend Nederland (Netherlands Enterprise Agency)
SDG	Sustainable Development Goal
SEZ	Special Economic Zone
SOBA	State of Basin Assessment, Ayeyarwady River
SSHS	Saffir–Simpson Hurricane Scale
UN ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
UN-HABITAT	United Nations Human Settlements Programme
WCS	Wildlife Conservation Society
WWF	World Wildlife Fund

Two twin pagodas at Ngwe Saung Beach, Myanmar.

8. The case of Senegal

Coastal erosion protection works in Saint-Louis.

Author: Nassirou Gueye

8.1 Senegal and its coastal zone

8.1.1 Physical and climatic parameters

The Senegalese coast is limited by Mauritania to the north, Guinea Bissau to the south, and the Atlantic Ocean to the west. Senegal nearly surrounds The Gambia, a country occupying a narrow portion of land along the banks of the Gambia River, which separates Senegal's southern region of Casamance and its coastal zone from the rest of the country. It is approximately 706 km long (Diaw, 1997) from Saint-Louis to Cap Skiring, with 198,000 km^2 of maritime space (Thiao and Cury, 2013).

Many rivers and streams flow along Senegal towards the Atlantic Ocean. The most important are the Senegal River, the Saloum River, and the Casamance River. The Senegalese coastal zone stretches over seven administrative regions (from north to south: Saint-Louis, Louga, Thiès, Dakar, Fatick, Kaolack and Ziguinchor), which thus corresponds to a maritime frontage marked by the presence of three types of coasts: sandy beaches, rocky shores, and mangrove estuaries.

Figure 8.1 Location map of Senegal.
© UNESCO-IOC.

Each of these coastal types has distinctive characteristics (Sall, 1982; Diaw 1997):

- The Great Coast or North Coast, which extends from the mouth of the Senegal River (Saint-Louis) to the Cap-Vert peninsula (Dakar)
- The Small Coast or South Coast, which covers the area from Hann (Dakar) to Point Sangomare (Fatick). The rocky shores and cliffs of the Cap-Verde Peninsula (Dakar) separate these two geomorphological complexes with sandy coasts
- The sandy-muddy deltaic and estuarine coasts of the mouths of the Senegal, Saloum and Casamance rivers, characterized mostly by the presence of mangrove forests

Oceanographic research has shown the existence in Senegal of two sea seasons, with very different characteristics:

- Hot season from July to October, corresponding to the wet season
- Cold season from December to May, corresponding to the dry season

During the cold season, the maritime trade winds, cool and humid north-westerly to north-easterly winds, establish themselves along the coast and generate a resurgence of deep water (upwelling) towards the surface (Camara, Quensière et Kane, n. d.).

On the other hand, the penetration of the monsoon into the Senegalese territory marks the appearance of the hot season. The monsoon is characterised by a south-easterly wind that gradually invades the interior of the country and is the main source of rainfall throughout most of West Africa.

The amount of rainfall decreases from south to north in Senegal. The annual mean rainfall is 300 mm. However, it can reach up to 1,500 mm in the south (Sagna, 2005). According to Gueye (2019), the average minimum temperature is 22 °C and the maximum 30 °C. There are significant temperature variations between the coast and the interior of the country. In terms of wave climate, the Senegalese coast is under the influence of two types of groundswell, generated north on the northern and southern hemispheres (Sall, 1982):

- North-northwest swell which takes place all year round
- South-southwest swell appearing during the rainy season
- Westerly swell mostly around November

North-westerly swells induce a littoral drift towards the south. This process favours important transits of sediment, as evidenced by the presence of sand dunes and inter-dune basins, thus creating a hydrographic network made up of coastal cordons, lagoons, fossil depressions or lakes (*e.g.*, Lake Retba) (Diaw, 1997).

Toubab Dialao, Senegal.
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Dakar, Senegal.
© schusterbauer.com/Shutterstock.com

The Small Coast is also subject to the north-westerly swell. However, the wave energy is reduced because of refraction and diffraction around the Cape Verde Peninsula (Dakar). Although a southeastward coastal drift is present, estimates of sediment transport indicate that the sediment supply is much less than along the North Coast. Thus, the Small Coast is characterised by a succession of headlands and bays (Niang, 1995).

On the Senegalese coast, the tide is semi-diurnal with great seasonal variations. The tidal range is low, varying between 1.2 to 1.6 m on a spring tide and between 0.5 to 0.6 m on a neap tide. Tidal currents are weak with maximum speeds of less than 0.15 m per second (Niang-Diop, 1995).

The strips of land located in the lowlands bordering the Senegalese coast are prone to flooding during high tides, storms, and heavy rains.

According to Sall (1982), the Senegalese coastal areas are exposed to two main ocean currents:

- The northern current or cold current of the Canaries, which has a north-northeast/south-southwest direction. It causes cold water upwelling, mainly from February to April, between Dakar and Saint-Louis

- The southern current or equatorial current, which moves from south to east. Contrary to the cold current, the southern current causes downwelling of hot and salty water. This current hits the coasts when the trade winds recede, mainly from June to August

8.1.2 Environmental diversity along the Senegalese coastal areas

The Senegalese coastal areas have varied ecosystems of cliffs, rocky capes, and bays, vast bodies of water, as well as long beaches and sand dunes. There are also vast estuaries and deltas with mangrove forests and seagrass beds. The diversity of these ecosystems and landscapes has resulted in the presence of diverse and dynamic habitats, rich in wildlife.

The ecosystems' diversity has motivated the establishment of many protected areas. The most important of these are the Djoudj National Bird Park, the world's third largest ornithological reserve, the Barbary Tongue National Park, and the Saloum Delta Biosphere Reserve, which was included on the UNESCO World Heritage List in 2011. These ecosystems also owe high socio-economic value and provide important ecological functions, such as flood regulation and carbon capture.

8.1.3 Social and economic aspects of the Senegalese coastal areas

Although fragile and sensitive, the Senegalese coastal areas are particularly attractive areas from an economic, demographic, and social point of view. They are subject to a high concentration of human settlements: 60% of the Senegalese population and around 85% of industries and services, including the two key sectors of the Senegalese economy: fishing and tourism. In fact, there are numerous fishing infrastructures (platform/quays, artisanal processing sites, marketing industries, coastal surveillance/control centre), hotels and tourist establishments along the coast of Senegal.

The livelihoods of coastal communities have always been linked to agricultural activities due to the highly fertile lands located along the coast. The most remarkable are gardening, horticulture, and arboriculture in the Niayes area and rice cultivation in the valley of the Senegal River and the lowlands of the deltaic/estuarine areas of the Saloum and Casamance rivers. Seventy percent of the vegetables consumed in the country are produced in coastal Niayes.

The climate is very favourable for breeding activities. Thus, many chicken production units have been set up along the Great Coast in recent years.

The discovery of oil and gas off the coast (Saint-Louis, Cayar and Sangomar) has led to the establishment of offshore exploitation platforms (Ndao, 2020). In addition to oil and gas, coastal areas are also home to mining and mineral resource exploitation sites (zircon and ilmenite).

Over the past 30 years, there has been a rapid and uncontrolled urbanization of coastal areas in the greater Dakar area, including its flood zones. Thus, according to Niang *et al.* (2005), there is a tendency to convert natural environments into cultivated areas or to convert cultivated areas into residential areas. In addition, many transport infrastructures are under construction along the Senegalese coast. Moreover, the Government of Senegal has promoted the creation of new economic and urban development hubs, including that of Lac Rose, a particular and fragile ecosystem (ANAT, 2015). Finally, a very lucrative activity of beach sand extraction for construction purposes has developed over time along the Senegalese beaches.

8.2 Coastal hazards in Senegal

The Senegalese coastal areas, generally sandy and low, are very sensitive to sea-level rise, coastal erosion, coastal flooding, saline intrusion, and rainfall flooding.

8.2.1 Sea-level rise and coastal flooding

Rising sea levels are one of the main consequences of global warming, which threatens many coastal areas (Becker *et al.*, 2010). Sea levels along the West African coast are expected to rise faster than the global average (UEMOA, 2011). The relatively low Senegalese coastal areas are particularly vulnerable to sea-level rise (Table 8.1). According to Niang-Diop (1995), sea-level rise enhances coastal erosion, degradation of mangroves, coastal flooding and salinization of water and soil.

Table 8.1 Sea-level rise projections due to climate change according to the various greenhouse gas (GHG) emissions scenarios.

Scenarios	2050	2100
Baseline scenario	8.4 cm	15.4 cm
Low hypothesis	7 cm	20 cm
Average hypothesis	20 cm	49 cm
High hypothesis	39 cm	86 cm

Source: Niang *et al.* (2005)

In Senegal, the phenomenon of coastal flooding has been recorded particularly in the Saloum Delta. Coastal areas located in the Ziguinchor region have also been exposed. On the other hand, the Langue de Barbarie, which is a 40 km long sandy coastal spit that separates the Atlantic Ocean and the Senegal River has, so far, protected the region of Saint-Louis from coastal inundation (Sambou, 2020). However, during dry periods in which river runoff is very low, the seawater has penetrated up to 200 km inland along the Senegal River.

8.2.2 Coastal erosion

The Senegalese authorities recognise coastal erosion as one of the four major natural hazards along with drought, locust invasions and floods (MEPN, 2006). The rate of coastline retreat over time in Senegal varies between 1 and 4 m per year, depending on the physical, environmental, and anthropogenic factors of the coastal areas (Niang *et al.*, 2005) (Table 8.2 and Figure 8.2).

Table 8.2 Projections for land loss due to coastal erosion in Senegal.

	2050	2100
Locations	**Land loss due to coastal erosion in km² and percentage of total beach area**	
Cape Verde Peninsula	0.2–1.8 km² (3.8–28.5%)	0.8–4.0 km² (12.2–62.8%)
Saloum Delta	0.1–1.8 km² (4.0–109%)	0.2–4.0 km² (11.4–241%)

Source: Niang *et al.* (2005)

Figure 8.2 Coastal erosion in the Saloum Delta area and Gorée Island near Dakar.
© Hama/WIACO (2019), Bakhoum (2017)

8.2.3 Rainfall flooding

As previously mentioned, rainfall flooding is one of the four priority natural risks in Senegal, as identified by the Ministry of Environment and Nature Protection (MEPN) (2006). It can severely affect livelihoods, including economic activities, public services, and community well-being. In recent decades, Senegal has experienced heavy rainfall causing flooding in almost all regions. However, the greater Dakar region remains the most affected, particularly in the Pikine, Guédiawaye, and Keur Massar areas. In addition to the rainfall flood, Saint-Louis, located on an island in the Senegal River estuary, has experienced recurrent flooding caused by the river flooding (Kane, 1997; Durand *et al.*, 2003).

This type of flooding is a major urban problem, especially for coastal regions like Dakar where many people live in low-lying areas (CSE, 2015). According to the 2009 Post-Disaster Needs Assessment Report, prepared by the Government of the Republic of Senegal with the support of the World Bank, the United Nations system and the European Commission, floods constitute one of the most serious menaces and therefore a major concern of the Government during the last three decades (Government of Senegal, 2010).

Studies carried out by Niang *et al.* (2005) include projections for flood levels in the Senegalese coastal areas for 2050 (Table 8.3) and 2100 (Table 8.4).

Table 8.3 Projection for rainfall flood levels in Senegal by 2050.

	North Coast	South Coast	Saloum
Minimum flood levels			
Basic scenarios	1.9 m	1.1 m	1.3 m
Low sea-level rise	1.9 m	1.1 m	1.3 m
Maximum flood levels			
Basic scenarios	6.9 m	6.0 m	7.1 m
Average sea-level rise	7.0 m	6.1 m	7.2 m
High sea-level rise	7.2 m	6.3 m	7.4 m

Source: Niang *et al.* (2005)

Table 8.4 Projection for rainfall flood levels in Senegal by 2100.

	North Coast	South Coast	Saloum
Minimum flood levels			
Basic scenarios	2.1 m	1.3 m	1.5 m
Low sea-level rise	2.1 m	1.3 m	1.5 m
Maximum flood levels			
Basic scenarios	7.4 m	6.2 m	7.4 m
Average sea-level rise	7.5 m	6.6 m	7.7 m
High sea-level rise	8.1 m	6.9 m	8.1 m

Source: Niang *et al.* (2005)

8.2.4 Degradation of wetlands and loss of biodiversity

Senegal's coastal areas are home to important ecosystems such as mangrove forests, seagrass beds, and breeding sites for turtles and sea birds. These mangrove forests and seagrass beds also play a key role in protecting the coastline from storm surges, extreme weather events and coastal erosion.

A coastal lagoon in Senegal.
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Many anthropic and natural factors contribute to the destruction and degradation of these marine and coastal ecosystems. These include the overexploitation of coastal resources, mangrove deforestation, extraction of beach sand, and the construction of infrastructures along the coastline. In addition to these anthropogenic factors, the ecosystems, particularly mangrove forests, are also exposed to the various coastal hazards addressed here, namely coastal erosion, sea-level rise, coastal inundation, and salinisation of the soil and water. In recent years, this has led to a reduction in the area under cultivation and the pruning of mangrove plants. According to Wetlands International (2012), West and Central Africa has lost 20 to 30% of its mangroves over the last 25 years. This mangrove degradation is accompanied by a profound modification of the associated wildlife and a decrease in marine and coastal biodiversity.

8.2.5 Marine pollution and degradation of water quality

Many West African coastal areas are highly urbanised. They are home to numerous industries, particularly in the agriculture, food, mining, and tourism sectors (WACA, 2016a). These various sectors, which do not have adequate waste and wastewater treatment systems, generate many pollution problems.

In Senegal, marine and coastal pollution is mainly due to wastewater discharges and solid waste deposits. In addition, the use of fertilisers, pesticides, and herbicides; water spills from maritime transport and natural resource exploitation activities (fishing, oil, gas, minerals) are other sources of pollution in the Senegalese coastal areas. All these urban, industrial, agricultural, and maritime transport activities pollute the coastline and modify the biochemical composition of marine and coastal waters, in turn threatening the health of aquatic ecosystems (*e.g.,* the Bay of Hann, the Niayes area, the Soumbédioune area, the Djoudji Bird Park in Saint-Louis) and marine and coastal biodiversity. They also affect economic activities such as aquaculture, fishing, and tourism.

8.2.6 Reduction in the abundance of fishery resources

The West African coastal areas are characterised by the richness and variety of their natural resources. Coastal upwelling materialised by the uprising of deep cold ocean water rich in nutrients leads to the development of phytoplankton, booming the entire marine food chain. In Senegal, marine and coastal ecosystems, including seagrass beds and mangroves in estuarine areas, serve as spawning and nursery grounds for fish and thus provide crucial services to the fisheries sector.

The degradation of coastal ecosystems and marine biodiversity due to several factors, namely coastal pollution, is negatively impacting the fishing resources (MEPN, 2006). Moreover, the studies carried out have also shown an increase in the surface temperature and salinity of Saloum estuarine waters. This is causing environmental stress in certain species of fish (Faye *et al.*, 2019).

Pollution on a beach near a fishers' area, Senegal.
© PHILIPIMAGE / Shutterstock.com

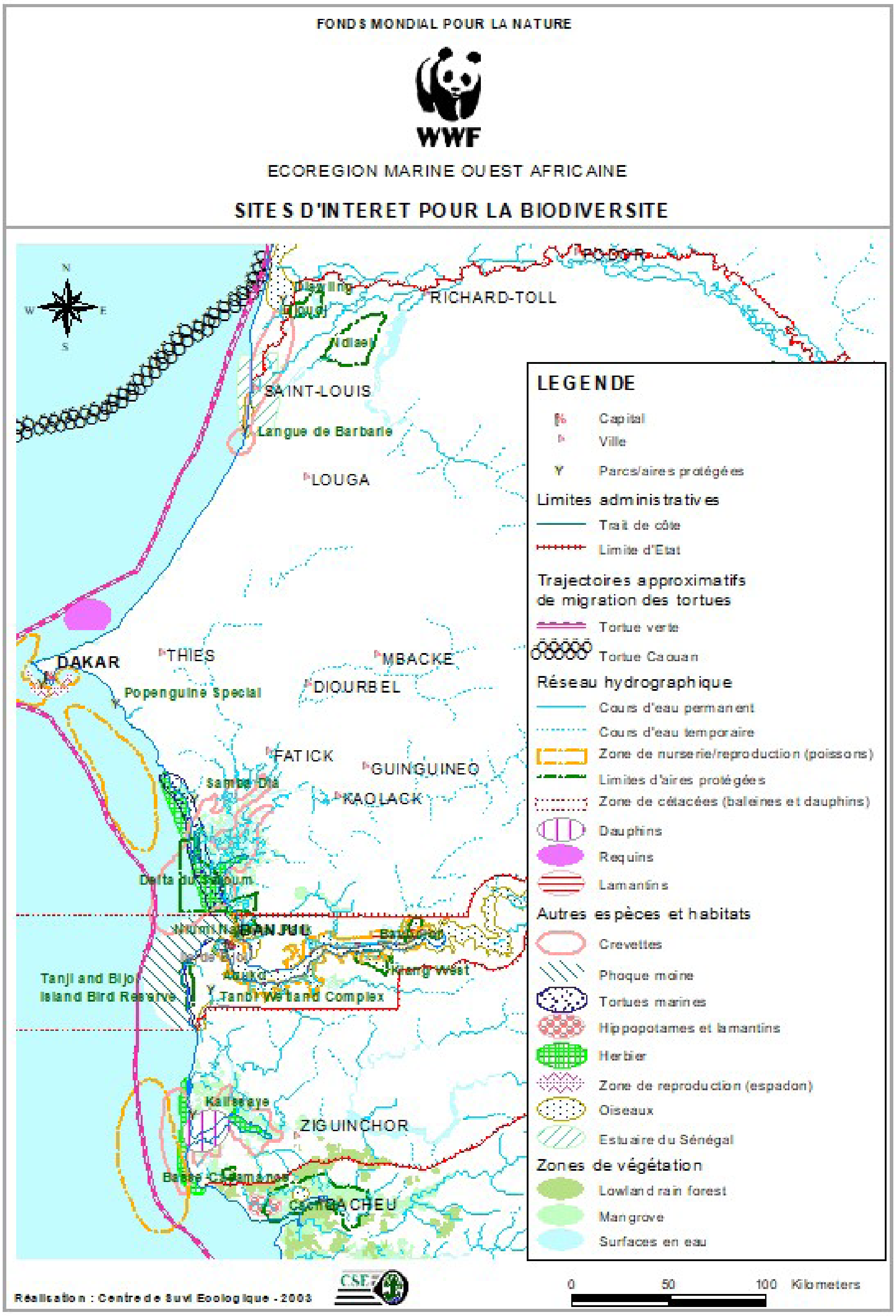

Figure 8.3 Marine and coastal ecosystems in Senegal.
Source: DEEC (2002)

8.2.7 Droughts

Like other West African countries, Senegal experienced droughts in 1963 and during the 1970s and 1980s. These years of drought led to the migration of populations from the interior of the country to the coastal areas. Farmers abandoned their land, which had become uncultivable due to the lack of rainfall, in favour of urban centres. In many cases, they abandoned their previous livelihood and became fishers. This reduction in rainfall also led to the lowering of the freshwater levels, the drying of wetlands, the salinisation of soil and water and the degradation of mangrove ecosystems (Figure 8.3), especially in the areas of Saloum and Casamance. (Niang-Diop *et al.*, 2005).

8.3 Coastal hazards management in Senegal

This section aims to assess the vulnerability, exposure, and ability of the Senegalese coastal communities to cope with the hazards addressed. Such evaluation is to be performed based on literature review and stakeholder interviews.

8.3.1 Coastal vulnerability assessment in Senegal

Due to its geographical position and geomorphological characteristics (low slope, sandy substrate), the Senegalese coastal zones are vulnerable to extreme events such as storms, high tides, powerful swells, and violent winds. The vulnerability of the Senegalese has been the subject of four studies. The first two global studies are based on aggregated data and estimate the vulnerability of all the world's coastal areas to a sea-level rise of 1 m. For Senegal, it was thus estimated that 1,350 km of coastline should be protected with a total protection cost of USD 1,596 million. On this basis, Senegal was ranked 45th among countries vulnerable to an acceleration in sea-level rise, out of the 181 countries examined (IPCC, 1992).

In the second Global Vulnerability Analysis study which considered a maximum flood level of 6 m, the risk area was estimated at 7,450 km^2, in which approximately 3.7 million people live by 2020. These results ranked Senegal as the eighth most vulnerable country globally. Protection costs have been reassessed at USD 3,623 million, or an annual cost of 1.7% of the Senegalese Gross National Product (Hoozemans *et al.*,1993).

Studies supported by the World Bank show that floods in Senegal affect an estimated 200,000 people a year, while extreme floods in 2009 caused USD 104 million in damage in Dakar alone (Government of Senegal, 2010).

A study conducted by the WACA Programme estimated the annual cost of environmental degradation in coastal areas in monetary terms. This study estimated the total cost of coastal erosion, including loss of assets and land, at USD 537 million (WACA, 2016b).

There are also case studies on the vulnerability of coastal communities (fishers, etc.), natural ecosystems (mangroves) and sectors (agriculture, water resources, etc.) in certain coastal regions or towns.

8.3.2 Vulnerability of Senegalese coastal communities

The 1970s and 1980s droughts led to a major migration of communities from the interior to the coastal zone, making the urban centres of the coastal areas highly urbanised. These centres include Dakar, Saint-Louis, Rufisque, Bargny, Mbour, Ziguinchor, and Kafountine, and traditional fishing villages, such as Potou, Cayar, Yenn, Joal, Djifére, and Djogué. These communities, depending essentially on the ecosystem services of these coastal areas (fishing, tourism, market gardening, etc.), occupy areas at risk of coastal erosion and flooding. The participatory analysis studies of the vulnerability of fishing communities to climatic hazards by the CSE (2017), as part of the USAID COMFISH project, made it possible to understand the coastal risks affecting the fishing communities of Saint-Louis, Ziguinchor and Kafountine (Table 8.5).

The Senegalese coastal communities have experienced disasters that caused the destruction of fishing equipment (boats, engines, and nets, etc.) and the loss of human life. As shown in Figure 8.4, these communities are also threatened by destruction of their homes and workspaces. The effects of coastal hazards are also observed in the destruction of coastal infrastructures, such as fishing docks (Point Saréne in Mbour, Guet-Ndar in Saint-Louis), fish processing sites, and even cemeteries (Rufisque, Goxu Bacc in Saint-Louis). It also affects the coastal infrastructure of other sectors such as seaside tourism (Saly in Mbour, Cap-Skirring in Casamance, etc.) which represent more than 50% of national tourism revenues.

Regarding floods, they occur in low-lying areas and cause urban problems, especially in the greater Dakar and Saint-Louis region. The Senegal River flooding would have engulfed the city of Saint-Louis, a UNESCO World Heritage Site, if urgent measures had not been taken in 2003 (Sambou, 2020). The excess of freshwater welling during periods of drought caused major obstacles for the exploitation of the immense potential of irrigable land by the coastal communities of Saint-Louis.

Figure 8.4 Top: Reduction of space for boats and houses in danger in Mbour and Guet-Ndar fishing wharf. Bottom: Point Saréne fishing wharf and hotel in Joal.
© Noblet (2012), Seck (2013), Seck (2020), Noblet (2012)

Table 8.5 Vulnerability of fishing communities to strong winds and powerful swells according to the stakeholders' perception.

Human or natural system	Sensitivity	Exposure	Adaptation	Vulnerability	Vulnerability level
Environmental					
Marine and coastal ecosystems (seagrass, reefs, mangroves)	2	3	0	5	HIGH
Natural resources	3	3	0	6	HIGH
Economic					
Fishing equipment (canoes, fishing nets, motors)	2	3	1	5	HIGH
Fishing wharf (landing site)	1	2	1	2	LOW
Ice maker	1	2	1	2	LOW
Human					
Fishers	3	3	1	5	HIGH
Transformers	3	3	0	6	HIGH
Wholesalers	2	2	1	3	MEDIUM
Service providers	2	2	1	3	MEDIUM

Source: CSE (2017)

8.3.3 Vulnerability of coastal ecosystems and biodiversity in Senegal

In Senegal, the deltaic and estuarine coastal areas hosting a large part of the marine biodiversity (mangrove forests and breeding sites for turtles and sea birds) are facing phenomena of sea-level rise, coastal erosion coastal inundation, saline intrusion, and drought.

Vulnerability to sea-level rise and coastal erosion is already established over a large part of the coastal zone, such as the mouth of the Senegal River at Saint-Louis, the Rufisque – Bargny – Cape Verde peninsula junction, the Small Coast and Casamance. Coastal erosion also affects coastal ecosystems (mangroves) which serve as nurseries for fish resources. This mangrove degradation is accompanied by a profound modification of the fauna (Niang, 2005).

The rainfall deficit of the 1960s and 1970s accentuated the salinisation and acidification of soils in estuarine and deltaic environments. This situation caused the degradation of the mangrove ecosystems, which were gradually replaced by bare surfaces (Niang-Diop *et al.*, 2005).

Table 8.6 summarises the vulnerability of the main coastal hazards in Senegal.

Table 8.6 Vulnerability to the main natural hazards on the Senegalese coast.

Areas	Vulnerable issues	Physical vulnerability	Biological vulnerability	Economic vulnerability
Great Coast (Senegal River; Niayes area)	Built heritage Urbanism Fishing Agriculture Tourism Biodiversity	Low zones Coastal barrier Erosion areas Flood zones	Nursery/Reproduction areas Protected areas Mangroves	Fishing infrastructure Tourism infrastructure Important city
Cape Verde Peninsula	Urbanism Fishing Agriculture Tourism Biodiversity	Erosion areas Flood zones	Nursery/Reproduction areas Protected areas	Fishing infrastructure Important city Large port
Small Coast	Urbanism Fishing Tourism Biodiversity	Low zones Coastal barrier Erosion areas Backwaters	Nursery/Reproduction areas Protected areas Mangroves Sea turtles	Tourism infrastructure Fishing infrastructure Important city
Saloum Delta	Urbanism Fishing Agriculture Tourism Biodiversity	Low zones Coastal barrier Erosion areas	Protected areas Mangroves Sea turtles Manatee	Fishing infrastructure Tourism infrastructure Important city Port
Casamance Estuary	Urbanism Fishing Agriculture Tourism Biodiversity	Low zones Coastal barrier Erosion areas	Nursery/Reproduction areas Protected areas Mangroves	Fishing infrastructure Tourism infrastructure Important city Port

Source: MEPN (2006)

8.4 Adaptation measures in Senegal

In Senegal, many coastal risk management strategies and measures have been adopted to reduce the vulnerability of coastal communities in affected areas (Table 8.7). This section presents the most remarkable ones that aim to maintain the coastline against sea-level rise and coastal erosion, fight against floods, to fix sand dunes, restore mangrove forests, and recover salty/degraded land. The Government authorities designed and implemented the most important coastal adaptation measures are through various programs and projects. However, some communities can initiate certain management measures and support the authorities in the implementation of technical options for adaptation or reduction of coastal risks.

