

## Article

# Coastal Hazard and Vulnerability Assessment in Cameroon

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**Abstract:** The coast is the most dynamic part of the Earth's surface due to its strategic position at the interface of the land and the sea. It is, therefore, exposed to hazards and specific risks because of the geography as well as the geological and environmental characteristics of different countries. The coastal environment is essentially dynamic and evolving in time and space, marked by waves, tides, and seasons; moreover, it is subjected to many marine and continental processes (forcing). This succession of events significantly influences the frequency and severity of coastal hazards. The present paper aims at describing and characterizing the hazards and vulnerabilities on the Cameroonian coast. Cameroon possesses 400 km of coastline, which is exposed to various hazards. It is important to determine the probabilities of these hazards, the associated effects, and the related vulnerabilities. In this study, in this stable intraplate setting, the methodology used was diverse and combined techniques for the study of the shore and methods for the treatment of climatic data. Also, historical data were collected during field observations and from the CRED website for all the natural hazards recorded in Cameroon. In addition, documents on climate change were consulted. Remotely sensed data, combined with GIS tools, helped to determine and assess the associated risks. A critical grid combining a severity and frequency analysis was used to better understand these hazards and the coastal vulnerabilities of Cameroon. The results show that Cameroon's coastal margins are subject to natural processes that cause shoreline changes, including inundation, erosion, and accretion. This study identified seven primary hazard types (earthquakes, volcanism, landslides, floods, erosion, sea level rise, and black tides) affecting the Cameroonian coastline, with the erosion rate exceeding 1.15 m/year at Cape Cameroon. Coastal populations are continuously threatened by these natural or man-induced hazards, and they are periodically subjected to catastrophic disasters such as floods and landslides, as experienced in Cameroon. In addition, despite the existence of the National Contingency Plan devised by the Directorate of Civil Protection, National Risk, and Climate Change Observatories, the implementation of disaster risk reduction and mitigation strategies is suboptimal.

**Keywords:** Cameroon; coastal hazards; coastal vulnerability assessment

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## 1. Introduction and Background of the Study

The history of natural hazards dates back to the beginning of human existence. However, their strong recurrence in the final decades of the 20th century is worthy of particular attention, as such disasters have occurred in all scientific environments and countries. The interest of the international community in natural hazards and their consequences

is, therefore, growing, and it will continue to increase despite the many decades of work devoted to them by the United Nations and efforts across all the continents to control them. Coastal urban centers account for over 70% of Cameroon's GDP, with Douala contributing a significant share, and they represent a strong concentration of residential, industrial, commercial, educational, and military facilities [1]. Also, coastal cities are locations with high levels of economic activity, mainly because of their associations with ports and waterfront development and their well-endowed coastal and marine environments [2]. Such conditions contribute to the creation of risks and high levels of exposure to hazards, mainly floods. The population in the "near-coastal zone" (defined as areas within both 100 m elevation and 100 km distance from the coast) was evaluated in 2023 by Cosby et al. [3]. The authors found that the population was significantly concentrated in this zone (approximately 2 billion within 50 km and 1 billion within 10 km along the coast), with higher growth rates, estimated at 463 million within 50 km and 233 million within 10 km. These authors also showed that Africa had the second-largest near-coastal population, with 256.2 million coastal inhabitants. This number represents 11.6% of the global coastal population. Moreover, according to Reimann [4], nearly half of the world's population lives in coastal areas, and coastal hazards exhibit severe impacts due to the high concentration of people and assets in exposed locations. Coastal areas are particularly subject to multiple hazards, particularly those related to shoreline mobility (evolution of beaches, dunes, and receding cliffs) and sea level rise [5].

Background and literature review on natural and coastal hazards.

A coastal hazard may be defined as the occurrence of any phenomenon that has the potential to cause damage to, or the loss of, natural ecosystems, buildings, and infrastructure. Coastal hazards can be natural or man-induced. Among the natural hazards, Hewitt and Burton [6] present a broad typology, which will be used in this contribution. Man-induced hazards are considered as technological hazards and can be identified in the coastal areas of Cameroon. The term "hazard" is often confused with the term "risk", but there are significant differences. A hazard is any source of potential damage, injury, harm, or adverse effects to individuals, organizations, or communities due to the environment. Hazards are "those elements of the physical environment, harmful to man and caused by forces extraneous to him" [7]. A hazard is a physical or man-induced process that has the potential to negatively affect humans, and it becomes a disaster only when it affects a population and its assets adversely [8]. A risk is the chance or probability that a person, environment, or society will be harmed or experience an adverse effect if exposed to any hazard. The term "risk" also bears a behavioral connotation, which is a determinant of vulnerability [9]. This explains why a natural risk is defined as the probability of occurrence of an undesired event, expressed by the equation  $R = H \times V$  (risk = hazard  $\times$  vulnerability) [10–12].

Natural hazards are processes that have the potential to affect human populations due to hydrometeorological, geological, or even biological factors. Natural disasters are catastrophic or hazardous events caused by natural processes that create large numbers of fatalities, overwhelming property damage, and social environment disruption [12,13]. As such, a disaster represents a serious disruption to the functioning of a community or a society, involving widespread human, material, economic, or environmental losses and impacts that exceed the ability of the affected community or society to cope using its own resources [12]. The severity of a disaster is measured in the lives lost, economic losses, and the ability of the population to rebuild. However, if a disaster is defined by the extent of the damage caused to people and property, there is not necessarily a correlation between the importance of a hazard and the magnitude of the damage.

Globally, natural disasters have killed more than 1.5 million people in the past two decades and affected 255 million annually [14]. Disasters—from earthquakes and storms

to floods and droughts—kill approximately 40,000 to 50,000 people per year. This is the average over the last few decades. Also, millions of people are displaced—some left homeless—by them each year [15], and 95% of them are produced in developing countries. Such data are confirmed by UNDRR [14], who add to complete that 7348 disaster events were recorded worldwide by EM-DAT. Those disasters killed approximately 1.23 million people, an average of 60,000 per annum, and affected a total of over 4 billion people and the approximate cost of disasters reached USD 2.97 trillion in economic losses worldwide [14]. In Cameroon, our investigations show that over the last thirty years, natural disasters have killed more than 8000 people and left 1 million homeless.

Natural hazards and their various manifestations (mass movement, flooding, coastal erosion, strong winds, tsunamis, etc.) caused great damage in both developed and developing countries. However, the difference between these countries can be in the capacity for adaptation and management of these risks. Coastal hazards have been studied broadly in developed countries but are still poorly known in African developing countries. The African continent has 26,000 km of endangered coastline along which most of the capitals of West Africa are concentrated (Nouakchott, Dakar, Cotonou, Conakry, Freetown, Monrovia, Lomé, etc.). Significantly, the coastlines are home to nearly 30% of the population of West Africa [16–18].

In North Africa, Lahlah Salah [19] mentions catastrophic floods that damage human activities and hinder economic activities in Algeria. Chouari [20] assessed land at risk of marine submersion related to climate change in Tunisia. Ali et al. [21] focused on intense coastal erosion and flooding in the Tahaddart and Saidia coasts in the Far North of Morocco, closely linked to human interventions, particularly in the Moulouya basin. The World Bank [22] realized a prospective study on coastal cities between 2010 and 2030 showing the prevalence of flooding, marine submersion, and coastal erosion at Tunis, Alexandria, and Casablanca.

Scattered studies on West Africa stressed mainly floods and sometimes sea level rise. Dakar city recorded floods from 1987 till today and this raised both natural and anthropogenic concerns, including the reflooding of the former dried-up lowlands and the occupation of these shallows by spontaneous habitats [23]. Rey and Fanget [24] are interested in coastal erosion observed in Saint Louis in Senegal, particularly in the Langue de Barbarie, where the opening of a gap has accelerated erosion. In Ivory Coast, Vami et al. [25] reported on overflowing floods and the high vulnerability of the city of Sinfra. In the last ten years, the sea has gained between 40 and 50 m in the Benin Coast, and in 2014, the country erected artificial dikes from 200 to 300 m [16]. In Nigeria, disaster-related records of Nigeria also prove that the number of flood occurrences tripled over the last 50 years [26,27]. Much of the Nigerian coast is low-lying with the consequence that a 1–3 m rise in sea level, which may result from eustatic or climate change, will have a catastrophic effect on human activities in these regions [28].

In Gabon, Central Africa, Ovono [29], using geomatics tools, analyzed coastal erosion on Gabonese coasts. In Cameroon, the World Disaster Report [30] finds that between 2005 and 2014, 96,867 people were affected by natural hazards and 717 lost their lives. Mbevo [31] highlights the occurrence of dramatic urban floods in the city of Douala. He also reports on situations of intense coastal erosion in the island of Manoka (Cap Cameroon) with 30 m of shoreline retreat between 1992 and 2015.

As far as Cameroon is concerned, and up until the last 30 years, the natural risks faced by societies or individuals have hardly been a part of the privileged fields of historical, fundamental, or applied research. However, by its long-term anchoring, through a specific approach of questioning, criticism, and analysis of sources, but also by new perspectives

and issues, the research allows a better understanding of the reactions of societies to the dangers incurred and the disasters suffered.

Weather usually causes natural disasters, which are events beyond human control. Such disasters include but are not limited to storm surges, flooding, tides, waterspouts, earthquakes, and volcanism. Human disasters are those that occur partially or fully due to human behavior, such as pollution, trawling, coastline modification, and human development (oil spills and urbanization). Human coastal disasters have been largely described by Madoungou Ndjeunda [32], who shows that since 1975, there have been almost 20 oil spills in the West and Central African Coast (Cameroon, Gabon, Benin, Côte d'Ivoire, Nigeria, and Mauritania), and Cameroon account for 4 of them (1975, 1979, 2001 and 2007). This results largely in pollution.

As far as urbanization is concerned, some West African countries have almost the same level of urbanization: Cameroon (52%), Senegal (41%), Mauritania (41%), Ivory Coast (40%), Benin (35%), and Guinea (32%) [33]. Rising sea levels cause coastal flooding and erosion, as well as the loss of coastal habitats that naturally protect the coastline from storm surges. The loss of these habitats increases the number of people at risk.

Sea level rise is occurring as the population of Africa's coastal cities skyrockets. Between 2020 and 2030, Africa's seven largest coastal cities—Lagos, Luanda, Dar es Salaam, Alexandria, Abidjan, Cape Town, and Casablanca—are expected to grow by 40% (from 48 million inhabitants to 69 million) [34], while the overall increase predicted for the continent is 27% (from 1.34 billion to 1.69 billion). Small coastal cities, such as Port Harcourt, Nigeria, could expand even more rapidly, with an expected 53% growth this decade. Globally, the coastal regions of Africa are expected to experience the highest rates of population growth and urbanization in the world. By 2030, an estimated 108–116 million people in Africa will live in low-lying coastal areas, defined as areas 10 m or less above sea level, a figure expected to double by 2060 [33]. Africa is urbanizing rapidly. Its urbanization rate increased from 15% in 1960 to 40% in 2010, and will be 60% by 2050 [35] (BAFD/UNDP/CEA, 2017). Since 1990, the number of cities in Africa has doubled—from 3300 to 7600—and their cumulative population has increased by 500 million people [34]. Consequently, urbanization appears to be a central lever in the pursuit of the objectives set by the 2030 and 2063 Development Agendas, as well as a factor in the integration of the continent within the framework of the African Continental Free Trade Area (AfCFTA). Consequently, urbanization appears to be a central lever in the pursuit of the objectives set by the 2030 and 2063 Development Agendas, as well as a factor in the integration of the continent within the framework of the African Continental Free Trade Area (AfCFTA). Urbanization appears as the main triggering factor of anthropogenic hazards along the coast.

Natural hazards associated with ongoing climate change make the African continent one of the most vulnerable on the planet. Coastal environments, due to their exposure to cyclonic winds and storms as well as numerous anthropogenic forcings are the most affected. The perceptible manifestations are a recurrence of floods and landslides, the worsening and multiplication of coastal erosion coupled with shoreline retreat, and rising sea level, all of which add to the earthquakes and volcanism observable in some coastal environments. The Cameroonian coastline is not immune to this phenomenon, and the objective of this work is to analyze the hazards and vulnerability of Cameroonian coasts. Taking into consideration the definition of Burton et al. [6], more specifically, coastal hazards are related to all geohazards, hydrometeorological, climate change, erosion and associated risks, pollution, and sea level rise, which can, because of their location, severity, and frequency, potentially affect humans and their property in coastal areas.

The study will proceed in the Methodology Section with the general presentation of Cameroon coupled with a Cameroonian coastal description. Afterward, it will sketch

properly the methodology used, followed by the description and analysis of the types of coastal hazards and associated vulnerabilities.

## 2. Methodology

### 2.1. General Presentation of the Cameroon Coastal Region

Located at the bottom of the Gulf of Guinea, Cameroon is the junction between Central Africa and West Africa. Its geographical situation explains the variety of its landscapes, climates, and populations, which are worth the name of “Africa in miniature”. Covering an area of 475,000 km<sup>2</sup>, Cameroon is bordered to the northwest by Nigeria (1720 km), to the north by Chad (1122 km), to the east by the Central African Republic (822 km), and to the south by Congo (520 km), Gabon (298 km), and Equatorial Guinea (183 km). It holds westwards 400 km of coast on the Atlantic Ocean, which represents 9.8% of the territory. In this coastal area, rainfall ranges from 3000 to 9000 mm on average.

Topographically, the country is made up of five major natural geographic features that are described from the north to the south (Figure 1).