8.4.1 Central administration

The central authorities, in particular the services of the Ministry of the Environment and Sustainable Development, implement the objectives of the United Nations Framework Convention on Climate Change (UNFCCC) at the national level. These services take adaptation measures or coastal risk management options in various forms. These are the technological, natural resource management, legal and institutional options (MEPN, 2006).

8.4.2 Coastal protection

Through development programs and projects, Senegal has built various structures along the coastline, such as coastal dikes, retaining walls, ripraps, breakwaters, groynes, and jetties to protect the shore against coastal erosion. These include:

Infrastructure built

The construction in 2009 of the Rufisque protection dike, which extends over 730 m long and 23 m wide, at a total cost of 3.6 billion CFA francs, financed mainly by the West African Economic and Monetary Union's (UEMOA) regional coastal erosion control program in member countries and the adaptation fund to global warming.

Although the infrastructure did not cover the entire town of Rufisque and the neighbouring town of Bargny, it provided peace of mind for the coastal communities affected by the destruction of the cemetery wall and numerous dwellings.

Facing the advancing sea, the hoteliers of the seaside resort of Saly (Mbour) spontaneously build numerous structures such as groynes, ripraps, or gabions to protect their beaches from coastal erosion. According to a recent environmental and social impact study report carried out in the area, most of these protective structures are poorly designed and increase the vulnerability of coastal areas by blocking sediment transfer (Royal Haskoning DHV, 2016).

Infrastructure in progress

The protection, restoration and maintenance works of the beaches of Saly, led by the Society for the Development and Promotion of Coasts and Tourist Zones of Senegal (SAPCO) as part of a World Bank project, plan to build protective structures, in particular groynes perpendicular to the coast and breakwaters parallel to the coast, 120 m from the shoreline. Artificial beach nourishment will then be performed to fill restore the beaches in-between the structures with 500,000 m^3 of sand.

Initially, the sand used in the beach artificial nourishment will have to come from the land quarry located near Saly. The dredging of an offshore sand bank located a few meters from the coast near other coastal villages of the Petite Cote (Nianing and Point de Saréne) is an additional source of sediment. This offshore dredging is expected to create a sedimentary imbalance in the local coastal dynamics (Egis International, 2013).

The construction of a new dike in the Langue de Barbarie, in Saint-Louis, aims mainly to protect the homes of the fishing communities of Goxu Mbacc and the fishing pier of Guet-Ndar against coastal erosion and coastal flooding.

8.4.3 River dams and dikes

In estuarine and deltaic areas, Senegal is faced with an invasion of marine waters, which affect rivers, aquifers, and agricultural lands. Thus, measures have been taken to deal with these situations of saline intrusion of water.

The Diama mobile dam, built in 1980 in the delta of the Senegal River, was a measure to fight against the intrusion of saline water during periods of low river runoff. It protects agricultural areas and improves the filling of lakes in Senegal (Lac de Guiers) and Mauritania for human consumption. According to the Organisation for the Development of the Senegal River (OMVS) website, the development of the anti-salt dam created many environmental and socio-economic problems:

- From an environmental point of view: invasive plant species, changes in the hydrological regime, the lengthening of the Barbary tongue, the salinization of the estuary in the dry season, and the degradation of mangroves
- From a socio-economic point of view: watering difficulties for livestock linked to competition with farmers, decline in tourist activities following the loss of biodiversity in the parks of Djoudj in Senegal and Diawling in Mauritania, and the development of water-borne diseases (malaria and bilharzia)

8.4.4 Mangrove restoration

The decrease in rainfall exacerbated by other coastal risks and human activities has resulted in the salinisation of water and land and the degradation of mangrove ecosystems in all estuaries of Senegal (Niang-Diop, 2005). To deal with this situation, many mangrove restoration projects have been carried out in collaboration with civil society (*e.g.,* Wetlands International Africa) in the deltaic areas through reforestation campaigns carried out with the participation of the local community.

Mangrove forest in the Saloum Delta National Park, Senegal.
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8.4.5 Sand dune fixation

There are different methods to stabilise the coastal dunes and preserve their sediment stock in the Great Coast. Filao plantations – *Casuarina equisetifolia*, whistling pine tree – remain the most widely used fixation method. Many government projects have succeeded in setting up a strip of plants to preserve the market gardening basins commonly called "les Niayes".

8.4.6 Water drainage channel

The central administration has implemented numerous measures to fight against floods in the most affected areas, particularly in Dakar and Saint-Louis. The most remarkable is the opening of the famous Breche sur la Langue de Barbarie, in 2003, to protect the city of Saint-Louis against the rising waters of the Senegal River resulting from intense rainfall.

Many consequences have resulted from the opening of this water drainage channel from the Senegal River. The breach of 4 m at the start, reached 5,200 m wide in February 2015, changing the biophysical characteristics of the area. Some villages (Doun Baba Dièye and Keur Bernard) have disappeared. The lands of other surrounding villages (Gandiol) that were once suitable for market gardening are affected by salinisation from the intrusion of the saline wedge (Diop, 2004).

8.5 Coastal community measures in Senegal

Coastal communities are also taking measures to manage coastal risks and reduce their vulnerability. The case studies carried out by Weissenberger *et al.* (2012) show that the implementation of these measures is most often carried out with government projects or civil society organisations (Table 8.8).

Table 8.7 Identification matrix of impacts associated with coastal risks and their management options.

Coastal hazards	Vulnerability factors	Associated impacts	Adaptation options
Coastal erosion	Occupation of risk areas (lowlands, groundwater recharge area, flood plains, etc.) Extraction of sea sand or gravel Construction of uncontrolled coastal protection infrastructures on the coast	Destruction of infrastructure (human settlements, hotels, factories, docks, etc.) on the coast Displacement of the population Destruction of natural habitats (siltation of estuarine areas) Insecurity on shipping lane Loss of farmland and beaches Food insecurity	Strategic retreat or relocation Artificial beach nourishment Construction of groynes and windbreaks Plantation of casuarinas or other species with fixing roots to stabilise dunes
Coastal inundation	Extraction of sea sand or gravel GHG emissions Global warming	Groundwater and surface water salinisation Land degradation Drop in agricultural production	Development of groundwater recharge areas Anti-salt dikes Reforestation of the mangrove Filao strip plantation for fixing sand dunes
Riverine flooding	Occupation of risk areas (lowlands, groundwater recharge area, flood plains, etc.) Obstruction of the natural channels of water flow to the sea Uncontrolled developments	Destruction of coastal infrastructure (human settlements, hotels, factories, docks, etc.) Population displacement	Use of rainwater evacuation motor pump Development of retention basins River water collection and evacuation works Relocation of communities
Water pollution	Absence of wastewater treatment plants or solid waste landfills Offshore oil and gas exploitation	Degradation of the natural environment Loss of biodiversity Loss of ecosystem services Resource scarcity	Pollution monitoring Water treatment mechanism as soon as a pollution is detected Strict control of the use of chemicals
Degradation of marine and coastal ecosystems and scarcity of fishery resources	Unsustainable fishing practices Destruction of natural habitats Spill of hazardous products	Loss of biodiversity Disappearance of natural ecosystems Reduction in fish production Modification of upwellings Water warming Displacement of marine species	Rehabilitation of natural habitats (mangroves, artificial reefs, etc.) Implementation of emergency disaster management measures Implementation of biodiversity conservation measures (creation of protected areas)
Extreme weather events	Lack of information systems	Loss of human life Destruction of infrastructure Resurgence of coastal erosion Modification of upwellings	Early warnings for extreme swells and winds

Source: UNESCO-IOC/Nassirou Gueye

Table 8.8 Adaptation measures implemented or planned in the rural communities of the Saloum Delta.

Village	Measures	Status	Effects
Fayako	Occupation retreat to the heights in the centre of the island	Completed	Avoid coastal erosion and flooding
	Walls made with makeshift materials (*e.g.*, household waste). A dike like in Felir or Djirnda is needed.	Fundraising	Avoid coastal erosion and flooding Protect crops and homes Health issues due to the use of makeshift materials
	Following the destruction of land and crops by seawater in times of heavy swell, the population waits for the water to recede to try to use what is left	Completed	Livelihoods dependence on natural events
	Increase agricultural production using better equipment (tillers, transportation)	Fundraising	
	Welcoming visitors for studies on climate change	Completed	Unable to generate significant changes or relief
	Boat and fishing equipment provided by FENAGIE and Action Aid	Completed but no follow-up	Equipment has deteriorated and has not been renewed
Djirnda	Construction of a dike	Completed but in need of repair	Fight against salinisation Allows rice growing during the rainy season In a state of advanced degradation
	Creation of marine protected areas as part of the USAID Comfish Project	In progress	The quantities of fish have increased The community seems to have high expectations for this project
Diogane	Creation of a natural resources' management committee in Diogane	In progress	Mangrove reforestation activities every year
	Mangrove reforestation (NGO Adaf Youngar in collaboration with village women, WAME project and Yarou Ndioulite)		
	Mangrove management plan (coastal water channel)		Follow-up of a research project with students from Thiès and Dakar Awareness raising
	Reforestation of palm trees	In progress	Past success motivates additional editions
	Construction of a dike	Under evaluation	
Félir	Construction of a dike	Completed	Protection against floods and salinisation
	Construction of rainfall retention basins		Supply of freshwater for crops and people
	Mangrove reforestation	Under planning	
Bassoul	Construction of dams and dikes		Protection against the salinisation of land Protection of buildings
	Mangrove reforestation		
	Search for mangrove propagules		Restore the mangrove to make up for the lack of fish
	Move homes		Avoid inundation and destruction
	New water well		Supply of 10,000 m^3 per day of drinking water

Source: Weissenberger *et al.* (2012)

8.6 Final remarks

As described in the previous section, the literature review combined with the analysis of the information collected from the stakeholder interviews allowed to identify some lessons learnt and good practices about coastal risk management in Senegal, namely with regard to coastal protection, construction of dams and dikes, mangrove reforestation, sand dune fixation, and opening of water drainage channels.

However, some observers claim that a few coastal risk management measures implemented so far were not based on scientific knowledge. This is the case for the opening of the river drainage canal in Saint-Louis and the extraction of beach sand to be used for the artificial nourishment of the beaches of Saly – Mbour.

The participation of engineers, scientists, researchers specialised in coastal and river dynamics, hydraulics, and geological engineering from different ministries, national agencies, universities, research centres, and local authorities in the planning and implementation of coastal risk management projects is necessary.

The Senegalese national economy is highly dependent on natural resources located in coastal areas, such as fishing or coastal tourism. However, these coastal areas are exposed to a variety of hazards. The most notable are the rise in sea level, coastal erosion, coastal flooding, land and water salinisation, degradation of mangrove forests, and reduction of fish stocks.

Coastal erosion remains the hazard that most affects the Senegalese coasts, which fundamentally is characterized by a low relief and sandy substrate that is vulnerable to the effects of swell waves, ocean currents, and wind.

Shoreline retreat causes enormous losses of land and property and damages various sectors linked to the economic and social activities of the local communities. The sectors most affected are urban planning, fishing, tourism, agriculture, and the marine and coastal biodiversity.

The Senegalese public authorities are aware of this situation. Thus, with the support of technical and financial partners, the Government has developed and implemented many strategies to reduce coastal risks and the vulnerability of coastal communities. These include the construction of structures to protect coastal areas, the artificial nourishment of beaches, the development of anti-salt dikes, the opening of canals, the management of rainwater, and the rehabilitation of certain coastal infrastructures. However, the impacts of coastal hazards continue to increase, especially in certain parts of the four major geomorphological zones of the Senegalese coast: Great Coast, Cape Verde Peninsula, Small Coast, and Casamance.

At this stage, the current knowledge available in Senegal on the implementation of these different measures is still insufficient. A proper analysis is not yet feasible, which invalidates the extraction of conclusions, lessons, and good coastal risk management practices.

Acronyms and abbreviations

ANAT	National Agency for Territorial Management
CDB	Convention on Biological Diversity
CEDEAO	Economic Community of West African States
CLPA	Local Council of Artisanal Fishing
COMFISH	Concerted Management for Future Sustainable Fisheries in Senegal
CRODT	Oceanographic Research Center of Dakar-Thiaroye
CSE	Ecological Monitoring Centre
CSRP	Sub-Regional Fisheries Commission
DEEC	Department of the Environment and Classified Establishments
DPM	Directorate of Maritime Fisheries
EDF	European Development Fund
ENDA	Third World Environment and Development
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility
GHG	Greenhouse Gases
GIE	Economic Interest Grouping
GIRMaC	Integrated Management of Marine and Coastal Resources
GNP	Gross National Product
IFAN	Fundamental Institute of Black Africa
IPAR	Agricultural and Rural Prospective Initiative
IPCC	Intergovernmental Panel on Climate Change
IRD	Institute of research for development
ISRA	Senegalese Institute for Agricultural Research
IUPA	University Institute of Fisheries and Aquaculture
JICA	Japan International Cooperation Agency
LPS	Sectoral Policy Letter
MEDD	Ministry of the Environment and Sustainable Development
MEPN	Ministry of Environment and Nature Protection
MPA	Marine Protected Area
OMVS	Organisation for the Development of the Senegal River
P2RS	Program for Strengthening Resilience to Food and Nutritional Insecurity in the Sahel
PANA	National Climate Change Adaptation Action Plan
PNUD	United Nations Development Programme
PNUE	United Nations Environment Programme
PSE	Plan Sénégal Émergent
SAPCO	Society for the Development and Promotion of Senegal Coasts and Tourist Zones
SCA	National Strategy for Accelerated Growth
SIPC	International Strategy for Disaster Reduction
UEMOA	West African Economic and Monetary Union
UICN	International Union for Conservation of Nature
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations International Strategy for Disaster Reduction
USAID	United States Agency for International Development
WACA	West Africa Coastal Areas management program
WB	World Bank
WWF	World Wildlife Fund
ZEE	Exclusive Economic Zone
ZPP	Protected Fishing Area

Traditional salt farming in Senegal.

9. The case of Uruguay

House over dunes on eroding beach in Rocha, Uruguay.
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Author: Mónica Gómez Erache

9.1 Uruguay and its coastal zone

9.1.1 General aspects of the Uruguayan coast

The Uruguayan coastal zone is a defined area of the national territory with specific natural, demographic, social, economic and cultural characteristics (Figure 9.1). It consists of a strip of land and maritime space of variable width where sea-land interactions take place. It contains very rich, diverse, and productive ecosystems, which supply goods and services that sustain activities such as fishing, tourism, navigation, port development projects, oil production, and where urban and industrial settlements are found. The Uruguayan coastline on the Río de la Plata and the Atlantic Ocean is approximately 714 km long (of which 748 km correspond to the Río de la Plata and 236 km to the Atlantic Ocean). The prevailing coastal formations are arc-shaped sandy beaches bounded by rocky headlands, and a ridge of dunes -- coastal lagoons and wetlands stand out along the oceanic coastline. Three macro-basins can be identified: De la Plata Basin (12,400 km^2), Santa Lucía Basin (13,250 km^2) and the Atlantic Ocean Basin (8,600 km^2). Their main uses are irrigation, public water supply (Santa Lucía River) and industrial use (Río de la Plata). In terms of water resources exploitation, the most affected areas are found on the coastal zones of San José, Canelones, Maldonado and Rocha departments, where intensive uncontrolled exploitation has caused saline intrusion events and poor waste-water disposal has created bacterial contamination issues in coastal waters.

Figure 9.1 Location map of Uruguay.
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The territory of the Oriental Republic of Uruguay is divided into nineteen administrative departments, six of which lie along the coastal zone (Colonia, San José, Montevideo, Canelones, Maldonado, Rocha; Figure 9.2). With a total area of 176,215 km^2, Uruguay is the second smallest country in South America. After having made a strong progress during the past years, the capital Montevideo gets the best position – followed by Rocha – when applying the Human Development Index (HDI) to coastal departments. At the other end of the scale is San José, ranking 15 at national level. At the same time, an analysis on the Gross Domestic Product (GDP) shows how relevant coastal departments are, accounting for 75% of the country's added value (taking 2018 as reference). One of the most impressive facts is the population growth that Maldonado and Canelones have experienced during the last fifteen years, which confronts them with the need for new investments and realignment of existing services and infrastructures.

The characteristics of the Uruguayan coast, with very old geological formations and crystalline outcrops near the shoreline, have served as a refuge for flora and fauna in direct relation with the diversity of environments and substrates. A third of the Uruguayan flora, a rich fauna of amphibians and reptiles, and 46% of the country's birdlife can be presently found within a coastal strip of 10 km. The main threats to coastal-terrestrial biodiversity are associated with habitat loss and disturbance.

Urban sprawl along the coast in Punta del Este, Uruguay.
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The Uruguayan coastline of the Río de la Plata and Atlantic Ocean is approximately 714 km long and is characterised by a diverse range of environments such as beaches and dunes, sedimentary ravines, and coastal lagoons. This coastline results from a series of factors: hydrodynamics of the Río de la Plata, wind dynamics and the nature of the geological material. Several problems associated with the landscape can be observed; these include erosion phenomena (receding ravines, disrupting the ridge of dunes, damaging infrastructure) of complex origin, and which essentially may be grouped into two categories: natural erosion – associated with extreme events (storms) – or anthropogenic activities associated with morphological evolution and sediment transport (sand mining, infrastructure works allied with sediments balance, modification of water table levels or afforestation).

Uruguay is aware of the impact of climate change, mainly in technical circles where coastal management is dealt with at national and sub-national levels. The Uruguayan coastal zone will most probably be affected by the impacts of climate change. Management and research programmes related to coastal issues have therefore provided baseline diagnosis in several disciplines in the areas of natural and social sciences. The level of vulnerability of coastal resources is high, considering changes in rainfall, discharges from Río de la Plata tributaries, modification of wind patterns and the rise of global mean sea-level. The different regions of this complex marine and coastal system will reflect these changes in diverse ways and with different intensity. The first study to assess the economic impact of climate change in Uruguay on various time frames (2030, 2050, 2070 and 2100; ECLAC 2010) reckoned that the total impact (accumulated to year 2100) of rise in sea-level will be of 12% of the GDP (reference year: 2008). The cost of floods is significant, with urban infrastructure being the hardest hit.

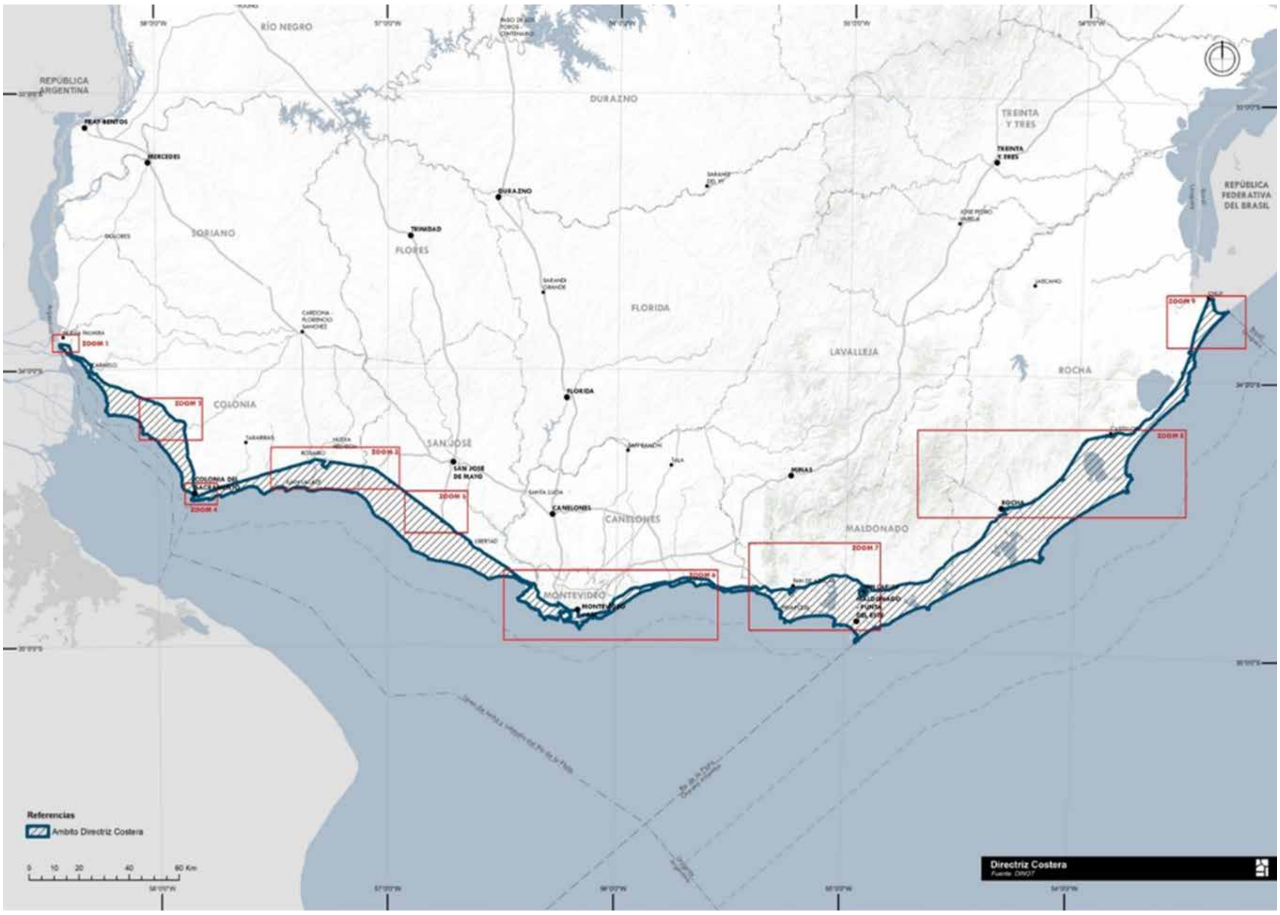

Figure 9.2 Delimitation of the scope of action of the regulations referring to the coastal land area in accordance with the provisions of Law No. 19772 (National Guidelines for Coastal Space and Sustainable Development).
© Ministry of Environment of Uruguay

At the same time, Uruguayan public opinion – as much as 90% of the population, according to periodic surveys (GEO, 2008) – regards the coastal zone as highly important. Analysis of inquiries to coastal zone municipalities (third level of government) indicate that the top three issues in the agenda of the "*intendencias*" (departmental government) are: response to formal and informal settlements on flood areas, development of beach-profile management (coastal erosion, restoration of dunes), and recovery of public coastal space from private occupation. Meanwhile, departments with a high level of coastal occupation present a broader beach-profile management, greater development of institutional areas dedicated to coastal zones, and a need to respond to demands. Such response is mainly focused on strengthening work teams and consolidating budget sources for the implementation of corrective and remedial actions on coastal areas. In these departments, discussions about institutional capacities give priority to redesigning the distribution of resources and competencies between national and sub-national levels.

Sub-national government strategies covered by specific regulations are recent. Law No. 19772 enacted in 2019 regulates the territorial planning and sustainable development of the coastal area of the Atlantic Ocean and the Río de la Plata and constitutes a general public policy tool on this issue. It limits the geographical scope for the first time in this country (Figure 9.2) and places a stress on inter-institutional coordination as a tool to better apply custody strategies on coastal assets. Yet, to delimit and define spaces currently considered in need of a special protection regime is still pending, as is to specify usage and management of natural resources. All this is subject to its prior regulation.

A conceptual framework (Figure 9.3) interprets information from different sources regarding current risks and vulnerabilities in the Uruguayan coastal area. Documentation was gathered with a focus on policies and national and sub-national land planning reference plans, as well as academic studies and reports supporting management of coastal areas. Issues, which were identified as priorities by people living in the coastal area, were also assessed in different occasions. Thus, this analysis was evaluated taking as a reference the impacts caused by climate change in the coastal zone. The information above was organised into three groups: vulnerability of coastal area communities, risks in coastal areas and adaptation measures proposed for the country's coastal area, and they are currently being evaluated and implemented in pilot sites in compliance with the United Nations Framework Convention on Climate Change (UNFCCC) (Undetermined Contributions by 2025).

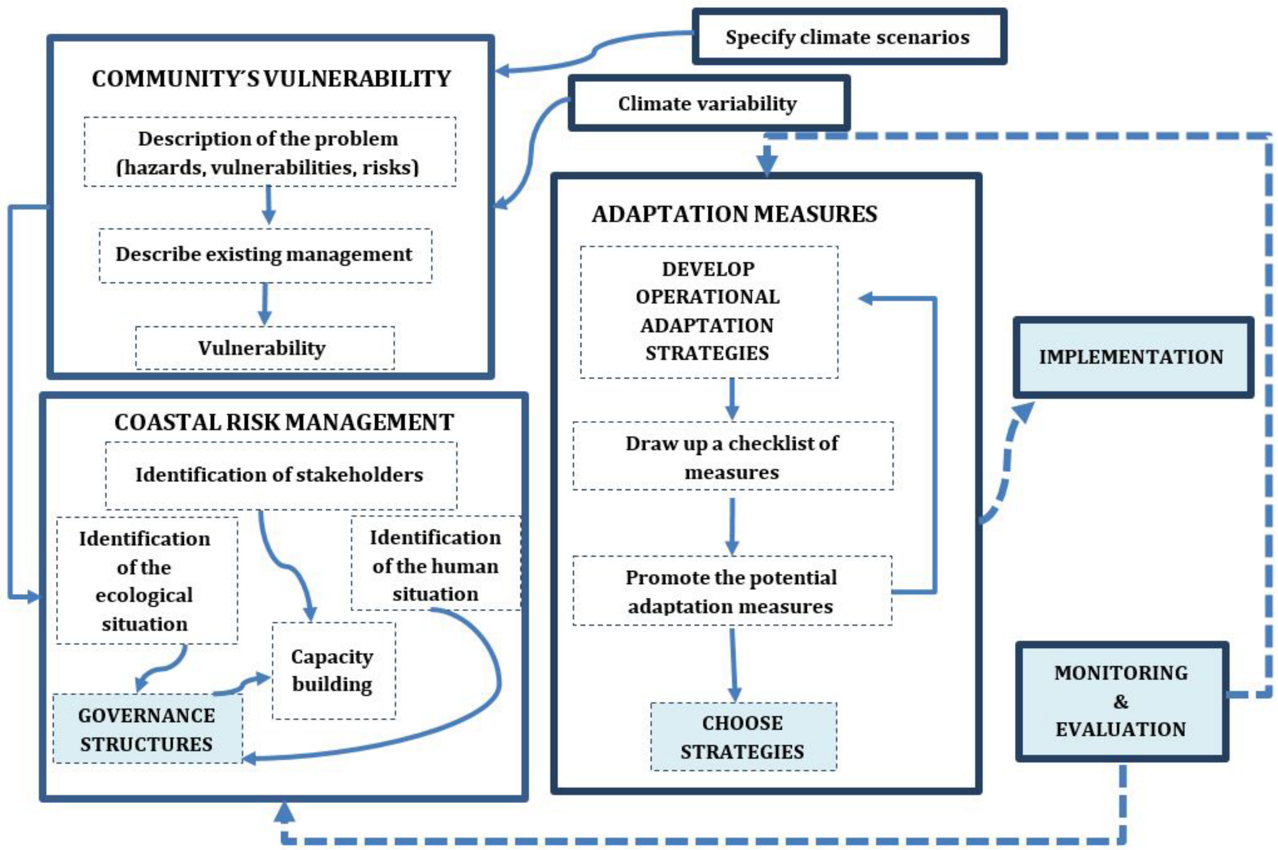

Figure 9.3 Conceptual framework for operationalising climate change adaptation strategy in the coastal zone of Uruguay. (The light blue boxes were not considered in this analysis because they are being assessed at the national and sub-national government levels).
Source: Mónica Gómez Erache

9.1.2 Climatology

Uruguay is the only South American country completely within the temperate zone, presenting characteristics of both tropical and extratropical climates. Its climate is under the strong influence of the South Atlantic High, which controls winds and rainfall within the national territory. During the winter (July – September), only Uruguay, southern Brazil and southern Chile get gentle northerly winds with rains. In summer (December – February), on the other hand, the semi-permanent anticyclone retreats towards the ocean, thus defining a low-pressure system which allows humidity and heavy rainfall to reach our country (Barreiro *et al.*, 2019b). In turn, winter is a season under transient cyclones and anticyclones (5-7 days long) with warm and cold fronts moving latitudinally (Barreiro *et al.*, 2019b). These cyclones are frequent in Uruguay, particularly in wintertime, and associated strong winds damage infrastructure and property along the coastal strip.