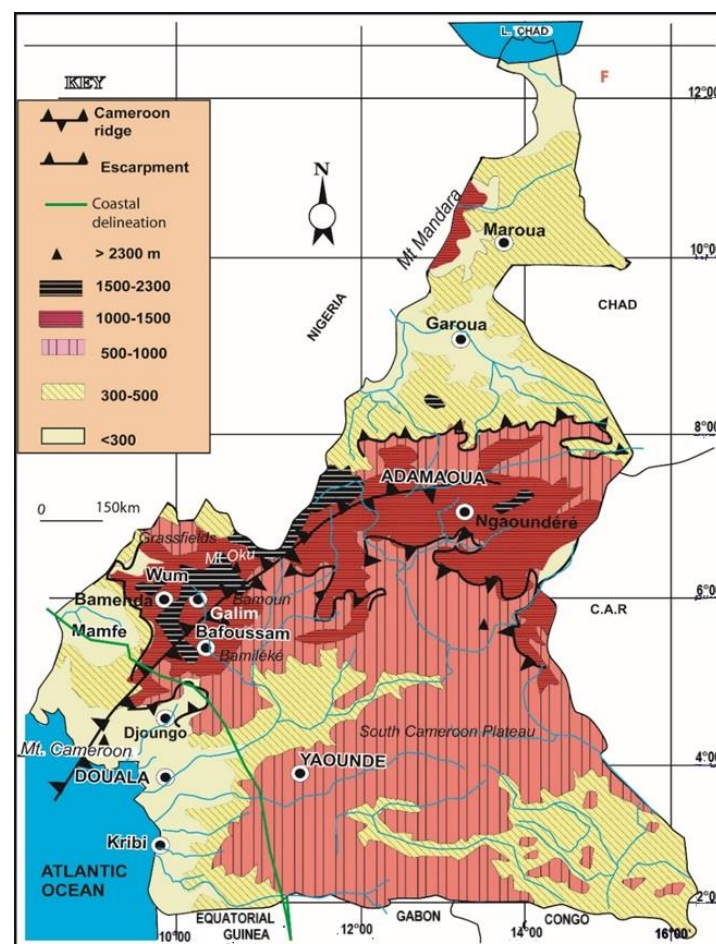


**Figure 1.** Main landforms and features of Cameroon (source: Tchindjang, [36]).

1. Northern Cameroon lowlands and troughs (300–500 m) consist of a vast relief of plain, including the Benue basin (Garoua plain), which meanders on the Alantika mountains to the west. It also comprises the Diamaré plain hemmed into the northwest by the Mandara volcanic mountains (1444 m) which progressively give way northeastwards to the Lake Chad depression. The vegetation is savannah and bush.

2. In the middle of the country, the Adamawa Plateau (1000 to 1500 m) slopes gently towards the Sanaga Valley to the south and collapses sharply to the north over the Benue basin. A rugged region covered by the equatorial forest stretches south of Adamawa. Almost all the rivers that crisscross Cameroon are born in Adamawa.
3. The southern Cameroonian Plateau is a topographic feature between 650 and 900 m. It extends from west to east, from Yaoundé to the Central African border, and covers 1/3 of the country.
4. The western highlands connect to the central plateau by a large area of ancient volcanoes (like the Bamboutos Mountains and Manengouba peak at more than 2000 m) and basaltic plateaus (Bamileke Plateau, Bamoun Plateau, and Grassfield Plateau). Westwards to this region, Cameroon Mountain rises to a 4094 m peak and overlooks the coast at Limbe.
5. The coastal region, about 100 km wide towards the north, narrows towards the south to form a soft, sandy coastline with a deep indentation, the Douala Bay. Southwards of this city, the coast is the domain of the mangrove (estuary of Wouri), and, further south, it is characterized by beautiful beaches. The coastal lowlands cannot be isolated from the mountains above (Cameroon Mountains and Rumpi Hills Figures 2 and 3), because they are located less than 150 km from the coast and influence both the relief and the surrounding climate.

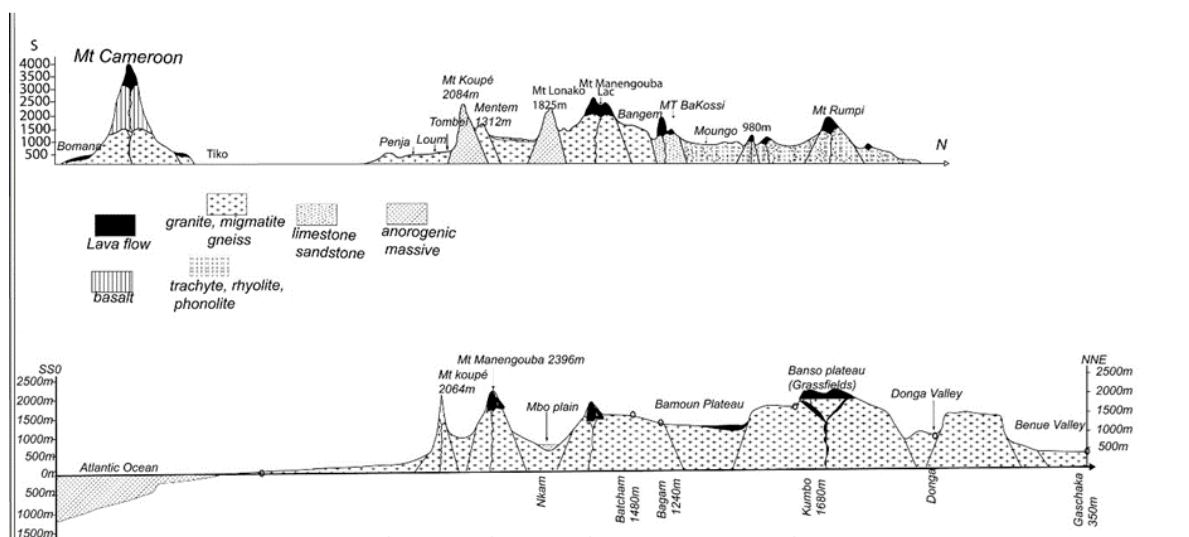


**Figure 2.** Geological cross-section of the coastal region (source: Tchindjang, [36]).

### 2.1.1. Cameroon's Coastal Region

The coastal region occupies a strip of nearly 400 km along the Atlantic Ocean from the Nigerian border in the north to the Equatorial Guinea border in the south. It concerns 20 municipalities and covers the administrative regions of South-West, Littoral, and the Ocean Division (Southern Region). The northern part is characterized by an abundance of estuaries, mangrove forests, and the presence of Mount Cameroon, a volcanic edifice that rises to 4094 m. In the southern part, the coastal strip is rocky. The width of the plains does not exceed 150 km.

### 2.1.2. Coastal Topography

The relief of this natural region consists of half highlands and half lowlands (sedimentary basin etc.). The coastal Cameroonian sedimentary basins, located on the edge of the Gulf of Guinea, cover an area of about 7000 km<sup>2</sup> [37]. It corresponds to a subsidence zone formed from the Cretaceous and progressively deepening towards the ocean, where it

reaches thicknesses of 4000 m at 40 km and 8000 m further offshore. The main deposits are black marls and clays as well as sandstone and sands. The relief has an average altitude of 90 m. These widely spread plains consist of sedimentary terrains covered in places with basalt. The morphology of detail shows many small convex hills or half oranges that rarely exceed 200 m altitude. The coastal land bases stretch between the mouth of the Akwa Yafé, which forms the western border between Cameroon and Nigeria, and the mouth of the Lokoundje, which extends uninterruptedly into the Atlantic Ocean, limiting it to the west. The coastal plains appear limited eastwards by the Southern Cameroon Plateau and northwards by the Western Highlands. This coastal region consists mainly of mangroves, coves, and sandy bars. The Cameroonian coast is divided into two major parts: rocky coasts and soft coasts (Figure 3).

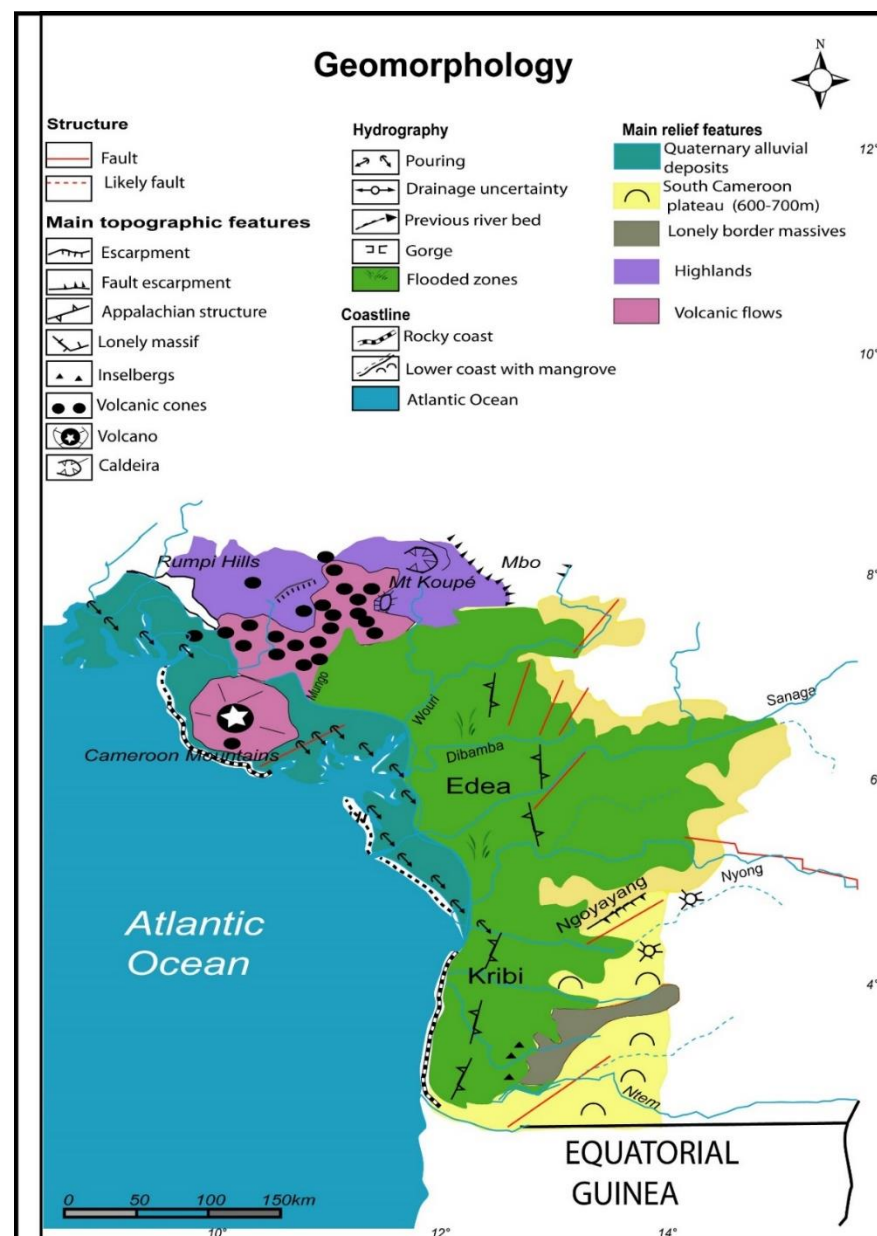


Figure 3. Cameroon coastal geomorphology (source: adapted from Tchindjang [36]).

### *Soft coasts*

It is the most developed part, with at least 220 km stretching from the mouth of the Sanaga to the Wouri estuary. The soft coasts are represented by 3 sub-basins: (1) The Ndian basin, which extends to the northwest of Mount Cameroon and is characterized by the presence of mangrove swamps. (2) The Douala basin, a low depression in which many sediments have been deposited. It constitutes the estuary of Wouri, which has an average altitude of 30 m and is characterized by creeks, bars, and lagoons. It extends to Kribi. (3) Mamfe graben which is drained by the Cross River. It forms a separate area located nearly 150 km from the coast. It appears surrounded by mountains (the Rumpi hills) that lock it on all sides outside its western part leading to the Nigerian coast.

### *Rocky shores*

They are rough and show two large morphological elements. The rocky volcanic cliffs are located on the outskirts of Mount Cameroon and stretch about 60 km from Bimbina to Idenau. The volcanic rocks that crash it are from Mount Cameroon, and the volcanic activity is responsible for the presence of some moles that emerge over the ocean in Limbe. This feature that breaks the monotony or the low profile of the coastal regions is characterized by the presence of bays, capes (Cape Limboh), cliffs, and rocky islands (Figure 4). The second morphological unit consists of rocky shores with narrow beaches that run from Kribi to Campo for nearly 80 km. These beaches were shaped on crystalline schist fragmenting into large blocks. These shales give a particular aspect to the coastal landscape of Kribi, famous for its sandy beaches (Figure 5).



**Figure 4.** Rocky volcanic coast with mole and cape in Limbe. (Source: Tchindjang, December 2012.)



**Figure 5.** Rocky and sandy shores at Kribi. (Source: Tchindjang, August 2017.)

### 2.1.3. Climate

The coastal zone is bathed in a hot and humid equatorial oceanic climate with little differentiated seasons with rainfall distributed throughout the year (0 to 1 dry month).

However, there are two seasons, an intensive rainy season from March to October and a dry season from November to February. The average rainfall is around 4000 mm per year with records of 13,000 mm at Debunsha (at the foot of Mount Cameroon), rightly considered as the second most rainy resort in the world after Cherrapunji in India.

Average temperatures are relatively stable and oscillate between 25 and 27 °C, while the relative humidity is maintained at values higher than 80% practically all the year. The coastal agroecological zone with single-mode rainfall is marked by a weighting of average temperatures related to the mountain fact despite a significant increase and marked differences by decade. Stressing on temperatures, Cameroon Second Communication on climate change as well as NAPCC [38,39] describe three main periods: a period of low temperatures (1961–1969), one of average temperatures (1970–2002), and one of high temperatures (2003–2010). These reports concluded that with a 1.3° increase per decade, the temperature in the coastal agroecological zone has increased by 5% per decade.

#### 2.1.4. Vegetation

According to Letouzey [40], the entire coastal zone belongs to the domain of the evergreen Guineo-Congolese rainforest, including the Biafra and Littoral Atlantic Districts. These can be subdivided on the basis of floristic, geographical, or physiognomic characteristics into three main types of forest: (i) the Biafrean Atlantic forests with *Caesalpinaceae*; (ii) Atlantic littoral forests with *Lophira alata* and *Saccoglottis gabonensis*; (iii) the mangrove swamp forests along the coast composed mainly of *Rhizophora* (red mangrove) in regular contact with brackish water, and *Avicennia* (white mangrove).

#### 2.1.5. Population

The coastal region is densely populated, gathering almost 70% of the country's economy, especially industrial and even touristic activities, of which it is one of the economic lungs. As a result, it is experiencing a significant concentration of population in major urban centers, such as Douala (economic capital), Limbe, Tiko, Nkongsamba, and Buea, which explains its high vulnerability. The average density of the population is estimated at 132.6 hts/km<sup>2</sup>. About 30% of the population is believed to be of immigrant origin from all parts of the country and/or from abroad.