Mean annual temperature in Uruguay is 17.5 °C, ranging from near 20 °C in the northeast to some 16 °C on the Atlantic coast. This average has risen about 0.8 °C in the last 65 years, the warming being greater in the eastern region throughout all seasons (Barreiro *et al.*, 2019b).

During the last decade, significant changes have occurred in sea surface temperature (Río de la Plata and Exclusive Economic Zone, Atlantic Ocean platform). Based on the linear model (NOAA OI. v2, Barreiro *et al.*, 2019a), from 1982 to 2018, the sea surface temperature has risen 0.46 °C each decade (Ortega 2019, pers. comm.). The confluence of the Brazil and Malvinas currents (37-38 S) controls this ocean region's average conditions and variability, while there is a south-north gradient in the sea surface temperature with cold waters off Buenos Aires and warm off southern Brazil.

Regarding rainfall, an increase has been observed in the order of 10-20% during spring, summer and autumn seasons (1961-2017) across most of the country; biggest changes in the eastern region concentrating in autumn (50 mm). The quarterly wind climatology in Uruguay is determined by the position of the semi-permanent South Atlantic anticyclone. The trend of the surface winds in the Atlantic Ocean Basin has shown a southward shift of easterlies and westerlies which is attributed mainly to the depletion of the ozone layer (Barreiro *et al.*, 2020). In Uruguay, these changes have modified the wind seasonal pattern in coastal areas – easterly winds prevail in summer, while southerly winds prevail in winter (Barreiro *et al.*, 2019b, 2020).

9.1.3 Geology

Uruguay's southern and Atlantic areas belong to the Uruguay-South Rio Grande Rise (Ab Saber, 1964) which is characterised by a long geological evolution, manifest through complex lithologic and tectonic features. The Uruguayan coast presents a rather diverse geological configuration. Yet, it could be shortly described as a series of ancient rocks (2,300 million years, Paleoproterozoic Era, and 500 million years, Cambrian Era) which form the rocky headlands, and where sedimentary rocks and sediments were deposited almost exclusively during the Cenozoic Era and in present times (Goso and Muzio 2006).

9.1.4 The Río de la Plata estuary

In the coastal zone, the main forces affecting the circulation of the Río de la Plata are fluvial discharge from its tributaries, tidal movement, and water surface winds, although variations on physical and chemical parameters, particularly salinity, also affect circulation as they modify water density. Over 97% of water in the Río de la Plata comes from the Paraná and Uruguay rivers, which drain two different basins with an average annual discharge of 15,970 m^3s^{-1} and 5,817 m^3s^{-1} respectively. Floods in the Uruguay River occur in winter, with a secondary maximum in October and minimum flow in summer and autumn (November – May). It discharges on the north coast of the Río de la Plata, directly affecting the coasts (GEO, 2008). The hydrodynamics of the system is also conditioned by the configuration of the coastline and floor bathymetry. From a geomorphology and dynamics perspective, the suggestion has been to divide the coastal zone into two regions: an interior one (or estuarine) and an exterior one (or oceanic), separated from each other by the Barra del Indio, a geomorphological sandbar (López Laborde, 1997). Depth in the coastal zone is below 10 m in the interior region, while in the exterior region it ranges between 10 to 20 m. The main channels system (Sistema Fluvial Norte, Canal del Norte and Canal Oriental) stretches along the entire Uruguayan coast.

View of the coast along the Río de la Plata estuary in Uruguay.

9.1.5 Socio-economy

The coastal zone has been and still is of great importance for Uruguay due to its natural, cultural, and economic values (GEO, 2008). This fact promoted a significant concentration of inhabitants and infrastructures on the coast, 70% of the Uruguayan population (2,240,678 inhabitants, INE 2011) living in coastal departments and 63% in the metropolitan area and east of the country (2,014,273 inhabitants, INE 2011). Although such concentration is not exclusively a consequence of tourism, the importance that the coastal zone has for this industry is self-evident. Tourism amounts to 9% of the Uruguayan economy (4% of GDP), and the coastal zone received 75% of Uruguay visitors. On average, the East and the Metropolitan regions received 89% of those visitors, but during the southern summertime and main sun-and-beach tourism season these two regions received respectively 45% and 25% of total visitors in the country (Ministry of Tourism 2018). The relative significance that the coast has for the tourism industry also shows in the visitors' spending level, which in average amounted to 87 % of the total (*i.e.*, around USD 2,037.8 million; Ministry of Tourism, 2018). Hence, just as it happened in the past and still happens in other coastal zones around the globe, Uruguay coastal systems have been affected by human intervention. This reflects the pressures posed by changes in land-use associated with urbanisation, afforestation and agriculture, directly on the coast or on coastal basins and micro-basins.

An important aspect of population growth in some departments – Montevideo and, to a lesser extent, Maldonado – is the occurrence of shanty towns. They tend to settle in the outskirts of cities, rural areas or near water courses, where services coverage is seldom available. Additionally, studies on the subject emphasise the risks implied in terms of residential segmentation processes, which result from a context of growing social fragmentation and disintegration. One element that should be considered when analysing the environmental impact and its relationship with population growth is the seasonal nature of the population number in the area. Tourism is the most relevant activity in all six departments addressed, where population cyclically increases in the summer seasons.

As a result of these population processes, a series of changes could be identified in terms of status and behaviour of the coastal system, even with a possible negative impact on goods and services provided by the system. The most important evidence collected is associated with degradation and loss of dune fields, shrinking of the beach area, groundwater surfacing, increase in pollution (physical, chemical and biological) and presence of alien or invasive vegetation (Panario and Gutiérrez, 2006; GEO, 2008; Defeo *et al*., 2009; Rodríguez-Gallego, 2010; Gutiérrez *et al*., 2015, 2016).

Surveyed information reveals the importance that the coastal zone has in the public opinion. A wide majority of 90% of the population finds it important or very important (GEO, 2008). The analysis of the results places environmental problems as the most frequently mentioned coastal issue, particularly by those who live in the area. Next comes a concern for pollution in general.

Social involvement with environmental policies in Uruguay shows significant progress during the last decade (Iglesias, 2014), which means that coastal and marine management achieved some highly positive tools, learning processes and pooling of public engagement experiences. Nevertheless, consolidating such processes requires addressing real participation for the existing advisory and informative approach to evolve into binding and co-constructive public coastal policies. At a local level, coastal municipalities have open-hall town meetings and participatory budgets as their main tools. Regarding land planning (at local, sub-national and national levels) and environmental impact evaluations, public audiences are clearly the main instrument of public participation.

Río de la Plata seafront in Montevideo, Uruguay.

9.2 Coastal hazards in Uruguay

The coastal zone of Uruguay is subject to the impact caused by human activities, such as coastal erosion, land-use and fertilisation of drainage basins, afforestation with alien species, urban and industrial expansion, among others. The increase of nutrients input into the ocean because of the population growth is yet to be assessed. The analysis of the use of agrochemicals would allow to infer eutrophication trends in coastal aquatic ecosystems.

There are no macroscale scientific studies on the effect of environmental threats, although four risk categories and their respective factors have been identified (FREPLATA, 2004): biological invasions (Asian clam, Golden mussel, *Rapana venosa*); biological contamination (algal blooms); benthic habitats alteration (navigation channel dredging, bottom-trawling); and chemical pollution (heavy metals and pesticides) and solid waste (plastics) from coastal point sources. The main environmental pressure comes from habitat alteration by polluting agents and exploitation of resources. Based on their degree of pollution, some critical areas (organic pollution, heavy metals) for special management have been recently identified, such as the Montevideo metropolitan area and surroundings (Santa Lucía River – Arroyo Pando) and the zone of maximum turbidity and the Andreoni channel. Out of those impacts and vulnerabilities, following is a state-of-the-art description of those which the coastal population identified as priorities (GEO, 2008; Zentella, 2015; MVOTMA, 2019).

9.2.1 Pollution sources

While the Río de la Plata accumulates fine and polluting sediments from all over the basin, severe problems concern limited areas. Coastal areas receive pollutant loads of urban, industrial, and agricultural origin, mostly from effluents (sewage pipelines) and tributaries, with the impact zone thus being limited to a strip of less than 2 km (FREPLATA, 2004). Port industry and navigation activities entail potentially polluting actions (ballast unloading, contingencies, bilge cleaning, and dredging operations). It should be noted that the zone of maximum turbidity is mainly where fine sediments and pollutants of transboundary and coastal origin accumulate. This zone is part of the Turbidity Front, an area with more dynamic variability than the Uruguayan coastal zone. Based on their degree of contamination, FREPLATA (2004) identified critical areas for special management: Montevideo metropolitan area (organic pollution, lead and chromium) and nearby locations (Río Santa Lucía – Arroyo Pando), zone of maximum turbidity, and the Andreoni channel (organic pollution and zinc). Yet, concentrations of heavy metals (mercury) detected in affected zones are still below permitted levels for edible fish tissue (silverside, mullet, and white croaker) (Viana, 2001).

Urban waste accumulating along the port area in Montevideo, Uruguay.
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9.2.2 Urbanisation and infrastructure

The Uruguayan coast has consolidated its substantial role in terms of national development. Coastal departments currently account for almost 70% of the total population, about 71% of private households and slightly over 72% of all houses in Uruguay. Sites of high natural value and man-made landscapes coexist within a narrow strip of land, to a certain degree fragile and in a dynamic equilibrium. Spatial distribution of the coastal population is quite heterogeneous both along the coast and inland in those departments. In each of them, a high percentage of the total coastal population is concentrated in at least one city, namely Colonia del Sacramento: 31%, Ciudad del Plata: 63 %, Ciudad de la Costa: 71%, Maldonado: 42%, Rocha: 49% and Montevideo: 65%. Additionally, Canelones is the department with the highest coastal urban occupation (1,779 inhabitants per km of coastline and 1,113 households per km of coastline), well over the average of the other departments.

Road building gets pressure from managing and decision-making urban agents. Erosion and changes in drainage patterns are common problems for road development. The initial environmental impact is magnified by the increase of human activities on the right-of-way area, changes in land-use caused by the forest industry, and housing and hotel infrastructures, among others. The construction of waterfront promenades (locally called "ramblas") consisted of land reclamation by eliminating and embanking dune fields and building retaining walls to withstand the direct pounding of the waves. These coastal roads contributed to coastal erosion indirectly, by loss of sand (dune fields), and directly due to the construction of retaining walls (*e.g.*, in Piriápolis) (López Laborde, 2003).

Punta del Este, Uruguay.
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Measures taken for stabilising and recovering the dunes were to add fencing (traps for wind-blown sand), build access walkways, introduce exotic grass vegetation, use vegetation to create artificial barriers on the dunes and even plant pine trees close to the coastal roads (*e.g.,* in Canelones and Maldonado). Such measures succeeded in strengthening the dune field development (FREPLATA, 2005a). Additionally, sand sports have significantly diminished in some zones due to direct sand extraction from beaches, submerged beaches, or dunes.

On the Uruguayan coast, activities are concentrated in the Colonia, San José, and Canelones departments. Urbanisation of coastal areas is the main reason for disturbances in the drainage systems due to the creation of large impermeable areas and the modification of dunes and beaches. On the Uruguayan coastal zone, the greatest urban development is concentrated around the capital; smaller urban establishments – usually seaside resorts – can be found all along the coast of the Río de la Plata and the Atlantic Ocean. Beach erosion and humidification issues are associated with this urbanisation processes, which despite being specific issues, may be found all along the coastline. Coastal restoration has proved successful in Maldonado, namely through the installation of a subsurface collector for draining and pumping the water table at Portezuelo beach (Zentella 2015).

Elevated beach access walkways in Uruguay that allow the circulation of people without harming the dunes.
© Mónica Gómez Erache

Ports are the infrastructures with a higher impact on coastal dynamics and evolution. The Uruguayan coastal zone presents a significant number of commercial ports (seven) and leisure ports (nine) with no marinas nor berths. A high percentage of the current port capacity is used for cargo traffic going to the Montevideo port or to river ports on the Paraná-Paraguay Waterway. This makes it a high-traffic area, which increases the contingency risk. Additionally, draining in the freshwater and estuarine regions is of vital importance to ensure vessel access to both major ports of Buenos Aires (in Argentina) and Montevideo.

The revision of successful measures regarding coastal protection or restoration demonstrates the need for a large-scale analysis which includes the whole Uruguayan littoral area. It is also necessary to carry out specific case-studies, especially together with municipal activities. For this to be possible, research must be conducted along with daily municipal management. Morphological coastal analysis, time evolution monitoring, observation of wave climate, winds and tidal systems, and characterisation of sediment transport processes are key for managing the coastal zone properly and to design effective restoring measures (EcoPlata, 2000). An integrated long-term strategy needs to be developed to address coastal erosion issues and other alterations in the coastal geomorphology, and it should be supported by an updated information system to underpin decision-making stages (FREPLATA, 2005b). To this effect, it is crucial that periodic beach topography assessments and updated information is available about the natural agents that affect coastal dynamics. Lastly, when searching for solutions to problems of coastal erosion and alterations of the coastline, special attention must be paid to the uses and services of the coastal zone to find a reasonable balance between such services and the ecological role of the coast.

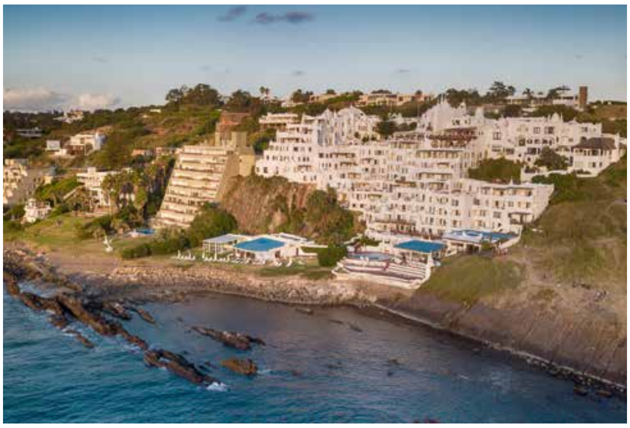
9.2.3 Tourism and recreation

Tourism in Uruguay is a growing industry in terms of visitors and foreign currency earnings. There is evidence of a record amount of 2 million visitors in a country with little over 3 million inhabitants. The population of 80 of the 135 communities (59%) in the coastal area works mainly in the tourism industry (INE, 2011). The number of local inhabitants is higher than the number of tourists only in Montevideo and Canelones. In Rocha, Maldonado, and Colonia, the relation is inversed. The most extreme case is Maldonado, where the ratio is almost 5 tourists for each resident. The Río de la Plata and Atlantic coast are the preferred destinations, accounting for 75% of visitors. Consequently, the total income Figure comes close to 90% for this activity (GEO, 2008).

Tourism is also an important industry in terms of exports of traditional goods. In the 1990s, exports of tourist services amounted to 20-30% of total exports and 3% of GDP in US dollars. From 1987 to 1996, the annualised total of admitted tourists per calendar quarter gradually rose at an approximate yearly rate of 10%, and then remained constant until 2001 (GEO, 2008). From then on, and due to the regional economic crisis, tourist admission dropped by more than 60%. In 2005, however, the tourists' origin pattern changed, total expenditure corresponded to visitors from beyond the region, who increased their spending by 70% over that period. Montevideo and Punta del Este stand out accounting for almost 50% of the country's total visitors. Some tourist attractions are promoted on a general basis, specifically the southeast coast, lower portion of the Río de la Plata, and the Atlantic Ocean (GEO, 2008).

A moderate increase is determined in sun-and-beach and business models and a low growth in ecotourism during the last decade. At a zone level, the evolution of demand shows a strong growth in Colonia, Montevideo and Punta del Este, and a moderate growth in Costa de Oro, Piriápolis and Costa Atlántica. Almost 50% of what tourists spent in Uruguay in 2006 is concentrated in Punta del Este, the second position being Montevideo, with 37% (IECON, 2007). There is a clear majority of visitors coming in by road (49%), 60% of which arrive by car.

Tourist activities pose considerable pressure on coastal ecosystems. The carrying capacity of the ecosystems has not been calculated. Massive tourism industry, which requires an increase in infrastructure, hotels, roads, restaurants, commercial and recreational centres, has not considered environmental and ecosystem variables, and derived environmental impact is frequently disregarded at planning stages.



Punta Ballena, Uruguay.
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Punta del Diablo is a fisher's village and a popular tourist site along the Uruguayan coast.
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9.2.4 Fisheries

The nature and distribution of resources along the Uruguayan coastal zone, as well as the coastal geomorphology and the size of the continental shelf, determine the fish resources' exploitation by a non-industrial fleet near the shore and an industrial fleet further offshore. This makes them sequential fisheries. Analysis by INFOPESCA (2001) and Defeo *et al.* (2006) show a negative progression of the exploitation phases of most resources, in most cases turning sub-exploited resources in the 1980s into currently over-exploited. Most of non-traditional industrial fisheries ignore the actual state of exploitation, due to the lack of long-term studies evaluating the fish abundance and population dynamics.

There is no updated information on the state of exploitation of resources exploited by non-industrial fleets in the inner and medium Río de la Plata (American shad and bogue). Traditional coast resources exploited in the outer Río de la Plata and the Atlantic coastal zone (whiting and white croaker) already indicates overexploitation. Analysis from previous works (INFOPESCA, 2001; Defeo *et al.*, 2006; DINARA, 2007) lead to the following conclusions in terms of fishery resources under non-industrial or sequential exploitation: (1) there is a relatively good scientific knowledge on traditional resources (meagre and whiting); (2) Biological Reference Points (BRPs) estimates are virtually limited to those resources, while there is a significant disproportion of information on quality and quantity of non-traditional resources; (3) information available on non-traditional resources is insufficient, inadequate or out of date, which prevents robust management measures from being taken; (4) estimates of biomass are circumscribed to traditional resources; and (5) no economic information has been included in the analysis despite the fact that exploited populations must be analysed under bio-economic criteria including earnings and costs.

9.2.5 Eutrophication

The Río de la Plata is the destination of nutrient input in the second most important basin of Uruguay. Nevertheless, research has so far demonstrated that it has a great capacity of land-nutrient enrichment. This is so mainly because of its physiography and the water column mixture processes caused by predominant winds which counteract human impact. Yet, this is no longer the case in the Montevideo bay, which is strongly affected by discharges of domestic effluents (hypertrophic in summer, ammonium >120 M, chlorophyll >100 µg Chlo-*a* L^{-1}, hypoxia levels) and heavy metals (chromium 35 – 711 mg kg^{-1}, lead 10 – 365 mg kg^{-1}) (Danulat *et al.*, 1998; Muniz *et al.*, 2004; Gómez-Erache *et al.*, 2003). Assuming that the main signs of eutrophication are nutrient enrichment, increase in primary production and phytoplankton biomass, seasonal blooms of dinoflagellates and potential hypoxia events under stratification methods, the Río de la Plata has shown an increase in eutrophication evidence since the 1980s. The main signs of eutrophication in coastal waters far from point sources are (Méndez *et al.*, 1997; Gómez-Erache *et al.*, 2003; Nagy *et al.*, 2002):

- High chlorophyll levels (16 – 38 µg Chlo-*a* L^{-1})
- Low oxygen levels below halocline depth during long stratification periods (10 – 40 % oxygen saturation)
- Higher frequency in harmful algal bloom occurrence
- High local concentrations of nutrients (>40 µM nitrate y >3 µM phosphate)
- Positive net system metabolism in mixture conditions (7 mol m^{-2} $year^{-1}$) in the estuary and
- High denitrification rates (-1.3 mol m^{-2} $year^{-1}$) in the estuary

The balance of evidence suggests that the Río de la Plata is already moderately vulnerable to eutrophication, due to both natural and anthropogenic causes (Gómez-Erache *et al*., 2003; Nagy *et al*., 2002).

Harmful Algal Blooms (HAB) caused by dinoflagellates and cyanobacteria are more and more frequent in the Río de la Plata and may have an impact on fishing resources, biodiversity and public health, and consequently on tourism and recreational coastal areas. Summer is the season with the highest risk from toxic blooms: consumption of shellfish rises because of being part of many typical dishes offered to tourists in the coast area. Cyanobacterial blooms in the Uruguay River estuary and Atlantic coasts in summer of 2019 are characterised as extraordinary (Kruk *et al*., 2019). Their wide spatial spread (500 km) and long duration (about four months) affected most beaches, from Colonia to Rocha departments. They were caused by a complex named *Microcystis aeruginosa* (MAC) of freshwater origin, although in this case high concentrations were found under marine salinity conditions (9.8 – 31.9). Extreme rainfall and river flow volumes in Uruguay River and Río de la Plata suggest that the blooms had a common origin in the Río de la Plata lower basin, and that special wind conditions made it possible for the boom to reach the Atlantic coast (Kruk *et al*., 2019). Northeast wind prevailed on the Uruguayan coast from 19 January to 5 February 2019. During that period, the intensity of these winds presented a negative anomaly, their magnitude and direction indicating they were warm and weak. The anomaly was positive in terms of air temperature. The moment of highest flow rates for the Río de la Plata coincided with the first heatwave event occurrence and low-intensity winds (Kruk *et al*., 2019).

9.2.6 Invasive alien species

The increase in trading operations has been the cause of the introduction of invasive alien species through ballast water from vessels. Consequences have been considerable, and damage has been made to ecosystems, native biodiversity, fishing activities and aquaculture, and human health. There are 14 alien aquatic species intentionally introduced for aquaculture purposes (76% fishes and amphibians, and 21% molluscs and crustacean). These were captive breeding projects (sturgeon, bullfrog, carp), but some species have been currently found in natural ecosystems, the impact being unknown. Twelve species were accidentally introduced (annelids, arthropods, molluscs and a chordate) and 19 cryptogenic species (arthropods, annelids, sponges, cnidarians and molluscs). The way they were introduced is unknown, but they are supposedly associated with maritime transport (ballast water and adhered to ship hulls) (Brugnioli *et al*., 2006). The main invasive species in the Uruguayan coastal zone are the golden mussel (*Limnoperna fortunei*), Asian clam (*Corbicula fluminea, Corbicula largilierti*) and common carp (*Cyprinus carpio*). Golden mussels were introduced and settled in the Río de la Plata in 1991, and in 1995 it breached inward in the basins of the Paraná, Paraguay, and Uruguay rivers. More than ten years after being first cited, this species has invaded at a rate of about 240 km per year. The Asian clam also has an extraordinary dispersal ability; it can travel long distances through water currents or floating objects. The common carp is characterised by its high tolerance to pollution and high temperatures, which would grant it competitive advantage over meagre, main fishing resource in the Uruguayan coastal zone (FREPLATA, 2004).

Invasive alien species affect biodiversity and undermine industries and businesses that use refrigerating systems with water intakes directly connected to water resources. Due to its high density and filtration rates, the Asian clam can limit food (phytoplankton) available for other aquatic organisms, thus affecting the trophic paths. This may result in a reduction of the density of commercial fishes while favouring species which feed on molluscs. Water clarification caused by high filtration rates of this clam also favours the growth of rooted plants (FREPLATA, 2004). Economic loss is associated with indirect expenses derived from filter obstruction, unusable hydraulic sensors, damages in pumps or decrease in pipework diameter, implementing mitigation or eradication measures of invasive organism populations (Brugnioli *et al*., 2006). Golden mussel presence has been reported in water treatment plants in Montevideo (Santa Lucía River, Canelones), Nuevo Berlín (Río Negro), Fray Bentos (Uruguay River) and Mercedes (Río Buequelo). It has also been detected in reservoirs, such as Embalse Palmar, and the Salto Grande hydroelectric plant (Uruguay River).

9.2.7 Climate change threats in the Uruguayan coastal zone

It has been diagnosed that variability and climate change will exacerbate the impact of current threats on coastal zones, either by magnifying current stress sources or by direct destruction of habitats and loss of species (Gómez-Erache, 2013). The level of vulnerability of the Uruguayan coastal resources is high, considering changes in rainfall, discharges from Río de la Plata tributaries, the modification of wind patterns and the location of the southwest Atlantic subtropical anticyclone (Nagy *et al*., 2006; Verocai *et al*., 2015). As a result, the adaptability to change in ecosystems and population at risk will be overrun and significant loss is to be expected. At a national scale, several studies (FCIEN, 2009) have estimated the sea-level rise in Montevideo at 11 cm, of which 2-3 cm correspond to the last three decades. The variation is even greater in the remaining tide stations along the Uruguayan coast (La Paloma, Punta del Este, Colonia). The most vulnerable zones at the impact of a general rise in the mean sea-level (MSL) have been identified, most of them being associated with wetlands (Santa Lucia river mouth would suffer significant impact with a rise of only 20 cm and severe impact with a rise of 50 cm; Verocai, 2009); low beaches with increased coastal erosion, and saline intrusion into aquifers. The two standard situations that cause extreme increase in the MSL of the Río de la Plata are related to littoral cyclogenesis and the arrival of fronts from the south.

Santa Lucia del Este, Canelones, Uruguay.
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The different regions of this complex estuarine-oceanic system will reflect these changes in different ways and further erosion will affect Uruguay's east coast. Estimations are that 191 km of the Río de la Plata coast (Nueva Palmira to Punta del Este) present coastal erosion process, shown in active cliffs, gullies, headlands and platforms; all these landforms account for 42% of the Uruguayan coast (Goso *et al*., 2011). Additionally, 32% of the Atlantic coast (Punta del Este – Barra del Chuy, 74 km) is subject to erosion, particularly during extreme events like storms caused by wind action and waves (Goso *et al*., 2011).