#### 2.1.6. Soils and Economy

This lowlands natural region is characterized by yellow ferralitic, sandy to sandy-clayish, alluvial, and volcanic soils that possess great agricultural potential due to climate and its natural richness. These soils are affected by upwelling and tidal seas that cause coastal erosion. The northern part of the coastline is characterized by rich and deep melanic andosols supporting large industrial plantations of plantain, rubber, tea, oil palm, and, moreover, food crops (tubers, maize, and cowpeas) and vegetables. The southern part is characterized by industrial plantations, rubber, and palm oil (SOCAPALM, CDC, HEVECAM, MONTE, PAMOL, etc.). Fishing enterprises, oil exploitation in Rio del Rey, and the port industry and large agro-industrial plantations are the main economic assets of the region, but also the causes of pollution and the degradation of natural resources.

The coastal landscape is one of the five natural and agroecological regions of Cameroon summarized in Table 1.

**Table 1.** Coastal agroecological region of Cameoon.

| Agroecological Zone                  | Relief                                                                                                                                                       | Climate                                                                                                                                          | Vegetation and Biodiversity                                                                                                                             | Soils                                                                                                                                                                                                              | Agricultural Production and Economy                                                                                                                                    |
|--------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Coastal zone with monomodal rainfall | Mountains (Rumpi hills, Bakossi mountains, Cameroon Mountains, Koupe Mountains, etc.) highest peak of Cameroon (4100 m), Many volcanic lakes, Coastal plains | 3000–9000 mm/year with a monomodal regime and 03 dry months. Average annual temperature: 25–27° with 15–24° close to the Cameroon Mountain areas | Evergreen coastal forests, Mangrove Swamp forests, and Montane and submontane forests (fauna, great apes, elephants, gazelle, Mandrill, and chimpanzee) | Very fertile nitosols, lithosols, alluvial and colluvial soils on slopes, fluvisols, aquisols, hydromorphic soils, chromic and melanic andosols, poorly evolved soils, and raw mineral lithosols in Mount Cameroon | Cocoa, coffee, oil palm, vegetable crops, rubber tree, tea tree, pepper, pineapple, and plantain<br>Many industries and sea ports<br>More than 40% of the National GDP |

## 2.2. Methodological Approaches

### 2.2.1. Assessing Coastal Hazards

Coastal hazards, as a concept, offer a richer and more diversified content, bringing together all the current and potential risks that may arise on the Cameroonian coast, including landslides, earthquakes, and volcanism in geological hazards; floods; erosion; sea level rising; and storms that are the most visible manifestation of climate change in the coastal environment. At least the modification of the shoreline, the pollution via the spill oil slicks, and the urbanization of coastal environments are taken into consideration. The range of coastal hazards brings us to assess each by the use of several tools ranging from surveys and field observations to geomatics, as well as approaches to vulnerability to climate change. First of all, because there are not existing records in Cameroon, the coastal hazards identification and assessment methodology used two approaches: (i) A participatory process (bottom up) based on specific surveys of coastal populations, administrations, and major development sectors. The purpose was to enable participants to express their perception of hazards and climate change. We analyzed the results based on the proposed questions, either open or closed. (ii) The use of historical profiles by local memory or chronological landmarks/archives (as shown by Table 2) to identify major seismic, volcanic, or weather events in history to better understand what is happening today. Semi-structured interviews can also utilize this method.

**Table 2.** Sketch of historical profile used during readings and field surveys.

| Events Felt or Recorded | Year 1951–1960 | Year 1961–1970 | Year 1971–1980 | Year 1981–1990 | Year 1991–2000 | Year 2001–2010 | Year 2011–2020 | Year 2021–2030 |
|-------------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Earthquake              | 5              | 3              | 5              | 10             | 12             | 13             | 15             | 10             |
| Floods                  | 0              | 0              | 0              | 4              | 7              | 26             | 17             | 25             |
| Landslide               | 0              | 1              | 0              | 2              | 7              | 12             | 9              | 1              |
| Volcanism               | 0              | 0              | 0              | 3              | 1              | 1              | 0              | 0              |

Also, there are some useful experiments conducted by (i) consulting archives, written and oral sources, historical documentation on certain hazards such as earthquakes and

volcanism, or natural hazard statistics on websites such as the CRED and the Munich from 1980 to 2020; (ii) mapping risk by natural region sometimes coupled with population density; (iii) overlaying the hazards to the population and affected assets to better detect vulnerability; (iv) analyzing and assessing the vulnerability by natural region and by sector of activity was based on the above factors grouped into 4 parameters: structural damage, bodily injuries, functional losses, and then the perception and lack of knowledge of the environment (Table 3). To achieve this goal, we constructed a critical grid that measures the severity and frequency of geohazards.

**Table 3.** Main components and ranking of the vulnerability in geohazards.

| Rank | Structural Damages (P1)                                                                                         | Functional Losses (P2)                                                        | Personal Injuries (P3)                                                                                    | Hazards Perception (P4)              |
|------|-----------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|--------------------------------------|
| 1    | Non-structural or light damage, stability unaffected                                                            | no resettlement, no unavoidable change                                        | No injury, no death, no homeless, undisturbed road traffic, and very low density of travelers             | Hazard well perceived and well known |
| 2    | Walls' cracking, unaffected stability, non-urgent repair                                                        | 1–10 resettlements, no road deviation                                         | Slight injury, no homeless, no traffic disruption, and low density of travelers                           | Hazard well perceived and known      |
| 3    | Major deformations, walls cracked, structural cracking, and evacuation required                                 | More than 10 resettlements, without deviation or deviation of less than 20 km | Serious injury or illness, with or without shelter, and a large number of travelers                       | Hazard perceived and poorly known    |
| 4    | Fracturing of structures, separation of parts, partial collapse, breach, evacuation, rehabilitation compromised | More than 10 resettlements with road deviation of less than 50 km             | Severe injury or threat requiring hospitalization, many homeless, travelers blocked, and deviation needed | Hazard weakly perceived and unknown  |
| 5    | Partial or total collapse, evacuation, rehabilitationHigh livelihood fatality                                   | More than 10 resettlements, with road deviation of more than 50 km            | Death, resettlement, deviation for long-term permanent disabling injury, and fatality                     | Hazard not perceived and unknown     |

Rank: 1: minor; 2: low; 3: moderate; 4: critical, and 5: catastrophic.

### 2.2.2. Hazard Quantification

Risk is expressed by the probability of occurrence  $\times$  hazard impact, or

$$R = f(p \times c) \quad (1)$$

where  $R$  is risk;  $P$  is the probability of occurrence of the natural hazard;  $C$  is the consequences (natural hazard impact) [41]. Risk assessments determine the probability of occurrence of a certain hazard of a certain intensity and are rendered by the equation

$$Risk = hazard \times vulnerability \times Elements\ at\ Risk \quad (2)$$

ref. [42] or a better equation

$$R = \sqrt[4]{Natural\ Hazard} \times vulnerability \times exposure \times susceptibility. \quad (3)$$

Vulnerability can be calculated by using the equation

$$V = \frac{\text{Lack of coping capacities} + \text{lack of resilience}}{2} \quad (4)$$

If so, the probability of occurrence is expressed by  $P = \sqrt{\text{natural hazard}} \times \text{vulnerability}$  i.e.,

$$P = \sqrt{\text{natural hazard}} \times \frac{\text{Lack of coping capacities} + \text{lack of resilience}}{2} \quad (5)$$

The probability impact becomes [42].

$$PI = \sqrt{\text{exposure}} \times \text{susceptibility} \quad (6)$$

In addition to these equations, the critical grid is also used in risk assessment to measure risks and define spaces based on how common and how serious they are. Crossing severity and frequency yields the critical grid, also known as the risk assessment matrix chart (Table 4). It estimates how bad an event could be and how likely it is given each task's risks. This information helps you make an informed decision about how to reduce risk. It also lists the possible severity and likelihood of an event, with clarifying words in each group to help figure out the real risk that comes with the hazards for a certain task. The rank of severity and frequency levels—safe (green), acceptable (blue), tolerable (yellow), and unacceptable (orange and red color)—applied to the risk areas is defined before starting the risk identification and analysis process. Such a quantitative or qualitative assessment will take into account the perceptions of climate change among individuals and actors. Perception helps to apprehend human behavior in the face of climatic hazards (flight, displacement, panic, death, resettlement, etc.). Therefore, the resulting critical grid is scaled to 5 degrees (1–5): minor, low, medium or moderate, high or critical, very high or catastrophic. From there, we establish a threshold set at the value 12 (Table 4 and Appendix A Figure A1), from which the vulnerability is significant and important. We must explicitly declare that we conducted the evaluation randomly by chance. The severity of any hazards is just as important as the frequency and may depend on the context. A critical grid was used to connect the needed alert to the high level of vulnerability found by combining severity and frequency. This risk matrix helps in assessing the vulnerability of every type of identified hazard: geohazards, meteorological hazards, and man-induced hazards in the coastal area.

**Table 4.** Final ranking score for hazard quantification and for vulnerability assessment.

|                                         |               |            |                         |                   |                       |
|-----------------------------------------|---------------|------------|-------------------------|-------------------|-----------------------|
| Ranking score signification for hazards | Minor<br>1–2  | Low<br>3–7 | Medium/moderate<br>8–14 | Critical<br>15–19 | Catastrophic<br>20–25 |
| Ranking score for vulnerability         | Very Low<br>1 | Low<br>2   | Medium/moderate<br>3    | High<br>4         | Very high<br>5        |

### 2.2.3. Assessing Coastal Vulnerability to Climate Change

We collected the available climate data (temperature and precipitation) to analyze the evolution of those parameters from 1930 to 2023 for rainfall and 1960 to 2022 for temperature. This helps us to compute in Excel the graphical evolution of those climatic parameters within 26–30 climatic stations and rainfall posts of the coastal region. Table 5 shows how we divide the coastal area of Cameroon into groups based on the main physical or natural forces at play, as well as the main risks that happen and how vulnerable people are to them. We split the Cameroonian coast typology into five entities with corresponding districts, cities, or localities (Table 5).

**Table 5.** Type of hazards and vulnerability in Cameroon coastal area.

| N° | Type of Coast                       | Corresponding Locality or District | Main Hazards                                          | Vulnerability                                                                                                                                                              |
|----|-------------------------------------|------------------------------------|-------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1  | Rocky/volcanic with cliff           | West coast (Limbe to Idenau)       | Seism, volcanism, floods, SLR, erosion, and landslide | Loss of marine habitats and ecosystems and socioeconomic vulnerability (fisheries, tourism, and agriculture)                                                               |
| 2  | Semi indented, semi rocky, and soft | Kribi                              | Seism, floods, and erosion                            | Loss of marine habitats and ecosystems and socioeconomic vulnerability (fisheries, tourism, and aquaculture)                                                               |
| 3  | Plain and alluvial plain low cliff  | Campo                              | Floods and erosion                                    | Loss of marine habitats and ecosystems and socioeconomic vulnerability (fisheries and tourism)                                                                             |
| 4  | Estuary and beaches                 | Douala                             | Seism, floods, erosion, and SLR                       | Loss of marine habitats and ecosystems spawning ground, socioeconomic vulnerability (fisheries and tourism), loss of property and infrastructure, and salt water intrusion |
| 5  | Mangroves and sand beaches          | Manoka and Rio del Rey             | Seism, floods, erosion, and SLR                       | Loss of marine habitats, spawning ground, and ecosystems; socioeconomic vulnerability (fisheries and tourism); and loss of property and infrastructure                     |

To assess coastal vulnerability, there are many ways depending on which factors/indicators we privilege. Numerous studies have examined the coastal vulnerability index from Gornitz et al. [43]. They were the first to create it and use eight parameters to figure out how vulnerable a coastal area is to expected SLR. These parameters are relief, rock type, landform, vertical movement, shoreline displacement, tidal range, and wave height. But nowadays so many recent studies [44–52] stressed the fact that we cannot assess CVI without taking into account social and economic or socioeconomic parameters. In order to achieve this goal, we selected the multi-scale coastal vulnerability index. Our efforts resulted in the division of the Cameroon coastal area into five distinct zones, each corresponding to the dominant physical features. This process also facilitated the creation of numerous indicators, enabling us to calculate the CVI physical index, CVI social index, and CVI economic index (see Figure 6). We added the three indices together to obtain a single index of coastal vulnerability along the coast of Cameroon. Figure 6 illustrates this, along with the primary equations utilized to compute the three indices.

$$CVIP = \frac{(X1 + X2 + X3 \dots + X6) - 6}{(5 - 1) \times n} \times 100 \quad (7)$$

$$CVIS = \frac{(X1 + X2 + X3 \dots + X10) - 10}{(5 - 1) \times n} \times 100 \quad (8)$$

$$CVIE = \frac{(X1 + X2 + X3 \dots + X13) - 13}{(5 - 1) \times n} \times 100 \quad (9)$$

$$ICVI = \frac{CVIP + CVIS + CVIE}{3} \quad (10)$$

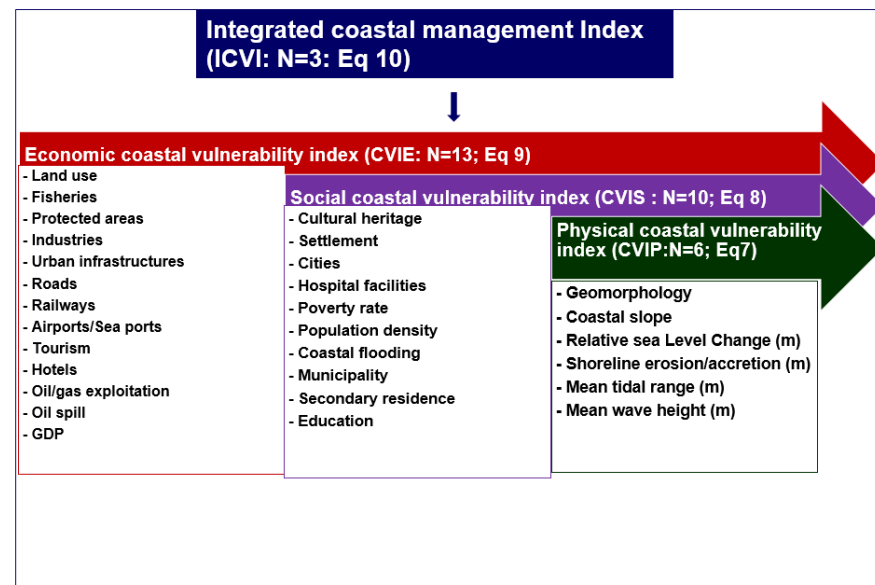


**Figure 6.** Coastal vulnerability indices and equation.

Table 6 classifies CVI variables as dimensionless “risk” variables, ranging from 1 to 5. We used 5–1 (4) percentiles as limits. We multiplied 4 by the total number of variables ( $n$ ) for each sub-index, i.e., 24 for the physical CVI, 40 for the social CVI, and 52 for the economic CVI. After calculation, we tried to rank each type of sub-index and the final coastal integrated vulnerability index in percentage in order to build graphics from Excel 2016 as well as maps of vulnerability in the whole Cameroon coast. Two main Excel graphs were found. The first showed a “risk” variable that ranged from 1 to 5 based on the levels of vulnerability and was calculated as a colored percentage. The second showed the physical coastal features, which are what determines the risk (Table 6).