Beaches behave following the El Niño-Southern Oscillation (ENSO) inter-annual climate variation, namely through accretion cycles (increase in sand volume) during El Niño events and the erosion cycles related to strong La Niña events (Gutiérrez *et al*., 2016). During La Niña years there is a stronger incidence of strong southern winds, particularly from the SW, while E-ESE winds increase during El Niño years (Gutiérrez *et al*., 2016). Three storm events coincided with elevations of 2.11 m (1921 – 2008) above MSL. In Montevideo, a shoreline retreat of 1.7 m is expected for every centimetre of sea-level rise (Gutiérrez *et al*., 2016).

Coastal erosion at Playa Grande, Santa Teresa National Park, Uruguay.
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Sea-level rise (1.1 mm year^{-1}; Nagy *et al.,* 2007), a deficit in sediment balance, and the consequences of some coastal engineering works during the 1970s and 1980s, would be the main causes of coastal erosion processes in Uruguay. In relation to coastal cliffs, the shoreline retreat ranges between 0.5 and 1.1 m year^{-1}. In some cases, the effects of storms and the increase in rainfall are combined, resulting in events with a high energy concentration of waves and river run-off that end up eroding non-consolidated materials. Regarding seasonality, out of 164 extreme events observed on the Uruguayan coast (Verocai *et al*., 2015), 32.7% occurred in summer, 27% in autumn, 24% in spring and 15% in winter. When cyclones develop on the Argentina-Uruguay littoral zone, strong southeast winds (35-50 km h^{-1}) are frequent on the Río de la Plata area and on the oceanic coast because of the combination of cyclonic winds.

Climate change scenarios

Climate change projections consider scenarios which describe future societies without new climate change policies other that current ones. Scenarios developed for the next IPCC Assessment Report 6 are called Shared Socio-economic Pathways (SSP) and they use last-generation climate model outputs (CMIP6), unlike those used for the previous IPCC Assessment Report 5. Uruguay's climate projections for the 21st century are based on models which shall be published in the next report IPCC Assessment Report (Barreiro *et al*., 2019). The models have been gaining complexity and spatial resolution by increasing the number of experiments. Barreiro *et al.* (2019) considered ten models for best representing Uruguay's climate; each of them was run for scenarios SSP245, SSP370 and SSP585 for two time horizons: short-term (2020-2044) and long-term (2075-2099). When contrasting the observed and simulated evolution of mean annual temperature in Uruguay for the 1961-2014 period against the end of 21st century projections, a quasi-linear rise in mean annual temperature is observed.

The annual aggregated rainfall of Uruguay shows a high inter-annual variability ranging between -5 and 10% in the short-term horizon, and between -7 and 35% in the long-term horizon. Future projections show a gradual positive trend with increasing occurrence of extreme events. The inter-annual phenomenon with a higher impact on Uruguay's rainfall is the ENSO. The CMIP5 model shows that extreme events associated with ENSO tend to increase in frequency as global temperature rises. Additionally, extreme La Niña related events could become more frequent, particularly three-month drought events in a short-term horizon.

Impact of sea-level rise on human occupation

The quantification of local-scale impact of sea-level rise (SLR) projections in Uruguay was performed by IHCantabria using historical sea-level databases (IMFIA 2018), as well as projections of high-resolution risk dynamics (IHCantabria, 2019c). Simulated data on winds and atmospheric pressure served to create a regional atmospheric model. Numerical models for wave propagation and currents were created using data on topography (IDEuy, 2018), bathymetry, and wind (Figure 9.4). The results were validated with instrumental observations, making it possible to infer changes in sea-level dynamics under different climate change scenarios (IHCantabria, 2019a). The elements considered for risk assessment were population exposure, constructed assets, critical infrastructures, and ecosystems below the +10 m altitude for the different scenarios and studied return periods (5, 10, 25, 50, 100, and 500 years).

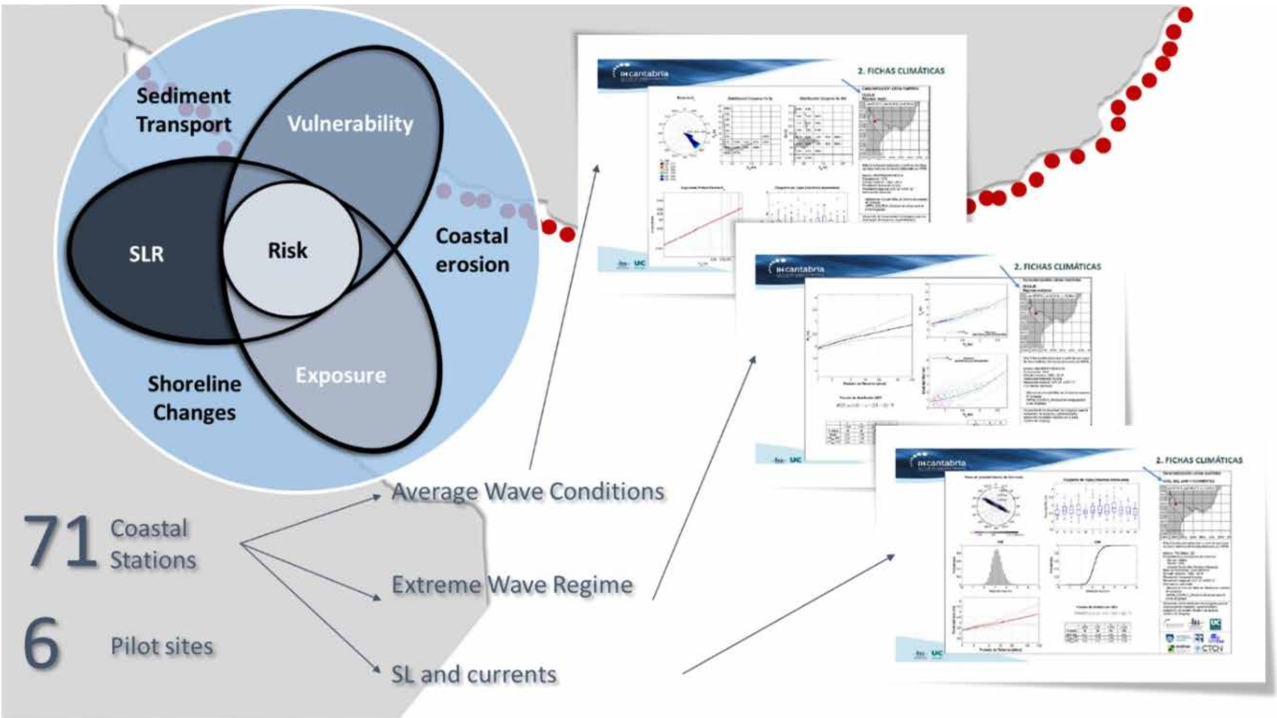

Figure 9.4 Location of sites where oceanographic and hydrological variables were modelled under climate change scenarios. For each site, there are climate sheets useful for characterizing vulnerabilities and implementing adaptation measures.
Source: Mónica Gómez Erache based on IHCantabria (2019)

Preliminary results indicate that the currently flooded coastal area ranges from 7,000 to 1,200 ha, for the 5-year return period. This area increases as the time horizon expands, turning critical for the RCP8.5 scenario. The increase expected by the end of the 21st century corresponds to an average of 43%, flood values ranging between 10,500 and 12,000 ha for a 500-year return period. In any of the studied scenarios, the greatest damage is observed on residential assets, corresponding to 50% of the damage on all constructed assets. Coastal erosion caused by extreme events is currently responsible for the loss of 15,000 to 22,000 km^2, and the area will increase between 2 and 3% by the end of the 21st century under the RCP8.5 scenario, over the coastal zone.

Identifying and defining the limits of the coastal areas with the highest vulnerability to or critically endangered by SLR will depend not only on how they are impacted, but also on the land-use practices in them (rural use, buildings, brownfield sites, beaches). A study calculated the human occupation for the different land-uses in the area under the Law of the Atlantic Ocean and Río de la Plata Coastal Areas (*"Ley del Espacio Costero del Océano Atlántico y del Río de la Plata"*, Law No. 19772). According to that study (Albín, 2019), Rocha is the department with the highest percentage of rural areas and beach systems, which makes it a special natural area. The study is still unfinished; analysis of the urban areas in Montevideo is still pending. Buildings is the predominant use in Canelones and Maldonado, the latter also showing a high percentage of brownfield, compared to the remaining departments. Based on this profile, a process of identification and estimation of the economic value of available assets on the Uruguayan coastal strip is carried out for the first time in the country. The creation of methodological basis for the efficient estimation of such assessment is in its final phase. It will employ the information that is available in the country through the public sector.

A different study focused on the potential impact of three very heterogeneous erosive processes (Piaggio, 2015a) and their impact on different coastal locations (Neptunia, Canelones; La Floresta, Canelones; Ciudad del Plata, San José) in terms of the value of property. The coastal erosion process in Neptunia is gradual. Although it is perceived as a problem in the area where it affects real-estate transactions, it does not prevent them. It is estimated that pricing of a piece of land threatened by coastal erosion may be affected as much as in 58% of its value. The case in La Floresta is different, though: coastal erosion affects the area so deeply that real-estate transactions have totally stopped. Lastly, the exact opposite is happening in Ciudad de Plata, where its boom as commuter town and the fact that no private sites have been affected yet has prevented the coastal erosion process from affecting house prices.

Piriapolis, Uruguay.

9.2.8 Coastal risk map for Uruguay

Risk in coastal ecosystems results from combining impact, exposure, and vulnerability in association with forcing factors, which are affected by climate change and variability. The elements considered for coastal flood risk assessment in the Uruguayan coast were population exposure, constructed assets (homes, industries, services), critical infrastructures (airports, schools, ports, health centres) and ecosystems (threatened and critically endangered) (IHCantabria, 2018). The assessment of vulnerability and coastal risk level are shown in Figure 9.5 illustrating the current coastal situation by administrative department.

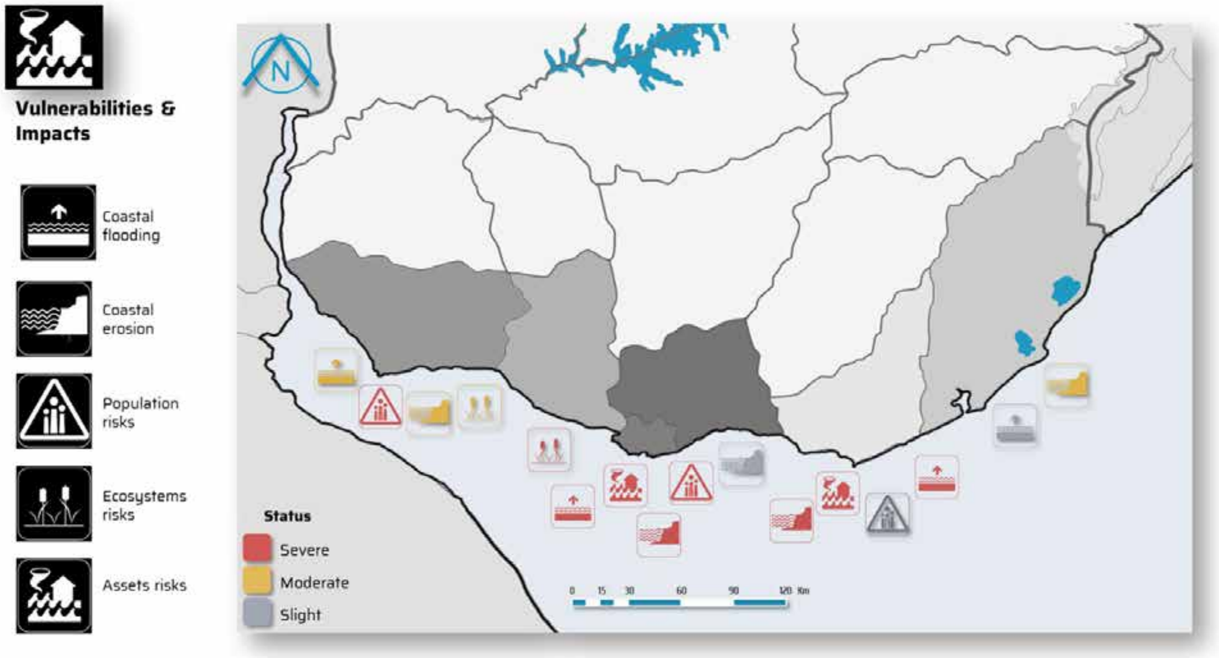

Figure 9.5 Location of impacts and assessment of vulnerability in the coastal zone of the six Uruguayan departments.
Source: Mónica Gómez Erache based on MVOTMA (2020)

Given that planning and implementation of adaptation measures have long-term timescales and predictions have been made based on the analysis of possible scenarios of hypothetical social and economic growth (IPCC, 2014) – each with its specific uncertainties – the challenge is to reduce timescales and properly convey information to decision-makers. For that purpose, consistency is key. Even though the information generated has been scientifically accurate, we must bear in mind that adaptation policies and strategies must be based on data and models fit for each activity, providing an honest perspective of the uncertainties inherent to the predictions made. Thus, following the IPCC approach, each mentioned risk had an additional concept assessment to express the level of certainty in the assertions (probable, medium certainty, high certainty). Below are the main risks observed for the priority issues in the Uruguayan coast (IHCantabria, 2019 a,b,c):

Coastal flood hazard

- The currently flooded coastal area ranges between 7,000 and 12,000 ha, depending on the return period of the event under consideration. The flooded area increases as scenarios considered turns pessimistic (RCP85) and time horizon grows (high certainty). An increase of 43% is expected by the end of the century – from 7,000 to 10,000 ha for a 5-year return period, and from 12,000 to 16,369 ha for a 500-year period (medium certainty).

Population risk in case of coastal flood

- Currently the number of affected people increases in connection with the return periods of the extreme events under consideration (TR5 several hundred; TR500 several thousands) (probable). Future projections for 2100 show that the number of people to be potentially affected is higher under scenario RCP85, increasing by 300 % (probable).

- The most affected municipalities from assessed cases are Colonia, Canelones, San José, and Montevideo (medium certainty).

Risk for constructed assets in case of coastal flood

- Current damages increase in the return period of extreme events under consideration (TR5 USD 26 million; TR500 USD 65 million) (probable).

- Future damage projections increase in connection with the time horizon, while for a single horizon (2100) the expected damage is higher under scenario RCP85 (high certainty).

- Under any scenario, the greatest damage is observed on residential assets, corresponding to 50% of damage affecting all constructed assets. The next most affected category is services (high certainty).

- Under horizon 2100, the damage will be increased in 49% (RCP45) and 185% (RCP85) in relation to the current status (high certainty).
- Of all assessed situations, the Maldonado stretch of coast is where the highest damage is expected (high certainty).
- In the Montevideo coastal zone, the risk is increased in 600% for the 2100 horizon under scenario RCP85 (high certainty).

Ecosystem risk in case of flood

- The currently affected area is about 500 ha of ecosystems regarded as vulnerable (probable).
- Future scenarios will show an increase in impact of 17% by 2050 and in 40% under the 2100 horizon (probable).
- Impact will be more intense in the municipality of Colonia (127%), followed by San José and Maldonado (75%) (probable).

Risk assessment associated with coastal erosion included beaches as an element of exposure. Beaches were physically characterised according to their area, and economically according to the protective and recreational services they offer. The beaches' vulnerability was established as a relationship between the eroded surface and the percentage of damage caused in each location.

Coastal erosion hazard

- Current loss per extreme event ranges between 1,463 and 2,175 ha (high certainty).
- For the 2050 horizon the values increase around 3% under scenery RCP45 (high certainty), and by the end of the century eroded areas will increase by about 1,562 and 2,325 ha (high certainty).
- Highest erosion is observed along the coast of the Rocha municipality, with a current area of 700 ha (high certainty) and expected to reach 850 ha after an increase of 21% (high certainty) by the end of the century.

Beach services at risk due to coastal erosion caused by extreme events

- The currently expected annual damage derived from erosion is approximately USD 45.5 million; a value that will be increased by about 25% (probable) by the end of the 21st century. The municipalities with the highest annual damage are Montevideo (USD 18 million) and Maldonado (USD 14 million) (probable).
- By the end of the century, these municipalities will still be the ones with the greatest damage (35% increase in Montevideo, 21% in Maldonado). The percentages will be lower in the remaining municipalities (14% increase in Rocha, 10% in Canelones and Colonia, 6% in San José) (medium certainty).
- From the perspective of recreational services provided by beaches, the municipalities of Maldonado and Colonia currently show the highest damages (USD 40,000 per year) (probable). By the end of the 21st century the situation will be different, and it will be the beaches along Rocha and Montevideo that will show the highest increases (25%) (probable).

Beach services at risk due to structural erosion

- By the year 2050, the beaches on the Uruguayan coast are expected to suffer damages amounting USD 6.59 million (probable). According to the different scenarios, this will represent between 0.6 and 1.1% (RCP45), and between 5.7 and 11.2% (RCP85) of the total beach value (probable). All this damage will be mainly caused by the reduction of the protection service that the sand dynamics provides to arc-shaped beaches (high certainty).
- The greatest damage will occur in the Montevideo coastal area, potentially reaching between USD 11.4 million (RCP45) and USD 28 million (RCP85) by the end of the century (probable). Under all scenarios, values for the Maldonado and Colonia coasts may vary from USD 24.4 to 13.5 million respectively by the end of the 21st century (probable). By 2100, the coasts of the Rocha and Canelones municipalities will suffer damage between USD 2.0 million and USD 5.7 million, while in San José damage is expected to be practically insignificant (probable).
- By the end of the 21st century, damage caused by structural coastal erosion derived from the rise of the MSL may be as significant, or even more significant, than annual coastal erosion caused by extreme events (high certainty).

It is worth stressing that the most important effects that climate change and its variability may cause in beaches are the modification of flood levels and the retreat/

advance of the shoreline. For a 2050-time horizon and under a pessimistic scenario (RCP85) the shoreline of all Uruguayan beaches will retreat ≤ 5 m; while by the end of the 21st century and for a medium increase of MSL, a great differentiation is observed in each stretch of the coast, with shoreline retreat ranging from 5 m to 20 m, particularly in fine-sand beaches and those with greater depths of closer.

Montevideo, Uruguay.
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9.3 Coastal risk management in Uruguay

9.3.1 National and local levels

A national system (*"Sistema Nacional de Respuesta al Cambio Climático y Variabilidad",* SNRCC) was created in 2009 to coordinate national policies, plans and actions related to climate change and its variability. The Ministry of Environment (MA) is in charge of this national system and is also the Chair to its coordination board, which is composed of other seven ministries – Ministry of Industry, Energy and Mining (MIEM); Ministry of Livestock, Agriculture and Fisheries (MGAP); Ministry of Economy and Finances (MEF); Ministry of Foreign Affairs (MRE); Ministry of Public Health (MSP); Ministry of Tourism (MINTUR); and the Ministry of National Defence (MDN) – the Planning and Budget Office (OPP), the Congress of Governors (CI) and the National Emergency System (SINAE). Occasionally some other public bodies have been invited to participate: Ministry of Education and Culture (MEC), Ministry of Transport and Public Works (MTOP), Ministry of Social Development (MIDES), Ministry of Labour and Social Security (MTSS), the Uruguayan International Cooperation Agency (AUCI), and the National Institute of Meteorology (INUMET).

The National Policy on Climate Change (PNCC) was created in 2016 under this inter-institutional framework. It constitutes a strategic document with measures up to the 2050 horizon that was conceived as the country's short-, medium- and long-term action guidelines for adaptation and mitigation of the challenges posed by climate change. The PNCC strategies and action lines, the National Policy on Integral Risk Management (PNGIR), the preparation of the National Adaptation Plan for the Agricultural Sector (NAP AGRO), the National Adaptation Plan for Coastal Areas (NAP COASTAL) and the National Adaptation Plan for Cities and Infrastructure (NAP CITIES), and the National Strategy for the Reduction of Emissions from Deforestation and Native Forest Degradation (ENREDD) are all examples of the political and inter-institutional priority given to progress on climate action and the United Nations Sustainable Development Goal 13 implementation in Uruguay.

The PNCC was the framework for the preparation of the first Nationally Determined Contribution (NDC) under the Paris Agreement, presented before the Conference of the Parties at the UNFCCC. This helped strengthen the national agenda by defining adaptation and mitigation measures, and it also strengthened capacities and knowledge creation about climate change. Policy monitoring and evaluation are currently a priority in Uruguay, as is the implementation of measures according to the NDC and progress follow-up towards its objectives. The country is strongly committed to achieving this implementation and the transparency of the process. Such objectives shall be achieved with national resources, while others may be achieved with additional specific means for their implementation, as approved by the Decree No. 310/017, on 3 November 2017.

Both the definitions on components and contents of NAP COASTAL (Gómez-Erache, 2019) and the creation of knowledge have been developed through the above-mentioned inter-institutional coordination concentrated at the SNRCC. General guidelines for the knowledge incorporation and decision-making were defined on the NAP COASTAL strategies and actions (Figure 9.6) were focused on iterative mechanisms for consultation and adjustment, which involved four levels of institutional participation. SNRCC guided the process and created a work group called "Adaptation in the Coastal Area" which was composed of national institutions (DCC, DINAMA, DINOT, DINAGUA, MINTUR, UDELAR, IDEuy). Its goal was to integrate emerging national, local, and sectoral priorities and to prepare and/or validate technical drafts for the different components during the creation of NAP COASTAL. Sub-national governments were also consulted through different participation ways and training workshops aiming at improving understanding of the vulnerability of the Uruguayan coastal zone.

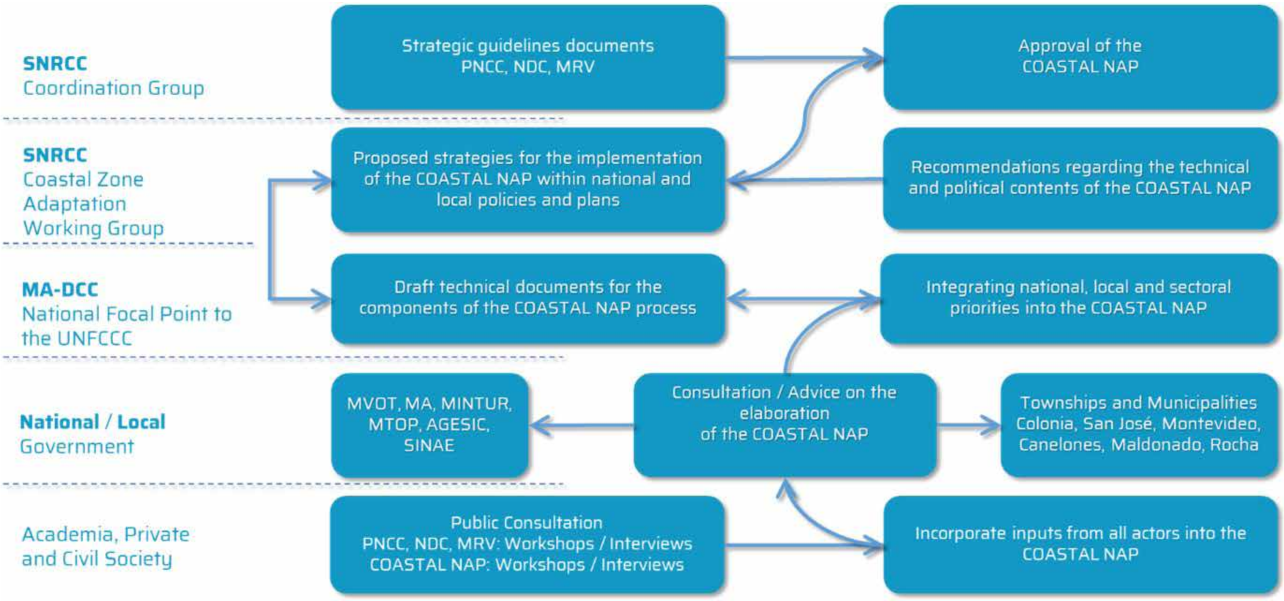

Figure 9.6 Flow of incorporation of knowledge and definitions in the elaboration of the Coastal National Adaptation Plan. (By its acronym in Spanish; SNRCC: National Climate Change Response System; MA: Environment Ministry; DCC: Climate Change Direction; PNCC: National Policy of Climate Change; NDC: Nationally Determined Contributions; MRV: Monitoring, Report and Verification; MVOT: Ministry of Housing and Planning; MINTUR: Ministry of Tourism; MTOP: Ministry of Transport and Public Works; AGESIC: Agency for Electronic Government and the Information and Knowledge Society; SINAE: National Emergency System).
Source: Mónica Gómez Erache

As stated in the initial phase of the NAP COASTAL elaboration process, SNRCC aimed at identifying impacts and assess risks and vulnerabilities in the Uruguayan coastal zone in collaboration with the University of Cantabria Hydraulics Institute and the Faculties of Science and Engineering of the University of the Republic. The information generated established a baseline for coastal vulnerability for the first time in the country and was then used to build future projections based on climate change scenarios.

In line with the laws and policies and within the framework of the institutional format described above, the preparation of the NAP COASTAL seeks to strengthen capacities for incorporating measures of adaptation to variability and climate change to the planning and management processes of national and sub-national government systems. For a period of five years (2015 – 2020), the NAP COASTAL has maintained various consultation and training strategies for the municipalities along the Río de la Plata and Atlantic Ocean coastal area.

The NAP COASTAL is conceived as a working method that acknowledges all concerns related to variability and climate change along the decision-making processes. In this regard, this mechanism intends to cover all the necessary structures for generating the knowledge that will be applied when it comes to strategic planning.

Within the NAP COASTAL framework, SNRCC is committed to enhance technical and institutional capacities at different levels focusing on medium- and long-term planning, and implementation of adaptation measures on the coastal zone in the departments of Colonia, San José, Montevideo, Canelones, Maldonado and Rocha. The NAP COASTAL is conceived as a working method that acknowledges all concerns related to climate change and its variability during the decision-making processes. The methodology applied was underpinned by the IPCC (2014) general framework, evaluating the risk on the socio-economic and natural coastal systems, and integrating hazard, exposure, and vulnerability factors to the current situation and to future horizons under different climate change scenarios.[1]

1. Financial support for this publication and for the preparation of the National Adaptation Plan for coastal areas climate change was granted by the Spanish Agency for International Cooperation (AECID, by its acronym in Spanish) under project *"Fortalecer las capacidades de Uruguay para la adaptación a los efectos del cambio climático en la zona costera"*, the Climate Technology Centre and Network (CTCN) under project "Development of technology tools for the assessment of impacts, vulnerability and adaptation to climate change in the coastal zones of Uruguay», Green Climate Fund (GCF) under projects "Integrating adaptation into cities, infrastructure and local planning in Uruguay Project" and "Institutional and technical capacity building to increase transparency under the Paris Agreement". Additional support was provided in the form of a digital terrain model used for the coastal area vulnerability study by the E-Government and Information and Knowledge Society Agency (AGESIC, by its acronym in Spanish) through the decentralised agency of the Presidency of the Republic "Spatial Data Infrastructure" (SDI).