**Table 6.** Types of physical parameters observed in the Cameroon coast.

| Variables                            | Very Low<br>1  | Low<br>2                            | Medium/Moderate<br>3               | High<br>4           | Very High<br>5             |
|--------------------------------------|----------------|-------------------------------------|------------------------------------|---------------------|----------------------------|
| Localities                           | West Coast     | Kribi                               | Campo                              | Douala              | Manoka and Rio del Rey     |
| Geomorphology                        | Rocky/volcanic | Semi indented, semi rocky, and soft | Plain and alluvial plain low cliff | Estuary and beaches | Mangroves and sand beaches |
| Coastal slope                        | >20            | 2–10                                | 0.7–2                              | 0.4–0.25            | <0.25                      |
| Relative sea level change (m)        | <2             | 2–2.5                               | 2.5–3                              | 3–3.25              | >3.25                      |
| Shoreline erosion/accretion (m/year) | >10            | 3–5                                 | −3 + 1                             | −10                 | −15                        |
| Mean tidal range (m)                 | >6             | 4–6                                 | 2–4                                | 1–2                 | <1                         |
| Mean wave height (m)                 | 30–35          | 15–20                               | 10–5                               | 4                   | <4                         |

#### 2.2.4. Shoreline Dynamics and Mapping of the Coastal Erosion

The measurement of the dynamics of the coastline has been carried out by using Landsat satellite images from 1973 to 2020 (Table A1). Coastal erosion mapping is based on the Digital Shoreline Analysis System (DSAS) model developed by Thieler et al. [53]. The

DSAS version 4.3 tool developed by USGS is an extension of the ArcGIS 10.5 software. It makes it possible to evaluate the evolution of the coastline. We used the 1973 shoreline to create the Baseline. Since it is moving due to the tide, we generated a 5 m Buffer around the 1973 line. Once established, the Buffer is transformed into a “polyline”. This is then exported to the “geodatabase”. Then, the land-oriented edges of this Buffer (for the movements of the offshore lines) and the sea-oriented edge (for the movements of the offshore lines) are extracted. This baseline plays an important role in calculation operations in DSAS. In the third step, orthogonal transects are generated at a specified spacing along the coast using DSAS when the “Personal geodatabase” is ready in ArcGIS. They are generated automatically by DSAS [54]. A total of 5828 orthogonal transects are generated across the entire Wouri estuary, and 962 at Kribi. The spacing between transects is 100 m. The length of each transect is 1100 m. The mean coefficient of determination is the average of all the coefficients of determination at each transect. The uncertainties in the annual rate of change in meters per year are the 95% confidence intervals (LCI95 or WCI95). As statistics are concerned, DSAS uses several statistical techniques comparing coastline positions over time to estimate the evolution of the coastline [54]. The main methods used in DSAS for this study are described below. In the last step, after creating the orthogonal transects, DSAS calculates the global changes in the coastline positions. The annual rate of changes in the coastline is calculated for each period using the end point rate (EPR) method, and the coefficient of determination ( $R^2$ ) is calculated by DSAS. The end point rate method is the distance on the transect between the two most recent and oldest coastlines divided by the number of years separating them [54] and rendered by the following equation:

$$R = D / T_e \quad (11)$$

where  $R$  is the speed in meters per year (m/year),  $D$  is the distance in meters, and  $T_e$  is the time elapsed between the oldest and newest coastline (years). EPR still works well when we have just two coastlines to analyze the evolution.

#### *Uncertainties and errors*

Several uncertainties and errors revolve around the DSAS model. Uncertainty values should ideally take into account both positional uncertainties associated with natural influences on shoreline position (wind, waves, and tides) and measurement uncertainties (e.g., scanning or global positioning system errors). Ruggiero et al. [55] provide a comprehensive summary of the methods for analyzing shoreline changes, which includes a detailed section on estimating uncertainty in shoreline position, as well as guidance on how to combine the various components of the uncertainty in a single attribute value for shoreline data. If the uncertainty attribute field is empty, DSAS uses the default value stored in the Shoreline Settings tab of the Set Defaults window. The spatial errors, specifically those of georeferencing for the different Landsat images, are estimated by the RMS (Root Mean Square) and the maximum value is 0.3 m. To calculate the margin of error based on the multi-date analysis of satellite images, we based ourselves on the USGS report [56] which expresses the error rates using the following equation:

$$ECI = \frac{\sqrt{(uncyA)^2 + (uncyB)^2}}{dateA + dateB} \quad (12)$$

With  $A$  = uncertainty of the attribute field of shoreline  $A$ ;  $B$  = uncertainty of the field of shoreline  $B$ ; date  $A$  = date of the assignment of shoreline  $A$ ; date  $B$  = date of the allocation of shoreline  $B$ . The annual value of uncertainties used is  $\pm 0.44$  m/year.

#### *Pixel error*

It relates to the precision of the image (resolution). It is the pixel size of the image. The pixel size of the image is 30 m for ETM+, TM, and OLI\_TIR images.

#### *Uncertainty rate on individual transects*

The shoreline change rate of a single transect is calculated as the quadrature addition of the uncertainties for each year's shoreline position divided by the number of years between shoreline surveys.

$$UR_i = \frac{\sqrt{Up1i^2 + Up2i^2}}{year2 - year1} \quad (13)$$

$Up1i$  and  $Up2$  are the uncertainties of the position of the banks of the first and second shore ( $year1$ ), respectively, at transect  $i$ , calculated by Equations (2) or (3). For the linear regression method (long term), the uncertainty of the rate of change in the shore of a single transect  $UR_i$  is found here in the form of a percentage at 90% on the linear [55]. Table 7 summarizes the different error margins calculated.

**Table 7.** Calculated error margins in m.

| Years            | 1973–1986 | 1986–2000 | 2000–2017 |
|------------------|-----------|-----------|-----------|
| RMS error        | 0.1       | 0.1       | /         |
| Mesurement error | 32        | 42        | 48        |
| Pixel error      | 2         | 4         | 3         |
| Annual error     |           | 0.7–1.3   |           |
| EPR: ECI         |           |           |           |

#### *Vulnerability mapping*

We performed the vulnerability mapping using data collected in the field, extracted from fieldwork (2007–2020), geoinformation, and data from the literature review. From a cartographic point of view, we superimposed the different layers of information in the Armap 10.5® software. Finally, to illustrate the finding, we use Excel 2016 to compute statistics with graphs of the CVI, ArcGIS 10.5, and ArcMap 10.5 to draw the vulnerability maps index of the whole Cameroon coast and to make the necessary projection. Due to some constraints (length of the paper) and because it has been previously published [57], only some sketches of the Kribi shoreline are presented in the results. Figure A2 in the Appendix A summaries the methodology chart.