Adaptation lines

Uruguay currently has a portfolio of strategic lines on adaptation ready to be executed in the short- and long-term, grouped into four implementation programmes (Gómez-Erache, 2019):

- Strengthening the capacities for climate change risk reduction by establishing early-warning systems, coordinating national, regional, departmental, and local policies, and training local managers.
- Elaboration of climate change adaptation departmental agendas in the coastal zone, implementing actions that acknowledge climate change in spatial planning instruments and focusing on incorporating climate change dimensions to local spatial planning and management of coastal-marine protected areas.
- Creation of knowledge regarding processes related to climate change and its variability, plus the consequent technology transfer for adaptation actions in the management of coastal areas. This line of action will specifically concentrate on studies on the combined effect of coastal vulnerability, rising sea-level, and increasing intensity and frequency of climate extremes. It will also determine physical, environmental, economic, and human impact thresholds, and will develop technological solutions to effectively protect coastal morphology.
- Encouragement of sustainable and climate-change resilient tourist activities, promoting adaptive environmental management in coordination with tourism agents and building practical information on adaptation measures to share with clients.

To implement the strategic action lines in each programme, national and local institutions must receive permanent strengthening of their capacities. Within this context, the national government finds it imperative to consolidate platforms for sharing knowledge and information in relation to adaptation at all governance levels, as well as to secure academic and civil society networks. Consequently, Uruguay started a consultative process to prepare NAP COASTAL to consider all above-mentioned measures covering all the necessary structures for generating the knowledge that will be applied when time comes to strategic planning, including local, sub-national and national plans.

Legislative Palace in Montevideo, Uruguay.
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On the local level, a cross-cutting look on these subjects may show how common priorities tend to group themselves into three wide policy-development processes: management of the beach profile and dune ridges, recovery of public coastal space, and freeing-up or adaptation of spaces exposed to coastal flood events (Gómez-Erache, 2019). With an approach that considers factors such as the urban network or the intensity of tourism, municipal governments pay the highest attention to combating coastal erosion through civil engineering works or nature-based solutions. Where major engineering works are necessary, costs are a limitation for sub-national governments. Yet, action is required, and technical assistance is sought in studies which integrate understanding of the problem with executive projects for implementing solutions. Additionally, in-between 2015 and 2020, alternative ecosystem-based solutions have been significantly developed, thus spreading these policies throughout the territory.

The adaptation process in urbanised coastal floodplains shows partial progress and strong tensions in management. Although the formal network no longer spreads over flood-prone areas, it is currently difficult to reverse or mitigate the problem in risk areas where it did consolidate since the 1990s.

Each municipality has its own particular situation regarding current institutional development of coastal working teams, which leads to different degrees in their requirements. Municipalities in the earlier stages of such development have not created any specific unit to address coastal issues (Colonia, San José), while the main claim from technicians involved in its management relating to its creation and to assigning the specific funding in the municipal budget to ensure continuity for the appointed staff (beach team leaders in San José; experts with hydraulic engineer background in

Colonia). Besides suitable staff for managing and impact evaluation tasks on the coastal zone, there are basic needs that must be covered in relation to equipment availability for urban works (Gómez-Erache, 2019). The municipality of Rocha is a good example of effective implementation of this basic level, with a coastal administrative unit run by someone responsible for coordinating management and coastline intervention actions, among the heads of the corresponding departments at each municipality.

Canelones and Maldonado are an example of a second-level development stage, where units integrate staff qualified in coastal issues, include climate change adaptation measures in routine activities, have a greater budget and explicitly mention the need for more personnel. Also closely associated with this situation is the setting forth of a need to create a national policy that ensures coastal actions (Gómez-Erache, 2019).

Montevideo has a more advanced internal organisation, and the developed structure is better adjusted to the challenges of the tasks. Lack of personnel is not mentioned as a problem, and strategies for the preservation of beach profiles and ridge of dunes are well consolidated (Gómez-Erache, 2019). According to the technical staff related to coastal management in the different municipalities, the basic problem is the gradual shift in the institutional agenda towards new coastal concerns, such as the impact of climate change and variability. Under these circumstances, no specific assignments can be identified in each coordination unit for addressing such issues and, therefore, neither is specific budget allocated. In this context, actions are underpinned by political will rather than by consolidated regulations, institutional structure and budgets which may transcend different administrations and be a constitutive part of sub-national governments.

9.3.2 Coastal adaptation in Uruguay

Well-designed adaptation strategies require that options under consideration be technically and economically feasible, as well as socially and politically acceptable. Nevertheless, there are many limitations that usually make it very difficult to apply planning and implementation measures on adaptation to climate change in Uruguay (Gómez-Erache, 2019). The characterization of future climate risks enables the identification of possible adaptation deficits and immediate actions:

- Reduction of the environmental vulnerability derived from rising of sea-level
- Monitoring and maintenance of the functioning and health of coastal ecosystems
- Reduction of the costs associated with disaster response and restoration operations
- Protection of the critical infrastructure from variability and climate change impact
- Minimisation of the economic loss derived from variability and climate change impact
- Reduction of the damage to natural environment and loss of public access through adaptation to variability and climate change
- Increase of the public awareness of how variability and climate change impact the coastal zone
- Improvement of the technical capacity for projecting variability and climate change impact
- Granting municipality leadership in climate change adaptation processes
- Increase of the intra- and inter-institutional collaboration and coordination

Its territorial scale and the fact that Uruguay has a unitary government system enable a closer approach to sub-national governments for building coastal adaptation strategies on balanced perspectives. It also allows for mutual feedback between national government priorities for coastal project management and priorities determined by sub-national and coastal zone communities.

Scattered human occupation in an elevated coastal area in Cabo Polonio, Uruguay.
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9.3.3 Adaptation capacities, gaps and needs

The origin of the main barriers for the implementation of future climate adaptation processes in Latin American countries has been identified to be weaknesses in many areas such as attitude, social behaviour, knowledge, education and human capital, financing, governance, institutions and policies, together with a low capacity for adaptation and development (Rosas *et al*., 2018). Some of the technical limitations identified are lack of quality data or lack access to existent data, lack of standardised criteria, methodologies and tools for assessing climate change risk and for implementing adaptation measures or establishing metrics and procedures for evaluating adaptation processes. Among the institutional and social barriers, it is worth mentioning the issues with relevant national and local competences in the coast, the lack of sufficient knowledge and capacities to address the problem derived from the lack of qualified human resources for climatological and hydrological modelling. A particular case is the poor quality of climate observations and the lack of robust continuous monitoring systems on the coastal zone.

According to the Uruguayan Act No. 9515/1935, the mission of sub-national governments includes ensuring conservation of maritime and river beaches. The first assessment of departmental government budget allocation to coastal management was carried out in Maldonado (Piaggio, 2015b), specifically in Punta del Este, resulting in USD 328,066 invested in 2014. Additionally, for the years 2010 and 2014 the investment increased by 8% (annual average of 1.7%) in items such as "beach cleaning" and "beach accessibility", which respectively accounted for 45% and 34.6% of the annual total. Items associated with the implementation of climate change adaptation measures (sand dune fixation) ranged between 15% and 21% of the annual total expenditure throughout a five-year term. It could also be observed that licensed services related to coastal activities (collapsible paradors, water sports, etc.) correspond to 84% to 93% of coastal restoration total (2010-2014), which indicates a high reinvestment rate by the Maldonado municipal government.

An economic impact assessment could be carried out for the Uruguayan coast from a recent risk and vulnerability analysis (IHCantabria, 2019). Integration of the different return periods applied resulted in an expected annual damage risk indicator for each scenario (RCP4.5, RCP8.5). So far, a total of USD 9 million was the resulting value of climate impact on the coastal zone. This cost will increase by USD 11 million for the 2050 horizon, amounting to USD 15 million by the end of the 21st century under RCP4.5 and over USD 20 million under RCP8.5. Disaggregation of this result according to asset type shows that the greatest damage (50%) will be on residences, as they are on the coastal frontline.

9.3.4 Adaptation lines of action at national and sub-national levels

Climate change and its variability have an adverse impact on the coast and its infrastructure. Managers and residents, as well as their means of livelihood, ecosystems, and services, are exposed to extreme events and to a rising sea-level. Through the MA's Division of Climate Change (DCC), the Uruguayan Government has seen the need to evaluate risk assessment and to prioritise adaptation measures in such a way that they may be included in the institutions' own coastal zone management systems, both at national and at local level.

Understanding local impacts of climate change is an inherently dynamic process, and permanent evaluation and adjustment are necessary to propose effective adaptation measures. For seven years (2012-2019), DCC focused on promoting the reduction of existent gaps in knowledge and diagnosis of coastal vulnerability by means of public consultation activities on the need for adaptation measures. This was co-coordinated with various departmental governments and led to 33 workshops to assess the perception of local stakeholders, messages from the scientific community, and to design the climate change adaptation response. A total of 210 actions were identified, of which 33% referred to strengthening capacities at sub-national governments, 26% focused on coastal spatial planning, and 25% proposed the creation of knowledge and the search for technological solutions. Five strategic lines of action have been agreed so far within the framework of NAP COASTAL, and progress has been achieved in the design and implementation of specific actions:

- Deepening of knowledge and search for technological solutions: Action has been taken to obtain better knowledge about coastal processes and their relationship with variability and climate change, both in general (*e.g.,* studies focused on coastal zone vulnerability caused by the combination of sea-level rise and climate extremes) and with a sectoral perspective (*e.g.,* economic assessment of coastal assets).
- Strengthening capacities to reduce vulnerability: The SNRCC work group for coastal issues has promoted inter-institutional coordination to solve technical challenges (shoreline definition, adjusted digital terrain model, gathering of historical data on coastal dynamics), establish methodologies for impact selection (set of combined methods for qualitative, statistical and spatial analysis, identification and selection of a defined amount of priority impact chains to set limits and focus on), transfer knowledge and raise awareness on climate change (training aimed at different communities involved in the implementation of adaptation measures, high-rank professional and technical local decision-makers).
- Coastal spatial planning: The goals for 2030 have gradually incorporated adaptation through the elaboration of national plans (National Environmental Plan for Sustainable Development, National Strategy for Sustainable Cities). Departmental Governments have worked under an interdisciplinary perspective in including coastal adaptation to these territorial planning instruments (local plans, PLOT), urban planning (Montevideo Resiliente), management plans for protected areas (protocol for the opening of the Laguna de Rocha bar), and in updating coastal infrastructure design standards (criteria for the classification of housing construction projects along the coastal defence strip, MVOT).
- Tourism management: Development strategies have been prepared for a sustainable tourism industry that will prove resilient to climate change ("*Sello Verde Turístico*", MINTUR). Entails the incorporation of the sector to the workshops on assessing perception of vulnerability in the coastal zone derived from variability and climate change and supporting the development of tourism in coastal areas of interest in terms of conservation of beach ecosystems.
- Restoration and recovery: Involves the implementation of specific measures for recovering dune systems (Kiyú), management of rain drainage (Punta del Diablo, Kiyú, Juan Lacaze, Ordeig), beach accessibility (beaches in Canelones and Maldonado), and recovering eroded areas (beaches and ravines in Colonia, San José, Montevideo, Canelones, Maldonado, Rocha).

The execution of an agenda on short-, medium- and long-term actions will prove, for the first time in the country, that the construction of a participative and inter-institutional model can increase the resilience of communities and coastal ecosystems subject to vulnerability and climate change.

Sand fences on a beach in Cabo Polonio, Uruguay.

9.3.5 Adaptation measures

The coastal risk assessment described above under an innovative methodology in Uruguay (IHCantabria, 2019c) leaves the country in the best possible conditions for implementing short-, medium- and long-term adaptation measures. The impact of variability and climate change is proven to disturb sites differently. Likewise, local needs will be different when addressing these issues. Consequently, there is a wide range of options for adaptation measures, many of which are not comparable in terms of intended effect nor in their time or spatial scales. The methodology applied to identify and implement adaptation measures shall be a tool to improve and make the selection of measures more effective and needs to be supported by a technical framework which takes social, political and economic criteria into consideration.

Best practices are to be potentially effective, fair, and legitimate. Adaptation to climate change means strengthening processes that permanently create capacities in all stakeholders. Such capacities must be related with local knowledge of the different actors and sectors to directly affect decision-making processes, which must be transparent and based on reliable and quality data.

Within this context, identifying measures that comply with adaptation planning objectives include considering options that would meet existing policies and/or plans, while also contemplating alternatives which may require an innovative approach. Sometimes plans may easily fit or overlap with existing planning measures. In other cases, however, there may be a need to revise existing actions, making climate change the new context for making decisions, or new actions and management objectives may prove necessary. In any case, identifying specific actions helps understand the needs of stakeholders and may encourage political, public, and financial support.

In Uruguay, a set of realistic measures to address the risks assessed was selected, and needs were identified in relation to the implementation of such measures (including public support for the measure itself and necessary institutional changes, or national and sub-national financial and planning management). To date, there is a consensual set of adaptation measures which may be applied along the coastal zone in general, while still in line with the results of the vulnerability and risk assessments described above. These measures have been sorted depending on whether they are meant for intervention on coastal territory or for general implementation processes. Depending on their structural typology, they are grouped as physical, social, or institutional. The NAP COASTAL focused on a limited set of essential measures (Table 9.1). There are proactive measures which intend to preserve and protect resources anticipating climate change impact (anticipatory measures), and reactive measures, which are applied because of the observation of climate change effects (establishment of surveillance methods to identify changes), as part of the reconstruction after natural disasters, of local communities joining action, or at the availability of extra or emergency resources.

Permanent strengthening of local and national institutional capacities is required to implement such adaptation actions. Within this context, the Uruguayan Government finds it imperative to consolidate platforms that enable knowledge and information sharing related with adaptation at all governance levels, as well as to build up networks with the academy and social organisations. The methodology applied during the creation of NAP COASTAL helped implement an iterative knowledge update on coastal vulnerability mainly focused on strengthening institutional frameworks to address long-term adaptation.

Table 9.1 Climate change adaptation measures in the Uruguayan coastal zone. The sixty measures were classified based on those that are directly implemented in the territory and those that enable adaptation processes. Three categories are recognized: physical structures, social and institutional.

Categories	Subcategories	Applicable to the Uruguayan coast
		INTERVENTION MEASURES IN THE TERRITORY
Physical structures	Engineering	Assessment of infrastructure in highly vulnerable areas, identifying those that are obsolete or that may cause coastal erosion processes.
		Elimination of hard and/or soft coastal structures to recover the system and move towards natural functioning.
		Establish at national level a procedure for the revision and maintenance of coastal infrastructures exposed to the SLR.
		Introduce into the design of new coastal infrastructure the effect of climate change on the useful lifetime of the work.
		Develop recommendations for highly vulnerable areas to avoid future hard infrastructure interventions without prior studies incorporating climate change scenarios.
		In the implementation of adaptation measures for beaches and estuaries: • Incorporate nature-based solutions. • Develop design and construction protocols adapted to the national reality when applying traditional measures (soft, hard, hybrid).
		In the implementation of adaptation measures for harbours: • Operational and structural risk analysis and assessment of harbours incorporating CC scenarios. • Study on the reconditioning or adaptation of critical infrastructures that have been compromised.
		In the implementation of adaptation measures for other structures (*e.g.,* wadis): • Analysis and evaluation of operational and structural risk of wadis incorporating CC scenarios. • Generation of a protocol for the design and execution of new infrastructures, alternatives to rigid works and resilient approaches.
	Sustainable Urban Drainage Systems (SuDS)	Protect and adapt drainage systems (rainwater, sewerage networks) to the possibility of flooding, especially in areas of gullies and river and stream mouths.
		Design and installation of sustainable drainage devices (filled basins, drains, flow dampers, roads) at the level of coastal basins and on sections of coast with high slopes (3-5% in the last 500 m).
	Technology	Identification, evaluation, and monitoring of impacts caused by extreme hydro-climatic events.
		Early warning and response systems for extreme weather events, windstorms, and heavy rainfall.
		Adaptive management of the opening of the bars at the mouths of rivers, streams, and lagoons in the coastal zone.
		Artificial sand recharge by refilling coastal banks on highly vulnerable sections.
		Implementation of drainage devices including filled ditches, rolling wetlands, infiltration plots, incorporating coastal aquatic vegetation.
	Nature-based solutions (NbS)	Renaturation of ravines and coastal wetlands as part of the design of sustainable urban drainage systems.
		Floodplain restoration and reconnection.
		Restoration and conservation of coastal *psamophilous* forest associated with dune and wetland systems in the coastal zone.
		Protection and restoration of coastal wetlands
		Management of exotic species (acacia, eucalyptus, pines) to reduce the risk of falls and fires and facilitate dune regeneration.
	Reduction in the risk of damages and economic loss	In partially affected areas introduce the necessary spatial planning by introducing studies of vulnerability to the effect of climate change and apply adaptation measures to the infrastructure associated with the area.

Categories	Subcategories	Applicable to the Uruguayan coast
		ENABLING MEASURES
		Basic specialised training in risk management and early warning systems.
Social	Capacity building	Participatory development, validation, and implementation of warning systems for extreme events (winds and rainfall).
		Training of OCS, nurseries, landscapers in NbS, restoration and conservation of coastal ecosystems.
		Training of technical teams from sub-national governments for the design, implementation and maintenance of sustainable road and drainage infrastructure.
		Continuous training programme on: • Dynamics of beaches and river mouths. • Calculation and assessment of natural risks.
		Generation of an information system for the calculation of risks that includes: • Comprehensive system for monitoring beaches (coastline, profiles, granulometry) at high frequency and in the long term. • Integral monitoring system of the evolution of river mouths (rivers, streams, and coastal lagoons). • Integrated system for monitoring flows in coastal lagoons. • Wave and wind measurement system, particularly in areas with non-existent information. • Operational system for level and wave prediction. Systematic update of database.
	Information	Generation of high-resolution database for the formulation of indicators to monitor impacts, vulnerability, and adaptation.
		Generation of georeferenced population data and indicators of social vulnerability (single-parent households headed by women, housing deficit, public childcare services).
		Preparation of hazard, vulnerability and risk maps for sectors identified as vulnerable.
		Preparation of coastal flood maps in urban centres along the coastal zone.
		Development of new high-resolution projections focusing on updated climate scenarios for the Uruguayan coast.
		To coordinate research agendas in partnership with national and local government managers as well as with institutions and non-governmental organizations to define the areas of knowledge to be strengthened and to generate research products that facilitate decision-making.
		Protocols for evacuation and/or relocation of populations affected by flooding in the coastal area.
	Public awareness and technical assistance	Diversification of activities in coastal areas to mitigate the impact on sun and beach tourism, addressing differential needs based on gender and generations.
		Incorporation of good practices associated with climate change adaptation into tourism management in the coastal area in coordination with the private sector.
		Keep the media, academia and the general public informed about climate change, technological tools, measures and instruments for adaptation, as well as successful stories and lessons learned.
		Creation of documentation (guides, manuals) to increase public awareness of how climate variability and change affect the coastal zone.
		Implementation of training instances by academic institutions to improve technical capacity about the projection of the impacts of climate variability and change in national and local planning.
		Elaboration of guidelines by the national government for the development of adaptation plans at municipal level.
		Expropriation, demolition and/or relocation of high-risk infrastructure in the coastal defence zone.
	Reduction in the risk of damages and economic loss	Develop a guide to appropriate building codes for the coastal area. Establish requirements for building construction to maximize flood protection (lifting and construction techniques and materials).
		Protection of infrastructures of high cultural and/or social value.
		Record, at the sub-national government level, the events and impacts associated with variability and climate change in the coastal zone.

Categories	Subcategories	Applicable to the Uruguayan coast
		Promote projects focused on NbS by attending to areas that act as natural buffers to the increase in SLR and extreme events (beach nourishment, wetland restoration, dune stabilization).
		Development of guidelines aimed at sub-national governments and the private sector that consider restrictions on the construction of hard coastal protection infrastructure and encourage the removal of structures that flood as the coastline recedes with the increase of the SLR and extreme events (increased river, stream and lagoon flows, loss of sand) to mitigate the impacts of coastal shielding.
		In places along the coast where critical infrastructure exists, the armour with hard infrastructure should control flooding and erosion processes, attend to the feasible impacts on sensitive ecosystems in the area and demand the corresponding mitigation actions considering future scenarios of an increase in the SLR and extreme events.
		Incorporate local experience through public consultation into national and local planning and policy development for coastal adaptation to climate change. This experience needs to be shared among different actors at the national level to build capacity.
	Communication and coordination	Consolidation of the "Coastal Zone Adaptation Working Group" belonging to the National System of Response to Climate Change, which is interdisciplinary and highly specialized to meet the demands of sub-national governments.
		Establishment of a multidisciplinary network focused on the application of BNS for national case studies.
		Identification and promotion of spaces for public participation and consultation with a gender and generational perspective.
		Develop a strategy to raise the awareness of managers and technicians in the different areas of public administration (Ministries of National Defence, Transport and Public Works, Energy).
		In coordination with secondary education authorities, develop materials with content on the potential effects of climate change on the coastal area.
		Economic evaluation of built coastal assets.
Institutional	Incentive structure	Creation of funds for coastal restoration, conservation, and monitoring with the participation of the third level of government, private sector and Civil Society Organizations.
		Collection of physical and socio-economic data profiled towards a better comprehensive understanding of social, housing, infrastructure, and loss and damage vulnerabilities.
		Revision of the regulations of Spatial Planning Instruments about land occupation factors and other urban planning parameters, with an impact on rainwater drainage and erosion (catchment structures and control of property flow, water rights).
	Regional and local plans and regulatory instruments	In the Management Plans of the Coastal-Marine Protected Areas, establish that in the risk zones the criteria for technical evaluation of the actions are incorporated considering the effects of the climate change.
		Review of the Spatial Planning Instruments' regulations referring to the transfer of basins to improve the conduction towards points of less vulnerability to erosive processes.
		Combine different land use regulations (National Coastal Space Guidelines, Land Use Planning Instruments, Strategic Environmental Assessment, Environmental Impact Assessment) and develop guidance to ensure that coastal development does not inhibit natural inland migration of coastal resources. To urban development initiatives, request feasibility studies on the use of soft-shell techniques (BNS) to reduce environmental impacts.
		Assessment of coastal ecosystem services and their incorporation into land-use planning instruments
	Government Policies and Programmes	Encourage the implementation of integrated management of the coastal zone that includes the potential effects of climate change as one more element to consider.
		Encourage the introduction of the effect of climate change in the Maritime Works Recommendations and other standards applicable to infrastructure in highly vulnerable areas.

Source: MVOTMA (2019)

9.3.6 Long-term strategy for implementing adaptation at national level

In line with an adaptive management style, the NAP COASTAL had to acknowledge the need to proceed despite information being incomplete, and to keep revising and updating the plan as information improved and experience in adaptation was gained. All along the process, the national and sub-national governments may choose to identify easy-implementation and therefore fit for short-term action adaptation measures, or to identify a set of more substantial long-term measures which include options with lower regret levels. To date, Uruguay has a portfolio of adaptation measures ready to be executed in the short- and long-term, grouped into four implementation programmes:

- Strengthening the capacities for climate change risk reduction by establishing early-warning systems, coordinating national, regional, departmental, and local policies, and training local managers.
- Elaboration of Climate Change Coastal Adaptation Departmental Agendas, implementing actions that acknowledge climate change in spatial planning instruments and focusing on incorporating variability and climate change dimensions to local spatial planning and management of coastal-marine protected areas.
- Generation of knowledge regarding processes related and climate change and its variability, plus the consequent technology transfer for adaptation action in management of coastal areas. This line of action will specifically concentrate on studies on the combined effect of coastal vulnerability and rising sea-level, increasing intensity and frequency of climate extremes. It will also determine physical, environmental, economic, and human impact thresholds, and will develop technological solutions to effectively protect coastal morphology.
- Encouragement of sustainable and climate change resilient tourist activities, promoting adaptive environmental management in coordination with tourism agents and building practical information on adaptation measures to share with tourists.

Permanent strengthening of local and national institutional capacities is required to implement such adaptation actions. Within this context, the Uruguayan Government finds it imperative to consolidate platforms for sharing knowledge and information in relation to adaptation at all governance levels, as well as to secure academic and civil society networks. Consequently, Uruguay started a consultative process to prepare the NAP COASTAL together with all above-mentioned measures and covering all the necessary structures for generating the knowledge that will be applied when it comes to strategic planning, including local and sub-national plans.

La Balconada, Rocha, Uruguay.
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9.3.7 Strategy for consultation and participation

The efforts to incorporate and apply climate change adaptation measures are often resisted. Such incorporation calls for agreements with a wide range of organisations and groups, each with its own policies and interests. Thus, it may take a long time and pose a real challenge. A certain amount of resistance is simply inherent to any new management proposal. In the case of climate change adaptation, it is exacerbated because of its cumulative nature and the long-term time frame of its effects. The fact that different people and organisations have different interpretations of the uncertainties around climate change and its impact results in dissimilarities in their risk-tolerance levels and makes the issue a little more complicated. Consequently, understanding local impacts of climate change is an inherently dynamic process, and permanent evaluation and adjustment are necessary to propose adaptation measures.

In Uruguay, there is broad experience in designing strategies to address various barriers inherent to coastal adaptation. The following are examples of worldwide coastal management best practices that have been applied in Uruguay:

- Implement pilot projects to test how a set of policy measures may contribute to social benefit. Dissemination of the results to inform the public at large on what is crucial to succeed in applying climate change adaptation measures on a wider scale.

- Promote debates on common pursuit of the desired social results; *e.g.,* healthy coastal ecosystems which support life.
- Build confidence by first addressing simple issues. This paves the way to later tackling more controversial or unclear issues.
- Perform further research on coastal vulnerability assessment and promote the dissemination of its results to raise awareness on the existing risks and their causes and solutions.
- Encourage addressing common interest and threats collectively rather than taking specific measures that favour radical positions.
- Involve a broad range of stakeholders when assessing coastal vulnerability in all stages of the process. It is necessary that all leading institutions and significant groups of stakeholders participate or be informed of any progress, so that they feel identified with it and become active associates in the application stage.

In Uruguay, there is a high degree of involvement of decision-makers and technicians from various ministries participating in coastal zone management. The same is true for managers and technicians from sub-national governments. Assessments of coastal evaluation in pilot sites from the six coastal municipalities are available and efforts have been made on adaptation measures, both cross-cutting and site-specific, and on creating monitoring indicators for vulnerability and effectiveness of adaptation measures.

It is worth mentioning that a gender perspective factor was added to the consultation process to ensure a balanced participation of both men and women, while the youth's perception was also considered. This is a result of making sure that the calls to participate in local consultation workshops explicitly posed the need of having both genders equally represented. Facilities ensured enough space and accessibility to all, and the incorporation of schools ensured the participation of young people. Moreover, a proposal for risk mapping promoted gender and generational awareness, and different tools enabled a bias analysis on the exposure to extreme events. Specific activities were carried out to raise awareness of women who are the head of single-parent households to demonstrate why it is more challenging to involve them in climate change adaptation processes.

In this beach in Rocha, Uruguay, coastal erosion has caused the shoreline to retreat further inland than the first line of human occupation.

9.4 Final remarks

Addressing climate issues in Uruguay has been characterised by the implementation of a cross-cutting public policies approach. Since the National Policy on Climate Change was approved in 2016, the country has been giving priority to climate action, anticipating measures for the short-, medium- and long-term, with the purpose of guiding mitigation and adaptation actions.

Identified technical barriers to face climate change impacts on the coastal zone include the lack of quality data or lack of access to existent data and lack of standardised criteria, methodologies and tools for assessing the climate change risk and implementing and evaluating adaptation measures.

Among the institutional and social barriers, it is worth mentioning the issues with relevant national and local competences in the coast and the lack of sufficient knowledge, capacities, and qualified human resources to address the problem. A particular case is the poor quality of climate observations due to the lack of a long-term robust, continuous monitoring systems in the coastal zone.

In order to strengthen Uruguay's capacities for climate change adaptation, the country innovated in the creation of knowledge by means of a joint collaboration of national researchers (Faculty of Engineering and Faculty of Science from the University of the Republic), international researchers (University of Cantabria Hydraulics Institute) and technical and professional staff from the Ministry of

Housing, Land Planning and Environment (DINAMA, DINOT, DINAGUA, DCC), Ministry of Tourism, Ministry of Transport and Public Works (DNH) and local governments.

Within the NAP COASTAL framework, SNRCC is committed to enhancing technical and institutional capacities at different levels focusing on medium- and long-term planning and implementation of adaptation measures on the coastal zone in the departments of Colonia, San José, Montevideo, Canelones, Maldonado and Rocha. The NAP COASTAL is conceived as a working method that acknowledges all concerns related to climate change and its variability during the decision-making processes.

The knowledge generated is mostly oriented towards interpreting the observed climate variability, developing climate change scenarios, and modelling coastal flood and erosion processes derived from the rise of sea-level and extreme events at national and departmental levels. Those studies assessed climate variability and climate change within the national territory and added research on how observed and projected changes increase vulnerability and risk on the coastal zone. At the same time, they allowed to substantiate assessments of consequences and costs implied from inaction when implementing adaptation measures for different climate change scenarios.

Knowledge transfer from the NAP COASTAL between scholars from UDELAR and IHCantabria was ensured through the implementation of training strategies for technical and professional staff as well as for decision-makers in ministries and local governments. Training was organised following technical specifications from academic institutions and managing specifications from the inter-institutional working group in charge of preparing the NAP COASTAL (DINAMA, DINOT, DINAGUA and DCC) (MVOTMA, 2019).

Historical databases as well as projections of high-resolution risk dynamics prepared by IMFIA researchers were necessary for local-scale impact quantification (IMFIA, 2018). A new analysis was hence designed with simulated data on winds and atmospheric pressure, creating a regional atmospheric model. At the same time, a model for wave propagation and another one for currents generation were created using topographic data (Modelo Digital de Terreno, IDEuy) and coastal bathymetric and wind data. The simulations on these models generate databases that are then validated with instrumental observations in the country, making it possible to infer changes in dynamics under climate change scenarios (IHCantabria, 2019). The variability observed in Uruguay's climate was also analysed, temperature and rainfall climate trends were identified based on the projection of climate models for potential changes during the 21st century (Barreiro *et al.*, 2019).

Due to the high resolution of the analysis (4-metre spatial resolution for flood cases, beach-level for erosion analysis), the proposed maps may be generated at different scales without losing information or analytical capacity. Proposed scaling levels are national (the whole Uruguayan coast), by municipality and by census district, although a detailed customised map can be generated for any zone. The possibility of generating graphic outputs, together with the high resolution of impact, exposure and risk analysis determines that a high number of potential maps (over 50,000 different outputs depending on the scale) will be available from the National Environmental Observatory (OAN, by its acronym in Spanish) (https://www.dinama.gub.uy/oan/) and from the Territorial Information System (SIT, by its acronym in Spanish) (https://sit.mvotma.gub.uy/js/sit/). The characterization of future climate risks enables the identification of possible adaptation deficits and the selection of immediate actions.

The combination of high-resolution basic information with impact processes models and a probabilistic approach contributed to significantly reducing uncertainties, when compared with other national-scale studies which are usually applied to indicators for characterising impact and other risk components. The applied methodology enabled us to identify zones with the potentially highest coastal flood and erosion risks, the most vulnerable natural and socio-economic sub-systems, and the areas with the highest need for adaptation action. Five strategic lines of action have been agreed (MVOTMA, 2019), and progress has been done in the design and implementation of specific actions.

Abbreviations and acronyms

AUCI	Uruguayan Agency for International Cooperation
BRP	Biological Reference Points
CI	Congress of Mayors
DCC	Climate Change Division, MVOTMA
DINAGUA	National Water Directorate, MVOTMA
DINAMA	National Directorate for the Environment, MVOTMA
DINARA	National Directorate of Aquatic Resources
DINOT	National Directorate for Land Management, MVOTMA
EEZ	Exclusive Economic Zone
ENREDD	National Strategy to Reduce Emissions from Deforestation and Degradation of Native Forests
ENSO	El Niño-Southern Oscillation
FCIEN	Faculty of Sciences, University of the Republic
GDP	Gross Domestic Product
HAB	Harmful Algal Blooms
IDEuy	Uruguay's Spatial Data Infrastructure, AGESIC
INUMET	Uruguayan Institute of Meteorology
IH CANTABRIA	Institute of Hydraulics of the University of Cantabria, Spain
IMFIA	Institute of Fluid Mechanics and Environmental Engineering, FING
IPCC	Intergovernmental Panel on Climate Change
MA*	Ministry of the Environment
MDN	Ministry of National Defence
MEC	Ministry of Education and Culture
MEF	Ministry of Economy and Finance
MGAP	Ministry of Livestock, Agriculture and Fisheries
MIDES	Ministry of Social Development
MIEM	Ministry of Industry, Energy and Mining
MINTUR	Ministry of Tourism
MRE	Ministry of Foreign Affairs
MSL	Mean Sea-Level
MSP	Ministry of Public Health
MTOP	Ministry of Transport and Public Works
MTSS	Ministry of Labour and Social Security
MVOT*	Ministry of Housing and Spatial Planning
MVOTMA*	Ministry of Housing, Spatial Planning and the Environment
NAP	National Adaptation Plan
NAP AGRO	National Agricultural Adaptation Plan
NAP CITIES	National Adaptation Plan in Cities
NAP COASTAL	National Coastal Adaptation Plan
NCCP	National Climate Change Policy
OPP	Office of Planning and Budget
PLOT	Local Land Management Plans
PNCC	National Policy on Climate Change
PNGIR	National Comprehensive Risk Management Policy
SbN	Nature-based solutions
SINAE	National Emergency System
SNRCC	National Response System to Climate Change and Variability
UDELAR	University of the Republic, Uruguay
UNFCCC	United Nations Framework Convention on Climate Change

* In 2020, MVOTMA was reorganised, and two new ministries were created, MVOT and MA.

The Fingers, Punta del Este, Uruguay.

10. The case of Venezuela

Puerto la Cruz, Venezuela.

Author: Ana Carolina Peralta Brichtova

10.1 Venezuela and its coastal zone

Venezuela has a population of almost 30 million inhabitants, according to the last national census carried out in the year 2011. About 75% of the population occupies 20% of the national territory that corresponds to the States that have coast on or border the Venezuelan maritime territory (Instituto Nacional de Estadística, 2014). Most of the international airports, oil refineries, oil and gas fields, as well as important ports are in the coastal areas of Venezuela. On the other hand, in the country's coastal zone are located important fishing resources (fish, molluscs, crustaceans, etc.), important marine species farming areas and a great biological diversity associated with various types of ecosystems, such as sandy beaches, rocky shores, seagrass meadows, mangrove forests and coral reefs. Under this scenario, Venezuela faces several challenges regarding the management and reduction of coastal risk, which is contemplated by the public administration, with well-defined laws and programmes. For this purpose, there is a Technical Directorate for Coastal Areas, attached to the Ministry of the People's Power for the Environment (currently the Ministry of the People's Power for Eco-socialism and Water), which has been coordinating, since 2004, the preparation of the Plan for the Integrated Planning and Management of Coastal Zones (POGIZC), through a management process involving key institutional actors at the national, regional, state and local levels, as well as the communities. This includes, among other aspects, concrete problems and the guidelines for the elaboration of operational programs with which it is expected to address those problems (Ministerio del Poder Popular para el Ambiente, 2010a).

Figure 10.1 Location map of Venezuela.
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The chapter exposes the factors or threats that Venezuela is facing, in relation to the activities and spaces in use within its coastal areas, and which of these factors are considered within risk management procedures and practices. An exploration of the measures adopted, and their effects is also presented. Suggestions and recommendations are also made, regarding threats that are not reflected in national coastal risk management policies, as well as possible measures and actions to be adopted to reduce such risks.

Isla de Margarita, Venezuela.
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Venezuela is in the north of South America, bordering to the north part of the Caribbean Sea (the territorial sea of Trinidad and Tobago, the West Indies, Puerto Rico, the French Islands Martinique and Guadeloupe and the US Virgin Islands), and to the east with Guyana and the Atlantic Ocean. To the south it borders Brazil and Colombia, and to the west Colombia.

The land domain covers 916,425 km^2 which includes the islands' surface; the maritime territory covers 860,000 km^2 (Lárez Hernández, Carrero de Blanco and García Tobar, 2004). The coastal area of Venezuela is very diverse from the geological and topographical point of view. It has a coastline of approximately 4,730 km (770 km of coastline around Lake Maracaibo) of which 68% is in direct contact with the Caribbean Sea and 21% with the Atlantic Ocean (Lara de González, Suárez-Ruiz and Marucci, 1997). The remaining 12% of the Venezuelan coastline (1,413 km) corresponds to a group of more than 300 islands and cays, of which Isla de Aves marks the northern limit of the country's territorial sea at 15 °N (Lárez Hernández, Carrero de Blanco and García Tobar, 2004; Ministerio del Poder Popular para el Ambiente, 2013). In this sense, Venezuela's coastal zone occupies 143,587 km^2 (58,507 km^2 of land and 85,080 km^2 of water), which represent 10% of the national territory, with approximately 4,222,831 inhabitants. This represents around 18% of the total population, with a population density of 72 inhabitants per km^2, a value that is three times the national average (Ministerio del Poder Popular para el Ambiente, 2013).

Venezuela's maritime region has a climate influenced by the Intertropical Convergence Zone (ITCZ), namely by the northeast trade winds. The country's coastal zone is also influenced by hurricanes which cause significant rainfall, large waves and strong winds. Annual rainfall in the coastal zone is approximately 400 mm and the average temperature is 28 °C. The sea surface temperature along the Venezuelan coast varies between 20 °C and 29 °C and is influenced by several upwelling zones, which vary in shape, extension and intensity. The north-south oscillation of the ITCZ is the main cause of seasonal changes in the salinity and temperature of the Caribbean surface sea (Muller-Karger and Varela, 1989 in Miloslavich *et al.* 2003).

Miloslavich *et al.* (2003) propose the division of the Venezuelan coastal zone into 12 main marine ecoregions, according to ecological criterion, considering the characteristic oceanographic variables and the types of marine ecosystems present. The ecoregions are Orinoco Delta, Eastern Upwelling Zone, Píritu-Tacarigua, Central Coast, Golfo Triste, Tocuyo, Paraguaná, Golfete de Coro, Maracaibo Estuary, Gulf of Venezuela, Insular Region and Oceanic Region.

In general, the diversity of flora and fauna on the Atlantic front is relatively low. However, there is little information recorded about the habitats of this zone, which are dominated by muddy and sandy areas resulting from the discharges of the Orinoco and Amazon rivers (Figure 10.3). The Caribbean coastal zone in Venezuela is known to be more diverse, there is less sediments suspended in the seawater making it more transparent, and the ecosystems are basically sandy bottoms, seagrass beds, and coral reefs, all with a high biodiversity (Figure 10.2) (Miloslavich *et al.*, 2003).

Figure 10.2 Two contrasting types of ecosystems present in the Venezuelan coast. The muddy Caño Mámo in Orinoco Delta (left) and, in the Caribbean Sea, the crystal clear Ocumare de la Costa (centre) and Parque Nacional Mochima (right). © Otto Castillo, Angel Farina and Ana Carolina Peralta

Within the activities carried out in the coastal area, the fishing production (hydrobiological resources) stands out, with the presence of 334 fishing settlements, vessels smaller than or equal to 10 GRT ("crawlers") and medium draft and industrial fleet. The artisanal fishery represents 70% of the total fishing production of the country. The exploitation of non-metallic minerals is associated with sand, gravel, clay, limestone, chalk, gypsum and salt; in addition, the current and future production of hydrocarbons (oil and natural gas), both on land and in the water (lake and marine). Additionally, in the coastal area, there are some 440 industries, with establishments dedicated to the production of food and beverage products, metal products manufacture, machinery and equipment, manufacture of substances and chemical products, petroleum derivatives, coal, rubber and plastic. Likewise, the coastal areas represent the main attraction of the national tourism industry, supported under the category of Areas of Tourist Interest (Ministerio del Poder Popular para el Ambiente, 2013).

From the territorial management point of view, the National Institute of Aquatic Spaces, as the organization of the aquatic spaces in the country, has divided the coastal areas into a total of six areas with the purpose of managing the existing resources in them (Lárez Hernández, Carrero de Blanco and García Tobar, 2004). Simultaneously, the Organic Law for Land Management (LOPOT) defined, in 1983, the Marine Protected Areas, which are grouped into generic categories corresponding to: 1) Protected Areas with strictly protective, scientific, educational and recreational purposes (National Parks); 2) Protected Areas with protective purposes through regulated uses (Protective Zones, Wildlife Reserves, Biosphere Reserves, Critical Areas with Priority Treatment, Areas of Tourist Interest) and 3) Protected Areas for the sustainable use of their resources (Hydrocarbon Processing Zones). In 2001 the Coastal Zone Law Decree was approved, which depended on the then Ministry of the People's Power for the Environment (now called the Ministry of the People's Power for Eco-socialism), under which the POGIZC was created, recognizing 49 Marine Protected Areas (~5,600 km^2), representing 0.65% of the country's maritime space (Ministerio del Poder Popular para el Ambiente, 2010b; Montaño *et al.*, 2015).

Los Roques, Venezuela.
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10.2 Coastal hazards in Venezuela

10.2.1 Sea-level rise

The coastal areas of Venezuela are prone to coastal flooding because of climate change. For an average sea-level rise of 0.5 m, it was projected that a total of 15,734 km^2 of land would be lost, of which 10,804 km^2 are in the Orinoco Delta Basin (Ministerio del Poder Popular para el Ambiente, 2011, 2014). Vulnerability studies indicate that a half-meter increase in sea level would flood more than 50% of the sandy beaches in the Caribbean in the next 50 to 100 years (NOAA, 2010, in Ministerio del Poder Popular para el Ambiente, 2011). Venezuela's First National Communication on Climate Change establishes that, according to the results of different scenarios, the rise in sea-level will impact an area of 31.8 km^2 in four coastal locations (eastern coast of the State of Falcón, Cabo Codera – Laguna de Tacarigua National Park, Barcelona – Puerto La Cruz – Guanta, and Margarita Island). Of the total indicated, 85.1% (2,709 ha) corresponds to the eastern coast of Falcon State. This estimate is considered valid considering the environmental implications of extreme weather events on the eastern coast of Falcón State at the end of 2010. A percentage of the Venezuelan coast is characterized by mountainous and steeply sloping cliffs, which will not experience significant impacts in the case of a rise in average sea-level. However, environmental impacts associated with this increase are expected to affect this type of coast on a smaller scale (Ministerio del Poder Popular para el Ambiente, 2011).

10.2.2 Coastal erosion

Associated with the increase in sea-level, coastal erosion is expected to happen on sandy beaches; however, the associated impact is not quantified in Venezuela, mainly due to the lack of data and monitoring of coastal dynamics with sufficient space-time resolution. Nevertheless, soil erosion processes in lowlands near the coast, are considered a socio-natural threat, according to the POGIZC (Ministerio del Poder Popular para el Ambiente, 2014). Among the consequences generated by coastal erosion in Venezuela, the reduction of recreational areas in beaches, the impacts on economic activities, and the reduction of sea turtle nesting areas stand out (Ministerio del Poder Popular para el Ambiente, 2011).

As it is estimated that, globally, the coast will retreat one meter, on average, for every centimetre of sea-level rise; a shoreline retreat of around 50 metres is expected in Venezuela's sandy beaches until 2090 due to a 51.7 cm sea-level rise (Ministerio del Poder Popular para el Ambiente, 2011). There are some factors that are accelerating the process of coastal erosion in Venezuela and that must be addressed to diminish the effects of climate change in these areas, such as: 1) obstruction, deviation and elimination of sediment inputs to the beaches; 2) occupation of the dunes by constructions very close to the coast; and 3) loss of coral reefs, seagrass meadows, and mangrove areas.

The beaches' resources are severely affected by coastal erosion. Research to elaborate a detailed analysis on the potential impacts of the increase of the sea level in five Venezuelan coastal localities demonstrated that the estimated total loss of land in Playa El Agua (Isla de Margarita, Nueva Esparta State) for a scenario of sea-level rise of one metre would be 0.3 km^2 in 100 years; the shoreline retreat would be 29.5 metres in 100 years, which is equivalent to 0.3 m per year. Other evidence demonstrate that the coast in this location is retreating in-between 0.8 to 1.5 m per year. Similarly, in La Guardia inlet (Laguna de la Restinga National Park), the average shoreline retreat is estimated at about three metres per year (Ministerio del Poder Popular para el Ambiente, 2011). On Juangriego Bay (Margarita Island), the total estimated land loss for a scenario of one metre of sea-level-rise would be 0.9 km^2 in 100 years, representing a shoreline retreat of 13.6 m in 100 years, equivalent to 0.1 m per year.

An extreme example of coastal erosion is found at Punta Botón on Margarita Island, which has already disappeared by almost 80%. The Ministry of Tourism determined, in 2006, that Playa El Yaque is losing approximately two metres of coast per year and that, in 19 years, 2.5 hectares of surface have been lost. Another example is found in Los Totumos Beach, in the state of Miranda, in which the ongoing coastal erosion has generated a 111 m shoreline retreat in 36 years (1975–2011); on average, this situation consists of an annual retreat rate of 3.1 m which translates into the loss of about 14,114 m^2 of beach, affecting the development of recreational and commercial activities in the area (Ministerio del Poder Popular para el Ambiente, 2011). It is therefore considered necessary to design and implement programmes and informative/preventive campaigns against coastal erosion in Venezuela, since it has been demonstrated that this could cause relevant economic losses in coastal areas dedicated to tourism and leisure.

Adicora, Falcon State, Venezuela.
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10.2.3 Tropical storms and hurricanes

Historically, the effects of tropical storms (sustained winds between 63 and 118 km/h) and hurricanes (sustained winds over 118 km/h) have been reported in Venezuela. Due to its geographical location, Venezuela should not be directly affected by these kinds of atmospheric disturbances. However, occasionally, some of these turbulences may follow a path close to the Venezuelan coast and, in some cases their influence may affect part of the Venezuelan territory. The most prominent cases have been the passage of two hurricanes (1933 and 2004) and the passage of the storms Alma (1974), Joan (1988) and Bret (1993); the latter being the most damaging of all these events, with winds of 90-110 km/h and a trajectory that followed almost the entire coastal area of Venezuela, strongly affecting the eastern coasts, north-eastern islands, as well as the west of Venezuela (Figure 10.3). Its way through the central region of the Venezuelan territory, was felt in Caracas, as well as in other towns off the range of the Venezuelan coastal zone. Consequently, the rainfall reached historic levels and this, in turn, caused the death of 84 people, affected other 5,000 inhabitants and 860 homes, and destroyed 150 homes (Córdova and López Sánchez, 2015). The POGIZC indicates the threats, vulnerabilities and impacts due to social-natural risks; however, this plan does not specifically mention the subject of tropical storms and hurricanes, although it does consider flooding because of such storms (Gaceta Oficial No 39,095, 2009; Ministerio del Poder Popular para el Ambiente, 2014).

Following the experiences mentioned above, the INAMEH has designed an information section on its website, where it provides access to a set on weather warnings, wave forecasts, tropical storms, and monitoring of hurricanes and tropical disturbances (INAMEH, 2020). Similarly, the National Directorate of Civil Protection and Disaster Management, in its website, shares a document with recommendations and measures to be adopted when a storm is about to hit the area where we live (DNPCAD, 2020).

Figure 10.3 Trajectory of the tropical storm Bret.
© Ana Carolina Peralta based on Cordova and Lopez (2015) and NOAA (2012)

10.2.4 Floods and landslides

In many sectors of the Venezuelan coast, most of the popular constructions are done by self-management or in an informal way: without a project, without technical assistance and in a progressive way. Thus, population centres are created in areas sensitive to extraordinary events of rainfall and sediment drag (López Sanchez, 2012). Venezuela's river network is grouped into various basins, within which the main basins associated with the coastal-marine zone are the Maracaibo Lake Basin, the Caribbean Coastal Basin and the Orinoco River Basin. The prolonged and intense rainfall that occurs in the mountainous areas (Andes and Coastal Mountains) during the rainy season can produce landslides affecting the villages within the influence zone of the Maracaibo Lake and Caribbean Coastal Basins. The collapse of these large land masses can give rise to landslides or torrential avalanches.

The total area of floodable areas in Venezuela is of the order of 191,000 km^2 and is located mostly at the north of the Orinoco River (López Sanchez, 2012; Córdova and López Sánchez, 2015). In many Venezuelan rivers, especially those located in the Caribbean Coastal Basin and the Lake Maracaibo Basin, floods are the product of the sequential arrival of various storms, making the pattern of rainfall to vary in a complex manner, both in time and space (Córdova and López Sánchez, 2015). One of the most vulnerable areas to flooding is the city of Cumaná, Sucre State, which is located at the level of the Manzanares River discharge into the Gulf of Cariaco. Its tributary basin covers 1,100 km^2 with rainfall ranging from 500 mm per year in the lower part to 3,000 mm per year in the upper part. The average flow is 26 m^3 per second with minimum values of 1.5 m^3 per second (Córdova and López Sánchez, 2015). Extreme flood events have been recorded, with a maximum flow of 800 m^3 per second with a return period of 25 to 30 years (Córdova and López Sánchez, 2015). There have been no new records of extreme flooding in this area in the last ten years because now there is a channel that reduces floodable areas. However, it has been noticed that the river has been losing depth in its lower basin due to sustained accumulation of sediment, which has caused flooding on a smaller scale (Córdova and López Sánchez, 2015).

Extraordinary flood events of strong and persistent rains hit a large part of the Venezuelan territory; the last two extreme events that were registered in the coastal area were in 1999 and 2010. Landslides in the central and western coast (Caribbean Coastal Basin and Lake Maracaibo) affected thousands of people, caused the total loss of 1,012 houses, and placed 3,000 others at high risk in the areas of La Guaira and Catia La Mar (Caribbean Coastal Basin). Similarly, in the Maracaibo Lake Basin area, extreme flooding has caused losses in the agricultural and livestock sector, as well as damaged road infrastructure with total or partial traffic restrictions (Córdova and López Sánchez, 2015). The area between the Tocuyo, Aroa and Yaracuy rivers was one of the areas most affected by the climatic events of November 2010, especially the eastern coast of Falcón State, which lead to the declaration of State of Emergency in the territory of Falcón State (Decree No. 7,856, 2010). A similar situation occurred in the states of Zulia, Mérida, Trujillo and Nueva Esparta (Ministerio del Poder Popular para el Ambiente, 2011).

The sensitivity of the areas to flooding (caused by rain or rising sea-levels) and landslides also occurs as a consequence of: 1) the illegitimate or unplanned occupation of some coastal areas, as well as alluvial fans, especially those located on the northern slopes of the Coastal Range, in the central coastal region; 2) that the occurrence of landslides is an endemic geological phenomenon in the mountainous areas of the country (part of the Maracaibo Lake Basin and the Caribbean Coastal Basin in its central and eastern coastal section), located between 1,000 and 2,500 m in elevation; and 3) due to the loss of vegetation in the rainforests as a result of large forest fires (Córdova and López Sánchez, 2015; Hernandez, 2020).

Vargas, near Caracas, Venezuela.
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Regarding the capacity of the Venezuelan population to reduce vulnerability to the threats of floods and landslides, there were both scientific and technological instruments for the periodic monitoring and evaluation of the conditions and risks associated with intense rainfall, river and stream flooding. Unfortunately, over the years, human and technological resources have been lost to continue in this subject. Meteorological and hydrometric stations have been lost, although there are promises from the National Institute of Meteorology and Hydrology (INAMEH) that 335 new hydrometeorological stations will be installed in the country (INAMEH, 2019). INAMEH is an institute dependent on the Ministry of the People's Power for Internal Relations, Justice and Peace, and its objectives is to function as a centre for collecting hydrometeorological data and providing citizens with information about the weather (forecasts, waves or tropical storms), the climatology and hydrology of the country. Everything is accessible through its web portal, where anyone can consult and download documents, such as the monthly climate bulletin, which presents a summary of what has happened in the country in relation to rainfall and atmospheric temperature (INAMEH, 2020). There are also urban design risk studies that identify flooding zones, define flood hazard maps, and provide actions and recommendations (López S., 2005; Córdova and López Sánchez, 2015).

Based on the extreme events in Vargas and Sucre states (1999 and 2007), both cases have led to the declaration of two new Areas under the Special Administration Regime (ABRAE), under the category of Environmental Protection and Recovery Areas (APRA), called Northern Slope of Vargas State (Decree No. 1,062, 2000) and Coastal Axis Arapo – Santa Fe (Decree No. 5,633, 2007), respectively, to address these emergencies (Ministerio del Poder Popular para el Ambiente, 2011). On the other hand, recently the Laboratory of Geographic Information System and Environmental Modelling of the Simón Bolívar University, Venezuela (LSIGMA-USB) and the Research Centre for Integral Risk Management (CIGR), created a project in which a social web was developed for the visualization of natural threats, where the levels of flood risks in three cities of Venezuela are represented. This tool contributes to the strengthening of prevention measures, warning or contingency campaigns, in addition to recovering and strengthening technological tools (Gonzalez and López, 2020).

In relation to the measures or actions that allow for the reduction of vulnerability to these flood events, there is a classification of social-natural risks within the POGIZC, which includes the threats of landslides and floods. Linked to this, within the National Policies of Conservation and Sustainable Development of Coastal Areas, there is a technical staff (Working Committees of Coastal Areas – CTZC) that is responsible for reporting environmental problems to be addressed, within which is considered the risk of population centres due to the nonconforming occupation of coastal areas (Ministerio del Poder Popular para el Ambiente, 2010b). There is also the National Directorate of Civil Protection and Disaster Management, which makes available on its website information on the management of socio-natural and technological disasters as well as recommendations and best practices for flooding or landslide events (DNPCAD, 2020).

Ologa, Maracaibo Lake, Venezuela.
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10.2.5 Soil erosion

Extreme events of rain can cause an impact on the physical environment, being considered as an activator of erosion processes which can cause socio-economic damage. There are few documents that highlight the erosive effects of rain in Venezuela, however in the most recent article by Mendez *et al.* (2020), results are presented based on pluviometry information, spatial-temporal distribution of rainfall, frequency of extreme events analysis and indices of the rainfall erosive potential, as indicators of rain erosion in a basin of the Central Coast of Venezuela. The authors conclude that agricultural activity creates conditions for the activation of soil erosion processes in the face of the impact of rainfall, indicating a low to moderate erosion potential of rainfall. The occurrence of erosive processes in the studied area is related to the intensity of extraordinary precipitations as isolated punctual events (Méndez, Pacheco and Landaeta, 2020). Despite the lack of documented information, Venezuela's Plan for the Ordering and Integral Management of Coastal Zones recognizes areas that are vulnerable to socio-natural risks due to threats from unstable terrain, whether through erosion or landslides, considering them within the classification and assignment of uses and management of coastal units (Ministerio del Poder Popular para el Ambiente, 2014). The scopes of this information towards the community in general, as well as the campaigns or contingency plans are insufficient or null, being necessary to strengthen the application and coverage of education programs for sustainability.

10.2.6 Droughts

In Venezuela, there are periods of extreme drought due to the sustained decrease of rainfall. The degree of decrease in rainfall and the vulnerability of the local environment is what give rise to another type of drought, called hydrological drought (Córdova and López Sánchez, 2015). The effects of extreme droughts in Venezuela are poorly documented and have received little attention. The last extreme drought recorded period was during the dry season of May 2009 and April 2010, caused by poor rainfall and the consequent decrease in surface and subsurface runoff in the Caroní and Orinoco Rivers (Orinoco Delta Basin). This event is considered the most severe hydrological drought in the last 100 years (Córdova and López Sánchez, 2015). An example of the effects of hydrological droughts in Venezuela corresponds to the effect of the operation of the Guri reservoir in the lower Caroní, affecting the water supply of urban areas, agriculture, and electricity production at national level. Previous studies have shown that the El Niño and La Niña phenomena generate a significant decrease in total annual rainfall in the country. It has been demonstrated that there is a high coincidence between the occurrence of El Niño and droughts, and the occurrence of La Niña and floods (Córdova and López Sánchez, 2015).

Within the POGIZC, the vulnerabilities, socio-economic and environmental impacts associated with desertification are pointed out. However, this plan does not specifically mention the problem of droughts but considers land desertification as a variable to be considered for the classification of use and management of the coastal zone (Ministerio del Poder Popular para el Ambiente, 2014).

Considering the events and phenomena mentioned above, the INAMEH, has created an informative space in its website that provides to all the Venezuelan population with a set of warnings and bulletins, where the drought monitoring is presented an agrometeorological context (INAMEH, 2020). Similarly, the National Directorate of Civil Protection and Disaster Management, in its website, shares recommendations and measures to be adopted before, during and after a drought (DNPCAD, 2020).

Araya Peninsula in the east coast of Venezuela.
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10.2.7 Aeolian erosion

The Paraguaná Peninsula, located on the western coastal zone of the country, east of Falcón State and belonging to the Golfo Triste ecoregion, is characterized by an arid to hyper-arid climate with a marked annual water deficit, strong north-easterly winds and shallow soils with predominantly sandy textures. These conditions, together, create the right environment to trigger important soil losses due to the action of wind. Rivas and Mogollón (2018) indicated that the erosive power of wind increases from the north to the east and west along the region. The minimum aggressiveness index obtained (2.8) exceeds the maximum value (1.5) established by the Food and Agriculture Organization (FAO) by 86%, indicating a very high climatic aggressiveness in the Paraguaná Peninsula (FAO, 1980). This aggressiveness is explained by the high average annual evaporation rate that the study area presents, which on average is 600% higher than the annual rainfall rate, generating a marked water deficit throughout the year. The results of current and potential aeolian erosion indicates, for both cases, maximum values that exceed 5,000 t/ha per year of soil loss, with a spatial distribution that shows a marked influence of soil, topography and vegetation factors. In general, 77% of that peninsula presents a risk to desertification by current strong to severe erosion (100-2000 t/ha per year) (Rivas and Mogollón, 2018).

In response to the problems of soil erosion and desertification, Venezuela has been participating in the National Action Program for the Fight against Desertification and Drought Mitigation since 2004. In 2018, the Official Gazette No 41,418 decreed a resolution, creating on a permanent basis, the National Coordination Committee for the Fight against Desertification under the responsibility of the Ministry of the Popular Power for Eco-socialism and Water, with the purpose of advising and technically contributing to the policies and environmental management about soils, desertification and drought (Gaceta Oficial No 41.418, 2018).

10.2.8 Salinisation of surface and ground water

In a coastal aquifer, there is a natural balance between the fresh groundwater of the aquifer discharging into the sea and the saltwater of oceanic origin that tends to penetrate inland. Saline intrusion is therefore a dynamic process, where the saltwater front moves inland during periods of lower aquifer recharge and moves back to the sea when the recharge is higher. Such phenomenon has been identified in the Paraguaná Peninsula, located on the Venezuelan northern coast of the Falcón State. In a hydrogeochemical study of "El Taparo" aquifer groundwater, the spatial distribution of the concentrations of Ca^{+2} and Na^{+} was analysed; the values point to a probable process of contamination of the aquifer by saline intrusion, due to wells overexploitation. The evaluation of the "El Taparo" aquifer groundwater quality and the potential contribution of the wells were carried out in accordance with the national norms by Decree 883 (Gaceta Oficial No 36,395, 1998). As a result, only 5.6% of the samples taken fulfil the regulations for domestic and agricultural use (Perez Zafra, 2013). This study also concluded that the predominant processes in the zone are determined by the water-rock interaction, mineral dissolution and marine intrusion; however, the process that contributes to the greatest number of ions to the captured waters, corresponds to the saline intrusion (Perez Zafra, 2013). On the other hand, salinisation is also registered in wells of the central coastal region of Venezuela, more specifically in localities of Vargas and Miranda States (Osma and Chuspa). Also, in Los Roques, La Tortuga and Margarita islands, most of the water wells are salinized; there are desalination plants by inverse osmosis and freshwater is brought from the mainland. These evidence are the result of scientific research carried out by the Department of Earth Sciences of the Simón Bolívar University, in Caracas (Crisanto Silva, per. comm.).

The Venezuelan population, in general, does not know how to deal with or mitigate water salinisation. Campaigns to raise awareness and disseminate information about it are therefore very necessary. On the governance side, this hazard has received little attention up to now and there are no concrete management actions planned to deal particularly with it.

Isla de Margarita, Venezuela.
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10.2.9 Marine pollution and changes in seawater quality

On the Venezuelan coast there is a considerable port activity, both for tourism (marinas and yacht clubs), and for the exchange of goods and services, through international maritime transport (ports for cargo ships). It is also known that one of the main industrial activities developed in the coastal area of Venezuela is the exploitation and processing of hydrocarbons. Croquer, Bone and Bastidas (2016) evaluated the water and sediment pollution levels in the Paraguaná Peninsula, where the largest hydrocarbons refinery complex of the country operates since 1949. The spatial variability of the organic and inorganic compounds registered showed high pollution levels in that area. The sites closest to the refinery had higher concentrations of heavy metals and organic compounds, both in water and sediment, compared to the sites found farther away from the refinery (Croquer, Bone and Bastidas, 2016).

Studies on heavy metal concentrations along the Venezuelan coast have been reported for more than ten years. Garcia *et al.* (2011) demonstrated that seawater samples taken in the Morrocoy National Park (Falcón State) had average concentrations of Cd, Cu, Pb and Zn above the reference values proposed by NOAA, with the risk of producing chronic effects on marine biota (Garcia *et al.*, 2011). Sediment samples also showed Cd values above the minimum allowed value; the authors consider that the Morrocoy National Park is extremely contaminated, also pointing out a temporary increase in the concentration of these metals, associated with precipitation anomalies which could cause sediment chemistry disturbances, or an increase in the Cd contribution probably associated with fertilizer production in the region studied (García *et al.*, 2011). In the same region of the country, it was reported that the sediments surrounding the Paraguaná Refining Complex (Falcón State), had relatively high concentrations of total petroleum hydrocarbons (>10,000 ppm); heavy metals such as Cr, Ni and Zn; and the presence of polycyclic aromatic hydrocarbons (ΣPAHs > 1000 ppb) (Ramos, Bastidas and García, 2012). Similarly, there are higher concentrations of heavy metals (Ba, Hg, Cu, Ni, Cr, Cd, Zn, Pb and V) in the sediments present in places with greater anthropogenic activity, mainly in the central and eastern coast of Venezuela. The potential of biological risk was between 12% and 30% associated mainly with oil facilities (Ramos, pers. comm.).

The year 2020 was one of the worst years of environmental contamination for the national oil company (Petróleos de Venezuela, PDVSA). In nine months, important oil spills occurred, reaching national parks, coral reefs, agricultural fields and even population centres (Figueroa and Quinterol, 2020). The last reported spill occurred in Golfo Triste (Carabobo and Falcón states) in July 2020, with an approximate volume of 22,000 barrels of hydrocarbons spilled in the ocean. From satellite images observations, it was possible to detect that the spill patch covered approximately 350 km^2 of surface with a linear extension of more than 50 km (Klein, 2020). According to the NGO Provea, between 2010 and 2016, the PDVSA and its contractors and affiliates were responsible for 46,820 oil spills and other incidents that contaminated the environment, with a total of 856,723 barrels of oil spilled (Provea, 2018). Similarly, the NGO AEPA Falcón, has documented 237 oil spills in the last 12 years in the Cardón and Amuay refineries (El Pitazo, 2020).

Isla de Margarita, Venezuela.
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Another technological risk present on the Venezuelan coast is that coming from boats antifouling paints. Even though in 1999 the International Maritime Organization (IMO) adopted a resolution recommending the prohibition of new applications of Tributyltin (TBT) as a biocide in hull paints (IMO, 2009), Venezuela registers the presence of TBT in the sediment and tissue of certain organisms, even years after the abovementioned agreement (Miloslavich, Penchaszadeh and Bigatti, 2007; Peralta, Miloslavich and Bigatti, 2014).

Based on the evidence indicated above, the POGIZC points out the vulnerabilities and technological impacts in relation to threats from industrial facilities, threats from port facilities and threats associated with aquatic transportation; however, few actions have been taken on the problem of oil spills and the discharge of certain chemical compounds into the marine environment. The website of the National Directorate of Civil Protection and Disaster Management, under the Ministry of the People's Power for Internal Relations, Justice and Peace, provides access to a document with educational information about the oil spill and the risks involved (DNPCAD, 2020).

On the other hand, in 1981, PDVSA and its affiliates began the development of the National Contingency Plan for the Control and Conflict of Massive Oil Spills in Waters, known as the NCP, which entered in operation in mid-1984. This plan also involves complementary plans, which consist of agreements between Venezuela and neighbouring countries to establish mechanisms that allow the joint use of the resources of the countries involved in oil spills (Bilateral Contingency Plans) (Rojas, 1995). There is also an Automated System for the Prevention and Control of Spills (SAPCOD), which was created in 2015. Through this tool, it is possible to establish predictive, preventive and corrective actions in this area and effectively control the management of the units responsible for attending oil spills (PDVSA, 2015).

It is worth mentioning that despite the organizational structure, plans and policies created to address these risks, there is a lack of immediate action in the face of the events that occur, leaving citizens, goods, services, and ecosystems vulnerable. This is evident when citizens state in a report that they are concerned about the situation of reefs, corals and mangroves, as well as marine fauna exposed to an oil spill: "We have not been called to act, nor have experts been called to study the environmental impacts". This is an example of the population's complaints about the lack of information from the National Institute of Aquatic Spaces (INEA) and the Ministry of Eco-socialism and Water (MINEA) (Gutiérrez Torres, 2017).

Oil and gas installations in Venezuela.

10.2.10 Changes in the distribution and abundance of coastal and marine species

Venezuela is among the top ten countries with the greatest biodiversity in the world, both in the terrestrial and marine environments. However, due to the enormous impact of human activities such as tourism, overexploitation of marine resources, physical alteration, oil industry, and pollution, among others, the environments are at great risk and their biodiversity is highly threatened (Miloslavich *et al.*, 2003).

Such is the case of corals, which are very well represented throughout the coastal zone of Venezuela, including the islands, but have been affected by various factors, both anthropogenic and natural, demonstrating the loss of living cover. Villamizar *et al.* (2014) have reported cases of coverage loss and changes in the stony corals' richness. Coral reefs in Venezuela are also threatened by other factors such as disease and bio-erosion and, in some areas; very deteriorated coral reefs are reported, with a low abundance of live coral and low diversity of coral species (Del Mónaco *et al.*, 2010). There is an important deterioration in Los Roques National Park reefs, because of the mortality of very large colonies of *Orbicella annularis*, *Colpophyllia natans* and extensive beds of *Madracis auretenra* (Villamizar *et al.*, 2014). On the other hand, the climate change-fuelled sea-level rise and seawater warming produces coral bleaching. This was demonstrated by a group of investigators of the Centre of Ecotoxicological Studies in Marine Systems of Simón Bolívar University, who indicated a sustained increase of the water temperature, from June until October 2010, producing the bleaching of corals located in the north and south of Los Roques National Park. It is also expected that the biological diversity and coastal ecosystems throughout the country will be negatively affected (Ministerio del Poder Popular para el Ambiente, 2011). Moreover, tourism activity has caused great damage to marine biodiversity, resulting in the mass mortality of corals, seagrasses, fishes, and invertebrates. Such evidence was documented by the Morrocoy Agenda Program, which was a three-year project (2000-2003), whose main objective was to evaluate the degree of alteration, disturbance and pollution in Morrocoy National Park (Bone and Spinello, 2000; Villamizar, 2000).

Another worrying aspect in relation to the change in distribution and abundance of marine organisms is due to the presence of invasive species. As a result of a bibliographic analysis, it was estimated that in Venezuela there are reports of around 70 species of non-native marine fauna, mostly from the Pacific and Indo-Pacific, and a few from the western Atlantic (Peralta *et al.,* pers. obs.). The most prominent case in these times is that of the lionfish, *Pterois volitians*, which has been distributed along the central-western, eastern and insular coasts of the country. The potential risks of the presence of this fish on the coast of Venezuela are centred on the abundance reduction of native fish, as has been demonstrated by Ballew *et al.* (2016) for other regions of the Caribbean. Another negative effect of the presence of invasive species in Venezuela has been the farming processes damage, due to the invasion of Mytilidae Bivalves in shrimp ponds (Lodeiros and Torres, 2018). Although Venezuela lacks reports in terms of economic disadvantages, because of the presence of invasive species, there are potential species such as *Tubastrea coccinea* (Cnidaria) and *Eualetes tulipa* (Gastropod) that could cause potential problems for industries, due to pipes collapse, metallic substrates collapse, among others.

The issue of biodiversity loss and changes in the distribution of organisms has been addressed in certain campaigns promoted by various national NGOs such as PROVITA, Venezuelan Society of Ecology, FUNDATUN, FUDENA, and international NGOs such as NANO-POGO. The latter has funding programs, for ocean education and ocean literacy campaigns. During 2017-2018 NANO-POGO supported a campaign to inform and educate about the Lionfish in Venezuela (Peralta, 2018).

It is also worth mentioning that as a strategy to reduce the vulnerability of the ecosystems to technological threats, in 2005 PDVSA took the initiative to prepare the study "Priorities of PDVSA in the Conservation of the Biodiversity in the Caribbean Region of Venezuela", with the purpose of providing the company with an environmental planning tool that resolves the requirements for the occupation of the maritime and coastal territory by the production units, with the conservation of biological diversity (Klein, 2008). On the other hand, Venezuela created the National Strategy for the Conservation of Biological Diversity and its Action Plan 2010-2020 (ENCDB), where 7 strategic lines are listed to achieve the conservation of Biological Diversity, considering the diagnosis and analysis of the Biological Diversity threats. Among these 7 lines, the Conservation of Threatened Species and the Prevention, Control and Eradication of exotic species are considered, among others (Ministerio del Poder Popular para el Ambiente, 2010).

10.2.11 Livelihood challenges, urban expansion and coastal development

From a demographic point of view, the Venezuelan population has been migrating towards the central coastal region since the oil industry began to dominate the country's economy. This geo-economic dynamic in the Venezuelan history, is the reason why today that region is the one that capitalizes the greatest demographic and economic concentration. In the POGIZC, several factors or variables are contemplated, like the projection of the number of inhabitants by 2030 for each Coastal Unit, the General Guidelines of the National Economic and Social Development Plan (Structural Works), the expansion and construction of infrastructure for the exploration, exploitation and processing of hydrocarbons, as well as other uses assignments proposed by the Coastal Units management. Also, the Nation Plan 2019-2025, contemplates, within its central axes, the National Territorial System, which includes a system of plans for the infrastructure development, services and mobility (Ministerio del Poder Popular para la Planificación, 2019).

Currently, the challenges in Venezuela are enormous; the opportunities for livelihood and development are limited due to political issues, which are reflected in the malfunctioning of goods and services throughout the territory. Under this scenario, it will be difficult to execute the plans already established, which at this moment are idealistic. However, there is a great potential for development and production in the agricultural, fishing and energy sectors in the entire coastal area of the country, and this is contemplated in the POGIZC.

Guanta Bay and port with a section of Mochima National Park behind, Venezuela.
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10.3 Coastal hazards management in Venezuela

10.3.1 Governance

In Venezuela, within the policies for coastal zone management, the Law of Coastal Areas of 2001 establishes that the conservation and sustainable use of this space will include the management of coastal areas, the protection of geomorphological processes that allow the formation, regeneration and balance of coastal areas, the determination of the use and load capacities of coastal areas, the management of watersheds that drain into coastal areas, the recovery and reorganization of spaces occupied by certain activities and the non-conforming uses.

In this sense, the Constitution of the Bolivarian Republic of Venezuela establishes, among others, the following mandates: 1) that the marine coasts are public property; 2) that the State must guarantee that the population develops in an environment free of pollution, where the air, water, soil, coasts, climate, ozone layer, and living species are specially protected; 3) that the State will develop a policy of territorial planning that takes into account the ecological, geographical, population, social, cultural, economic, and political realities, in accordance with the principles of sustainable development; 4) that the security of the Nation is based on the co-responsibility between the State and civil society; the principle of co-responsibility is exercised in the economic, social, political, cultural, geographic, environmental, and military spheres; therefore, in accordance with the principles of sustainable development, the formal expression of these facts and activities in the territory must be ordered according to realities, not only economic, but also ecological, financial, socio-cultural, and political, in order to conform a policy adjusted to the new development scheme.

Under these premises, the POGIZC was created between 2013 and 2014 in agreement with the:

- Constitution of the Bolivarian Republic of Venezuela
- Organic Law of the Environment
- Organic Law of Public Administration
- Organic Law for Territorial Planning
- Organic Law of Urban Planning
- Organic Law of Tourism
- Decree with the Range, Value and Force of Organic Law of Aquatic Spaces
- Organic Law of National Security
- Environmental Criminal Law
- Soil and Water Forestry Law
- Coastal Zone Law

In 2001, the Decree with Force of Law on Coastal Areas was published (Gaceta Oficial No 37,349, 2001), creating the Technical Directorate for Coastal Areas (DTZC) under the responsibilities of the Ministry of the People's Power for the Environment (MINAMB), which is the public body with competence to define the guidelines for the planning and integral management of coastal areas. The DTZC identified documented and prioritized environmental problems, as well as the management critical factors affecting performance and risk. It also designed management indicators and the respective programmes for each of the Venezuelan coastal states, including the islands (Ministerio del Poder Popular para el Ambiente, 2013).

The POGIZC forms a modern technical instrument focused on the conservation, regulation and protection of spaces and resources through the design of actions that ensure adequate management and integrated coastal management, with the participation of public agencies and entities, organised communities, as well as private institutions, in order to reconcile the needs of all stakeholders in the economic and environmental development of the country (Ministerio del Poder Popular para el Ambiente, 2014). The guidelines and directives of the integrated coastal zone management are directed to the different uses and activities that are developed in each coastal areas, as well as other specific aspects, such as natural hazards. Within the guidelines, there are plans with appropriate actions to mitigate the effects of various natural phenomena that impact the Venezuela coast (Ministerio del Poder Popular para el Ambiente, 2010b).

In turn, the National Policies of Conservation and Sustainable Development rules the POGIZC, in which Article 8 addresses the "reduction of the population's vulnerability to social, natural and technological threats in the coastal areas", in accordance with Article 5 of the Law for the Integral Management of Social, Natural and Technological Risks (Gaceta Oficial No 39,095, 2009; Ministerio del Poder Popular para el Ambiente, 2014). Socio-natural risks appeared defined as the potential hazard associated with the probable occurrence of physical phenomena whose existence, intensity or recurrence is related to environmental degradation processes or human intervention in natural ecosystems. Technological risks are defined in the same guiding documents as the potential hazard generated by human activity related to the access or use of technology, perceived as events controllable by man or that are the result of his activity. Vulnerable areas to threats are defined as the probability that a certain phenomenon will occur at certain intensity, in a specific site (Ministerio del Poder Popular para el Ambiente, 2014). The Ministry of the People's Power for Internal Relations, Justice and Peace, within the Vice-Ministry for Risk Management and Civil Protection and under the National Directorate of Civil Protection and Disaster Management, oversees risk analysis and the action plan. It oversees developing, strengthening and consolidating the processes of risk management through the planning and execution of measures and actions aimed at reducing risk conditions through prevention (DNPCAD, 2020).

Continuing in the context of coastal risk assessment and future perspectives, in 2011, the Ministry of the People's Power for the Environment prepared a document entitled "Implications of Climate Change in the Coastal Areas and Aquatic Space of Venezuela" (Ministerio del Poder Popular para el Ambiente, 2011). This document was created as a tool to evaluate and assess what the consequences of climate change may be, and how these may impact the Venezuelan coastal system, its natural resources, ecosystems, productive sectors and communities, to enable decision makers to adopt measures and develop effective policies on climate change. The document outlines the implications of climate change in Venezuela, in terms of evidence and projections of average sea levels, the effects of erosion on sandy beaches, rising sea temperatures, sea acidity, marine hypoxia, currents, hurricanes and storms, rainfall and flooding, biological diversity, water resources, fisheries and aquaculture, maritime works, industrial activity, energy generation and use, and tourism. This document states that it is necessary to establish a national strategy for adaptation to climate change, and that the actions to be taken must be defined and implemented at the regional or local level, since vulnerability and associated impacts are specific to each place. The elaboration of the National Climate Change Adaptation Plan will constitute a medium or long-term strategy, used as a framework for the coordination between public entities for the evaluation of impacts, vulnerability and adaptation to climate change in Venezuela (Ministerio del Poder Popular para el Ambiente, 2011).

Government building in Caracas, Venezuela.

Regarding the management of risks associated with the conservation of biological diversity, in 2008 the Law of Biological Diversity Management was decreed, contemplating continental, insular, lacustrine and fluvial spaces, territorial sea, interior maritime areas and the soil, subsoil and air spaces (Gaceta Oficial No 39,070, 2008). This law, together with the Law on Socio-natural and Technological Risks Management and the POGIZC, are the ones that guide the management of the current risks and future perspectives, with proposals and plans to mitigate the effects of the socio-natural and technological threats previously identified for the coastal areas of Venezuela.

10.3.2 Academia

In Venezuela, there are professionals related to marine sciences, dedicated to study the impacts and the sensitivity of certain spaces or marine ecosystems in the presence of socio-natural and/or technological threats. Among them, there are representatives of national universities and research institutes, starting from the easternmost side of the country, with the Universidad de Oriente and its Oceanographic Institute of Venezuela, where scientific research has been developed for decades, reporting the ocean and marine ecosystems vulnerability to different pollutants (ecotoxicology), the biological diversity monitoring of the eastern region and its relationship with anthropogenic activities (marine biology and oceanography) and the strongest topic of this institution is the fisheries resources monitoring and evaluation (www.udo.edu.ve).

In the central region of the country, representatives of the Simon Bolivar University, with the Institute of Technology and Marine Sciences, the Department of Environmental Studies, the Department of Biology of Organisms and the Department of Earth Sciences, have been generating for decades databases associated with cartographic products, as tools for the mitigation and prevention of risks associated with oceanographic and biological environments of our coastal areas, as well as the geographic sectoring of vulnerable areas; they also carry out studies of the impacts generated by natural and anthropogenic phenomena on the different marine ecosystems (www.usb.ve).

Also in the central region, the University of Carabobo, with its Experimental Faculty of Science and Technology, within which the Department of Biology functions; where professionals of the marine sciences generate knowledge, since a few decades, about the potential impacts of anthropogenic activities on our coasts and islands (www.uc.edu.ve/facul_facyt.php). Finally, in the westernmost region of the country, the Institute for the Control and Conservation of the Lake Maracaibo Basin (ICLAM) carries outstudies on the sustainable and rational management of the natural resources of the basin (www.iclam.gob.ve/iclam_web/wordpress/la-institucion/).

10.3.3 Civil society

Regarding the conservation of biological diversity management, it was mentioned before the lack of risk management, specifically for threats to marine biodiversity in coastal ecosystems. In this context, INCOSTAS S. A. and its scientist's team from the Department of the Environment prepared an Environmental Management Plan specifically for Morrocoy National Park, addressing mainly the effects of environmental impacts because of liquid effluents, solid waste, and atmospheric emissions on coral reefs. A procedure was developed that consists in identifying environmental aspects and contrasting them with a series of independent criteria (legal limits, environmental sensitivity, risks). The method was applied to evaluate the impacts (reef degradation) and their causes (environmental aspects), proposing an Environmental Management Plan that minimizes these environmental aspects and consequently mitigates the continuous impacts on the reef (Latchinian *et al.*, 2017).

On the other hand, the Venezuelan Society of Ecology was, in 2020, very committed with the oil spill events occurring on the coast of Venezuela; reason why they have organized support groups for divulgation of and research on the events and their potential effects to the marine ecosystems. In 2020, the team gathered data and produced reports about the occurrences, magnitude and threats that these events generated on the national marine and coastal heritage. These reports and news are available through the Association's website: www.svecologia.org (Sociedad Venezolana de Ecología, 2020).

10.3.4 Private sector

With respect to the management carried out by the maritime sectors, regarding the management of coastal risks, it is worth mentioning that marinas, ports and all navigation activities are governed by the statutes of the National Institute of Aquatic Spaces (INEA), in accordance with articles 5, 73 and 74 of the Organic Law of Aquatic Spaces, taking into account the Aquatic Policies of the State, the preservation of the marine environment against the risks and damages of contamination (Asociación Venezolana de Derecho Marítimo, 2020). On the other hand, the Law of Marinas and Related Activities, indicates as attribution of the Port Captains, in its article 13, numeral 14: "To know, investigate and administratively instruct the aquatic accidents and forced arrival, in coordination with the Board of Investigation of Accidents". Title VI of the law also contemplates the sanctioning system in contamination events such as the one currently affecting the Golfo Triste with the continuous oil spills (Asociación Venezolana de Derecho Marítimo, 2020).

Puerto La Cruz, Venezuela.
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10.4 Adaptation measures and their effects

10.4.1 Ongoing actions

Most of the adaptation measures to the risks and threats mentioned in previous sections within this document have yet to be developed. There is a great Integrated Management Plan, founded by many laws and decrees; the legal framework is quite broad, but action plans need to be materialized. Many of the diagnosed risks and their future implications, as well as the consequent action plans are still in the analysis phase. Proposals, plans and projects that could mitigate the effects of a risk event have been written, but their implementation has only been applied to deal with certain threats, such as oil spills, floods and torrential landslides (PDVSA, 2015; DNPCAD, 2020).

Another plan in the execution phase is the National Plan for Adaptation to Climate Change, which is based on the scenarios proposed for 2030 and 2050, as a result of studies completed by the Technical Unit for Coastal Areas, which is attached to the General Directorate for Ecosystem Management and Conservation Policies, and within which the following is expected: (1) ensure that the State is aware of the vulnerability to climate change, (2) incorporate the various measures or actions for adaptation into the policies and planning mechanisms, and (3) ensure that the population is aware of climate change risks; all without compromising the principles of sustainable development (Ministerio del Poder Popular para el Ambiente, 2011). Also, within the National Policies for the Conservation and Sustainable Development of Venezuela's Coastal Areas, there are proposals to reduce the vulnerability of the population to natural or socio-natural phenomena in coastal areas and to strengthen environmental education and community participation (Ministerio del Poder Popular para el Ambiente, 2011).

Other action plans to be implemented are those mentioned in the National Strategy for the Biological Diversity Conservation 2010-2020 and its National Action Plan. To this end, a National Action Plan is being drawn up collectively, in which actions are specified at the country level and eight Bioregional Action Plans, including the Marine, Coastal and Island Bioregions. As a result of the analysis of the participatory diagnosis of the Biological Diversity threats, seven Strategic Lines are established necessary to achieve the conservation of Biological Diversity: (1) biological diversity information management, (2) conservation of threatened species, (3) strategic areas for conservation, (4) sustainable use of biological diversity, (5) prevention, control and eradication of exotic species, (6) control and supervision of genetically modified organisms, and (7) Prevention and management of illegal trafficking or species trading (Gaceta Oficial No 39,070, 2008; Ministerio del Poder Popular para el Ambiente, 2010).

10.4.2 Completed actions

With respect to the strategic guidelines for the prevention of natural and anthropogenic disasters, in June 2005, Venezuela passed a Law on the Humanitarian Task Force under which a multidisciplinary and multisectoral operational unit was formed under the Ministry of Interior and Justice, through the National Directorate of Civil Protection and Disaster Management. The purpose of the "Simón Bolívar" Humanitarian Task Force is to coordinate and execute operations for the prevention and attention of natural and anthropogenic disasters (Gaceta Oficial No 38,201, 2005). In the same context, in 2017, the Ministry of the People's Power for Internal Relations, Justice and Peace (MPPRIJP), created the Strategic Regions for Damage Evaluation and Needs Analysis (REDAN). These new agencies, in which the National Directorate of Civil Protection and Disaster Administration participates, together with the Fire Department, are responsible for monitoring environmental threats that could affect the Venezuelan territory (Gaceta Oficial No 41,113, 2017). Under these measures, whenever there is an event of risk to nature or to a community, the National Directorate of Civil Protection and Disaster Administration is the first to attend to the emergencies, report and diagnose those events (DNPCAD, 2020).

Based on the threats and risks discussed in the previous sections, the cases of extreme events of rainfall and landslides that occurred in the states of Vargas and Sucre (1999 and 2007) have led in both cases to the declaration of two new Areas Under Special Administration Regime (ABRAE), under the category of Environmental Protection and Recovery Areas (APRA). This category is composed by all those areas where environmental problems caused or induced by the action of man or by natural causes, require a management plan that establishes a recovery treatment or eliminates the degradation phenomena. Thus, Venezuela has two areas called Vertiente Norte del Estado Vargas (Decree No 1,062, 2000) and Eje Costero Arapo – Santa Fé (Decree No 5,633, 2007) (Ministerio del Poder Popular para el Ambiente, 2011; Ministerio del Poder Popular para el Ecosocialismo, Hábitat y Vivienda, 2014). Under the effects of these risk events, the political and legal declarations and the instruments in the subject of planning and development, these areas were incorporated into the Planning and Regulation of Use, sectorising and urbanising the spaces according to the levels of risk due to flooding and landslides (Ministerio del Poder Popular para el Ambiente, 2014). On the other hand, the main institutional responses to this situation, within the framework of the current legal system, have been oriented towards the formulation of policies and implementation of actions intended to achieve sustainable development. This is expected to occur through the gradual rehabilitation of the affected areas, the materialization of risk minimization mechanisms, considering similar events and those derived from other types of natural hazards, as well as the significant improvement of environmental and urban conditions (Jiménez Carrasco, 2012).

Regarding technological threats, specifically those coming from oil activities, PDVSA, through the Corporate Management of Environment and Occupational Hygiene, sets different technical norms on environmental regulation, which presents innovative elements such as the guidelines to elaborate environmental and socio-cultural studies in the regions where oil activities are developed, to ensure the minimum impact to the communities and the environment. PDVSA, through its Environmental Department, provides environmental management indicators carried out by the company and certified by external auditors (PDVSA, 2020). On the other hand, the Executive Directorate for the Environment completed the implementation of the Automated System for Spill Prevention and Control (SAPCOD) in all PDVSA organizations nationwide and in the Curazao Island refinery. Through the SAPCOD, predictive, preventive and corrective actions are established. The management of the units responsible for attending oil spills in PDVSA are also effectively controlled. Up to now, a total of 526 km of production lines have been incorporated into the system, corresponding to the 18 main oil pipelines of the Eastern Region, which aims to minimize the environmental impact that could be generated by the spills that occur in such facilities (PDVSA, 2015).

10.4.3 Planned actions

Identification of actions to reduce coastal vulnerability

In Venezuela, the POGIZC has established a long-term planning horizon, covering 20 years, that is, until 2030. The actions proposed at the national, state and local levels will be carried out in the medium- and short-term to obtain long-term results, considering and integrating the legal frameworks that governs the different uses of the spaces and activities (Ministerio del Poder Popular para el Ambiente, 2014). In this sense, ten Programs of Integrated Management of Coastal Areas have been designed, which contain activities, deadlines and key actors for the implementation and adaptation of the programs (Table 10.1).

Table 10.1 Integrated Management Programs to reduce coastal risks. Short-term corresponds to an execution period of up to three years. Medium-term corresponds to an execution period of three to five years. Long-term corresponds to an execution period of five to ten years. Permanent corresponds to those programs that will be executed constantly within the twenty-year planning horizon.

Program	Subprogram	Activities
1. Diagnosis and Monitoring of Ecosystems, Natural and Socio-cultural Resources	1.1 Diagnosis of Ecosystems, Natural and Socio-cultural Resources	a. Assess the physical-chemical and biological-ecological components in coastal areas
		b. Incorporate groundwater quality and quantity data in the planning and integrated management of coastal areas processes
		c. Inventory and diagnose the sewage networks of population centres located in coastal areas
		d. Identify areas subject to eutrophication processes in coastal areas
		e. Identify the environmental problems that affect the migration processes of the socio-economic sectors in coastal areas
		f. Analyse climatic and hydrodynamic variables in coastal areas
		g. Carry out studies of urban axes growth and their areas of expansion
	1.2 Monitoring of Ecosystems and Natural Resources	a. Monitor the fauna and flora in coastal areas
		b. Monitor species that have some category of protection
		c. Monitor coastline and sedimentary dynamics in coastal areas
		d. Monitor identified areas in coastal areas subject to eutrophication processes
		e. Monitor invasive alien species within coastal areas
	1.3 Monitoring of Socio-Cultural Resources	a. Develop a geo-referenced database of activities capable of degrading the environment and affecting coastal areas
		b. Monitor identified areas in coastal areas, subject to soil and water salinisation processes
		c. Monitor the quality of drinking water and wastewater in coastal areas
		d. Monitor the quality of the beaches used as recreational spaces
		e. Monitor air quality in major cities located in coastal areas
		f. Monitor environmental problems that affect morbidity and mortality rates in coastal areas
		g. Monitor environmental problems that affect the migration processes of the socio-economic sectors in coastal areas
2. Conservation of Natural and Cultural Spaces	2.1 Areas under Special Administration Regime in Coastal Areas	a. Promote the development or updating of Management Plans and Regulations for the Use of Areas under Special Administration Regime located in coastal areas
		b. Adequate management plans and regulations for the use of Areas Under Special Administration to adjust them to the management plans and integrated management of coastal areas
		c. Include spaces destined to the conservation of hydrobiological resources, protection of biodiversity and underwater archaeological heritage into the System of Areas Under Special Administration Regime
		d. Encourage financing mechanisms aimed at consolidating the System of Areas Under Special Administration Regime in coastal areas
	2.2 Other Spaces for Conservation	a. Promote the protection and integral management of water, as an indispensable element for life, human welfare and the sustainable development of the country

Program	Subprogram	Activities
		b. Develop strategies to increase the number of wetlands listed under the Ramsar Convention
		c. Strengthen the processes of conservation, protection and sustainable use of mangroves as key ecosystems and traditional use within coastal areas, as well as indispensable elements for the process of adaptability to climate change
		d. Design strategies aimed at the conservation and recovery of coral reefs
		e. Participate in the elaboration and implementation of the Conservation Plans of the Cultural Heritage present in the coastal areas
		f. Promote the processes of management and administration of the Open Field Recreational Parks located within the coastal areas
	2.3 Indigenous Lands	a. Encourage the permanence of indigenous peoples and communities according to their traditional pattern of territorial occupation
		b. Promote the incorporation and participation of indigenous communities in economic activities, conservation and preservation to be developed within coastal areas, based on their traditional knowledge
		c. Promote the processes of demarcation and communal planning of lands considered as collective property of the various indigenous communities settled in coastal areas
3. Public Domain Spaces	3.1 Delimitation and Demarcation of Public Domain Areas	a. Elaborate a Methodological Proposal directed to the delimitation of the areas of public domain
		b. Delimit and demarcate the areas of public domain present in the land space of coastal areas
		c. Identify key areas to conserve (particularly protection) within the public domain areas of each State
	3.2 Sanitation of Public Domain Areas	a. Identify the structures located within the public domain areas and analyse the feasibility of relocation
		b. Recover public domain areas through the execution of engineering, planning and sanitation projects
		c. Develop the Special Plan for the Public Domain of Coastal Areas that includes the guidelines and directives aimed at the sustainable use of this space to regulate activities according to the current legal framework and its environmental characteristics
	3.3. Sustainable Management of Sandy Beaches	a. Design the National Strategy for Sustainable Management and Recovery of the Beach Resource
		b. Establish the methodology to be used for the character station of the sandy beaches of Venezuela
		c. Carry out the inventory and characterisation of the sandy beaches of Venezuela
		d. Promote, together with regional and local governments, the development and implementation of legal instruments related to the protection and management of beaches
4. Sustainable Management of Natural and Socio-cultural Resources	4.1 Management of Agricultural Resources	a. Enhance and promote sustainable agricultural systems, according to the categories of agricultural preservation
		b. Delimit the agricultural areas that present characteristics of degradation or loss of fertility
		c. Identify degraded agricultural areas that require reforestation processes
		d. Identify areas of common interest between agricultural and tourism – recreational use

Program	Subprogram	Activities
	4.2 Management of Fishery and Aquaculture Resources	a. Identify and manage the areas destined for fishing and aquaculture use, both continental and marine
		b. Make fishing and aquaculture uses compatible with the rest of the current and proposed activities in coastal areas
		c. Locate the facilities and spaces destined to the nautical activities, the marine transport and the routes of circulation of boats that can affect the fishing and aquatic uses
		d. Strengthen and adapt fishing settlements and support infrastructure for fishing and aquaculture uses according to the principles of responsible fishing activity
		e. Carry out detailed studies of the aquaculture species to be cultivated, including the determination of areas where favourable habitat conditions appear
		f. Identify ways of financing that allow to have in the short-term, the necessary technical infrastructure for the development of the aquaculture activity (continental or marine)
	4.3 Sustainable Tourism	a. Identify existing and planned infrastructure to support tourism and recreational activities
		b. Reconcile criteria and interests with organisms, entities and social organic stations for the development of tourist and recreational activities in a sustainable way
		c. Require studies of the carrying capacity of ecosystems, human settlements or other economic activities, to support the location of facilities associated with tourism use
		d. Formulate projects aimed at the environmental adaptation of equipment and tourist and recreational infrastructure in coastal areas
	4.4 Mining and Energy Resources and Other Key Activities	a. Identify and delimit current and potential areas for the location of infrastructure to support uses and activities: non-metallic mining, mining – energy, industrial, port and water traffic
		b. Include in the regulation the areas destined to the non-metallic mining or mining – energy development to minimise the social and environmental conflicts
		c. Formulate, review and update the National Development Plan for the Aquatic Sector, the National Contingency Plan against Hydrocarbon Spills, the National Port Development Plan and other plans intended and linked to coastal areas
		d. Consolidate the Beaconing System for navigation routes, anchorage zones, and recreational areas
5. Infrastructure, Equipment and Sustainable Urban Spaces	5.1 Infrastructure and Equipment	a. Identify, through regional and local governments, the projects required in terms of equipment, treatment systems, improvement of sanitary facilities, control of final disposal of solid waste and sewage and other specific services and networks
		b. Reconcile the National Plans of Structural Works with the diagnoses made within the states through which the service corridors will pass, with the arguments, advantages and disadvantages in each case
		c. Define areas where it is feasible to install sanitation systems that incorporate efficient or low-impact technologies that allow for the reuse, disposal and final management of waste and residues
		d. Delimit areas whose load capacity allows the location of infrastructure for the management of solid waste and sewage

Program	Subprogram	Activities
	5.2 Sustainable Urban Development	a. Execute works of recovery or redesign of degraded public spaces, for their sanitation or preservation, especially those located in the public domain
		b. Increase the areas of natural and cultural conservation within the population centres
		c. Promote the updating or elaboration of urban planning instruments in their different hierarchies
		d. Promote the review of the expansion areas of the main cities located within the coastal areas
6. Research and Documentation	6.1 Scientific and Applied Research	a. Guide environmental research to meet the demands of the following research areas: • Global Climate Change, Desertification and Drought, Habitat Modification and Marine Sedimentation and Socio-Natural Risk Prevention • Biological Diversity • Environmental Quality • Technologies for Conservation and Sustainable Development • Environmental Planning and Land Management • Alternative Sustainable Strategies • Human Systems in Relation to Sustainable Development and Conservation • Environmental Education and Community Participation
		b. Determine and evaluate the potential of complementary natural energy sources (wind, solar, marine, among others)
		c. Evaluate the impact of human activities on the karst spaces present in coastal areas
		d. Identify areas in coastal areas, subject to soil and water salinisation processes
		e. Design methodologies and procedures for the economic valuation of natural resources present in coastal areas
		f. Expand and improve the Hydrometeorological Network linked to coastal areas
		g. Strengthen the Oceanographic Monitoring System
		h. Identify hydrobiological resources and evaluate their degree of conservation to establish strategies for their sustainable use or recovery
		i. Determine the seasonal variation of the coastal zone plankton mass as a climate change mitigation tool and key element for the sustainability of hydrobiological resources
		j. Assess desertification processes in coastal areas
		k. Carry out the detailed cartographic survey of the coasts of Venezuela and the Federal Dependencies
	6.2 Documentation of Knowledge	a. Have a database with the information generated in the universities, institutions and organic stations, linked to the coastal areas
		b. Promote the creation of a centre to produce knowledge in research and development in coastal areas with a view to strengthening the Research and Documentation Program, through the Information System for Integrated Coastal Zone Management (SIGIZC)
7. Vulnerable Zones	7.1 Areas Vulnerable to Socio-natural and Technological Threats	a. Determine risk levels for various types of adverse events
		b. Develop micro-zoning maps of vulnerability in coastal areas
		c. Establish regulations and practice manuals that guarantee the conservation of spaces with slopes greater than 43%.
		d. Assess the vulnerability of basic infrastructure (schools, hospitals, roads) located in coastal areas
		e. Require the updating and delivery of Contingency Plans to those responsible for all industries within the coastal zone

Program	Subprogram	Activities
		f. Establish protection measures and Emergency and Contingency Plans for possible spills (persistent and non-persistent hydrocarbons), or disaster situations associated with service corridors
		g. Elaborate a Georeferenced Database with the possible areas to be affected by technological events and the spaces to be used for the contingency
		h. Involve the communities present in vulnerable areas in the Contingency Plans, preparatory exercises and drills
		i. Formulate specific plans and programs aimed at reducing vulnerability in coastal areas
		j. Establish strategies to execute the relocation of structures located in vulnerable areas within coastal zones
	7.2 Adaptation to Climate Change in Coastal Areas	a. Assess areas that are threatened and vulnerable to sea-levels rising
		b. Identify and quantify, within coastal areas, the potential damage to be generated in threatened areas vulnerable to the implications of climate change
		c. Design and implement Climate Change Adaptation Strategies for Coastal Areas
8. Recovery and Sanitation of Coastal Areas	8.1 Recovery of Coastal Environments	a. Elaborate specific studies in altered or degraded coastal locations, to execute engineering projects linked to the recovery or protection of these locations
		b. Establish and implement projects of Integrated Management of Waste and Solid Wastes within coastal areas
		c. Identify sources of financing for the implementation of technology and the execution of projects required for the recovery and sanitation of coastal areas
	8.2 Artificial Reefs and Naval Scrap Removal	a. Inventory the elements considered as naval scrap
		b. Design a project aimed at the proper handling of naval scrap
		c. Select the areas for the adequate final disposal of the ship's scrap
		d. Designing projects for the creation of biomass generation devices and for the protection of the coastline, with the use of naval scrap as a base element
9. Environmental Education, Citizen Participation and Training	9.1 Environmental Education	a. Encourage individual initiatives and the participation of civil society organic stations, regional and local governments, in the process of environmental education and management
		b. Institutional se the process of teaching and learning about the environment and coastal areas at the different levels of the educational system
		c. Coordinate actions with the Ministry of the People's Power with competence around University Education to increase the offer of technical and scientific careers linked to the knowledge of the dynamics of coastal areas and marine space
		d. Implement community projects to educate people about the importance and economic value of conserving the coastal environment and the social responsibility to achieve sustainable development
		e. Develop didactic materials for environmental education at different levels and modalities of the educational system aimed at disseminating the environmental problems present in coastal areas
		f. Establish education campaigns for the protection of threatened and endangered species and key areas
		g. Produce documentaries on environmental problems and sustainable development of coastal areas
		h. Disseminate through the mass media the results of the diagnosis of the quality of the beaches

Program	Subprogram	Activities
		i. Disseminate laws and regulations related to coastal areas
		j. Raise awareness among the population of fishermen and private companies about the damage that some arts and fishing methods can generate.
		k. Raise awareness of communities in the conservation, preservation and sustainable development of environmental goods and services in coastal areas in the legal system governing the matter.
		l. Systematically evaluate, control and monitor the results of the Environmental Education Programme
	9.2 Citizen Participation	a. Strengthen the interrelation of national, state and local authorities and governments in the processes of planning and integrated management of coastal areas
		b. Give conferences, talks and workshops on industrial safety to companies and institutions that generate waste and pollutants that may affect coastal areas
		c. Rescue the values associated with the cultural heritage present in coastal towns
		d. Establish campaigns, programs and conferences for the defence and improvement of the coastal environment using the mass media
	9.3 Training	Train and coach municipal authorities, communities, agencies and institutions, in the implementation of the Management Plan and Integrated Coastal Zone Management
10. Environmental Nursery	10.1 Environmental Monitoring and Control	a. Strengthen and implement the Environmental Monitoring and Control System for the coastal areas
		b. Design the integral circuits (route map and frequency) of environmental monitoring and control for the coastal areas
		c. Increase the technical staff, equipment and training of institutions that perform environmental monitoring and control functions in coastal areas
		d. Train volunteer environmental monitors in coastal areas
	10.2 Monitoring for Environmental Control	a. Design and implement the Environmental Monitoring System for coastal areas
		b. Design and complete the integral circuits (route map and frequency) of environmental monitoring for the coastal areas
		c. Develop an inventory of illegal environmental regulatory activities in coastal areas
		d. Monitor of pollutant sources present in coastal areas
		e. Monitor sites for temporary and final location of solid waste within coastal areas
	10.3 Identification and Control of Illegally Occupied Spaces	a. Spatially identify areas subject to illegal occupation processes
		b. Determine the level of healthiness and coverage of basic services in each area subject to illegal occupation
		c. Define the areas to be relocated and design projects to build housing or other types of infrastructure in suitable areas
		d. Establish supervision and control mechanisms to avoid the growth of illegally occupied areas and prevent the emergence of new ones

Source: Ana Carolina Peralta based on the Plan for the Development and Integrated Management of Venezuela's Coastal Areas, Executive Summary (Ministerio del Poder Popular para el Ambiente, 2013, 2014).

Adaptation pathways for proposed actions to reduce coastal vulnerability

With respect to the measures to implement the proposed actions in order to reduce the vulnerability and make appropriate use of Venezuela's coastal areas, in the Article 51 of the Decree of the POGIZC, it is stated that "the implementation of the Guidelines and Directives intended to regulate the intensity of uses in the Management Units will be carried out through the following: Regional, State and Municipal Plans for Land Management; Urban Planning; Municipal Ordinances; Community Development Plans; Community Plans; Strategic Plans for the Integrated Development of the Motor Districts; State, Municipal, Local and Community Plans for the Management and Integrated Management of Coastal Areas and other plans provided for in the National Planning System." The basic document of the plan, which is an integral part of this decree, is based on the diagnoses and identification of the different regional attributes, within which are considered the environmental problems, the environmental impacts, the threats, and the vulnerability (Ministerio del Poder Popular para el Ambiente, 2014). The actors involved in the management process interact to plan and implement in a decentralized, integrated, and participatory manner, the activities in the coastal areas to guarantee their sustainable use and exploitation, thus giving way to the compliance with the policies, guidelines, programs, sub-programs, and projects established in this decree. The key actors include the different levels of government, social and community organization that participate in the adaptation of the actions to be carried out in each place and for each program (Ministerio del Poder Popular para el Ambiente, 2014).

10.5 Final remarks

In general terms, the coastal areas of Venezuela present evidence of events that threaten ecosystems and population centres, thus establishing levels of vulnerability that potentially translate into a deterioration and loss of habitats and natural resources. Pollution, non-conforming occupation of space, deficiencies in the execution of existing territorial planning and administration, deficient environmental supervision and control are the main points that need to be addressed. In recent years, the national authorities have built an integrated management program that contemplates risks, threats, vulnerabilities, measures, those responsible, institutional actors and communities, who together define the guidelines established in the integrated management process, and with which the operational programs are then drawn up to address the problems. The POGIZC of the Bolivarian Republic of Venezuela is thus presented as an integral framework that seeks to contemplate aspects that involve the participation of different sectors under a single action. Technical criteria are considered to make decisions on land-use planning, and all social, economic and political actors are consulted and have a say in the matter, which means that it goes beyond the normative diagnosis to a strategic action.

In Venezuela, there is a good diagnosis of environmental problems and a good institutional structure formed by governmental entities, institutes, universities, research centres, private companies, NGOs and communities. These actors define three major components: community, science and government. However, the programme reflects major weaknesses in the operational level or contingency plans needed to address the problems diagnosed. The programme also reflects the lack of information regarding databases, monitoring or follow-up of attributes, variables, and indicators, which are the basis for projecting risks and generating solutions. Science needs to be strengthened and it is also important to solve the lack of association between the scientific community and the governmental management-administration of resources and spaces. In the same way, it is essential to build a knowledge base so that the community knows and understands the influence that the ocean has on us and the influence that we have on the ocean. This is fundamental for living and acting in a sustainable manner (UNESCO, 2018), so that the communities have the appropriate tools to address the scope and solutions to the coastal hazards with which they coexist.

From the executive point of view, it is also important to mention that efforts must be increased immediately in the infrastructure and equipment programmes, as well for the creation of sustainable urban spaces and for the monitoring of environmental variables. Regarding the latter, it is extremely important to collect oceanographic data, which is a weak point in the programmes and activities described in the POGIZC, which treats this aspect very lightly. Meteorological and atmospheric conditions and their consequences on coastal areas are closely linked to oceanographic conditions. The establishment of oceanographic stations to collect data on currents, water temperature, O_2 and CO_2 levels, among others key ocean parameters, are crucial for the development of the forecasts that will serve to create early-warning systems, mitigation plans and adaptation measures against natural hazards.

Another weak point, which must be addressed to face and generate solutions to the environmental problems of Venezuela's coastal zone, is the insufficient professional training and availability of technological tools and equipment. Otherwise, the Venezuelan strategy for the coastal zone becomes idyllic and utopian. The available integrated plan for the coastal zone presents a good general framework, but it is necessary to go deeper into the action plans. This is where science and innovation must support much more the development of Venezuela.

Acronyms and abbreviations

ABRAE Area under the Special Administration Regime
APRA Environmental Protection and Recovery Area
CIGR Research Centre for Integral Risk Management
CTZC Working Committees of Coastal Areas
DTZC Technical Directorate for Coastal Areas
FAO Food and Agriculture Organization of the United Nations
GRT Gross Register Tonnage
ICLAM Control and Conservation of the Lake Maracaibo Basin
IMO International Maritime Organization
INAMEH National Institute of Meteorology and Hydrology
INEA National Institute of Aquatic Spaces
ITCZ Intertropical Convergence Zone
LOPOT Organic Law for Land Management
LSIGMA-USB Laboratory of Geographic Information System and Environmental Modelling of the Simón Bolívar University, Venezuela
MINAMB Ministry of the People's Power for the Environment
MINEA Ministry of Eco-socialism and Water
MPPRIJP Ministry of the People's Power for Internal Relations, Justice and Peace
NCP National Contingency Plan for the Control and Conflict of Massive Oil Spills in Waters
NGO Non-Governmental Organisation
NOAA National Oceanic and Atmospheric Administration (USA)
POGIZC Plan for the Integrated Planning and Management of Coastal Zones
PDVSA Petróleos de Venezuela, S.A.
REDAN Strategic Regions for Damage Evaluation and Needs Analysis
SAPCOD Automated System for the Prevention and Control of Spills
TBT Tributyltin

Los Roques, Venezuela.

Annex 1 Bibliography

Introduction

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Annex 2 List of figures and tables

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This product developed by UNESCO's Intergovernmental Oceanographic Commission (UNESCO/IOC) contributes to implement its MSPglobal initiative, its 2020 Regional and global development actions in support of Ocean Literacy for all and its Joint Roadmap on marine spatial planning processes worldwide in the context of the United Nations Decade of Ocean Science for Sustainable Development.

UNESCO/IOC continues building collective capacities to respond to emerging ocean and coastal issues through ecosystem and area-based management tools such as integrated coastal zone management, marine spatial planning and sustainable blue economy initiatives, including transboundary and large marine ecosystem approaches for the sustainable use of marine resources, with a view to achieve a safe, healthy and a productive ocean. The integration of natural hazards affecting coastal zone is, in the context of climate change, intended to support coastal adaptation and enhanced hazard and disaster management through multidisciplinary, sound science, ecosystem-based, inclusive, participative, and sustainable management of coastal communities.

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