### **3. Findings and Interpretations**

Coastal hazards in Cameroon's context, being natural or man-induced, hereafter included seism, volcanism, landslide, erosion, storms, and associated flooding. In addition, sea level rise and shoreline dynamics have also emerged as modern forms of coastal hazards with climate change. Figure 7 illustrates all types of hazards found within the Cameroon coast. In the coastal domain, one can list all the potential hazards, classifying them by a family of processes as previously mentioned. Classically, geohazards were the most known. All these are briefly described below.

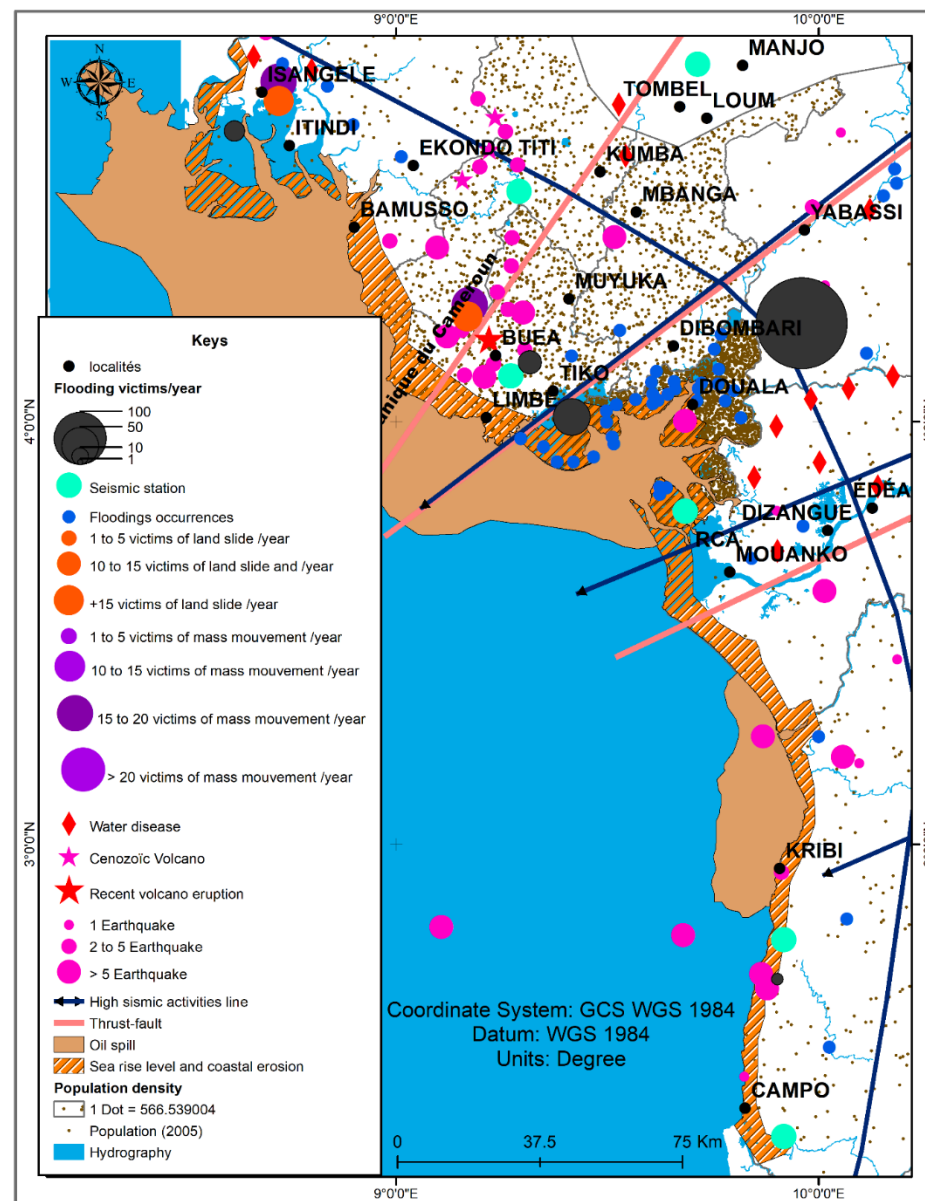


**Figure 7.** Coastal hazards in Cameroon.

### 3.1. Cameroon Coastal Geohazards

The Cameroonian coast is a complex environment because it associates a mountain part where the landslides take place and a plain part in which the floods occur. In addition, the northern section of this coastal region is volcanic while the southern section is established on sedimentary and basement formations. Natural hazards are ubiquitous on the Cameroon coast (Figure 4). However, the coastal zone appears as one of the most exposed. In addition, it is an extreme zone where the rainfall goes from single to triple, and then earthquakes are more frequent, especially around Mount Cameroon, without forgetting the more recurrent volcanism, even if both hazards seem less destructive.

#### 3.1.1. Coastal Seismic Hazards

Due to its intraplate situation and bordering the African plate in the Gulf of Guinea, Cameroon is experiencing regular earthquakes, particularly in the Mount Cameroon area, where Zogning [58] underlines more than 50 earthquakes per year for an average of 1 earthquake every six years [36,59]. This average is not far from earthquakes mapped by

Krenkel [60] Africa [59]. The Cameroon line records 11 to 20 earthquakes per year. Within this area, Mount Cameroon experiences at least 21–50 earthquakes annually (Figure 7). This illustration takes into consideration previous works [36,60–64]. Figure 8 compiled the main sites where most felt earthquakes are found in Cameroon (19–20 centuries). It means that the coastal zone around the Fako Mountains alone accounts for the largest number of earthquakes recorded in Cameroon (more than half). This total, nevertheless, appears lower than what is observed on the side of the Great Lakes. In addition, these earthquakes rarely exceed level 6 on the Richter scale, and this is one of the reasons why it never brings more damage. Cameroon, as well as Central and West Africa, have always been considered stable [65] and less exposed to these hazards, even though the occurrence of hazards related to geodynamics is common. Thus, the Cameroon Volcanic Line, which is still active, is one of the major past and current volcanism.

As shown by the map, Ntepe [62], stressed that close to 40 felt tectonic earthquakes have occurred in and around Cameroon within the last 165 years with the Richter scale ranging from 2.6 to 5.7, and their intensities (Modified Mercalli) range from III to VIII [66]. These earthquake occurrences are caused by the existence of a mega fault structure (the Fouban Shear Zone, or Ngaoundere lineament in the north, and the Congo craton and Sanaga fault systems in the southern part of the country (Figure 8)).

Frequent or periodic movements along these faults result in earthquakes in areas like Tibati, Magba, and Garoua-Boulai to the north, and Kribi, Lolodorf, Akonolinga, and Yokadouma to the south [67]. As Cameroon Mountains are concerned, eruptive activity is also associated with the occurrence of volcanic earthquakes, some of which are strong enough to rock houses [62] even if these houses are built without respecting earthquake-resistant standards.

### 3.1.2. Coastal Volcanic Hazards

Outside earthquakes, volcanic hazard is the preserve of the Cameroon highlands, but it also occurs in the coastal zone, particularly around Mount Cameroon, which remains the current most active volcano in Central and Western Africa. It has erupted seven times within the last 100 years [36,68], with the last two eruptions occurring in 1999 and 2000. In terms of volcanic hazards, Bardintzeff [69] identifies seven primary volcanic hazards, four of which are applicable in the Mount Cameroon area and were really observed in 1999 and 2000. These are lava flows (Fako, 1982, 1999, and 2000 eruptions), pyroclastic fall and ash fall (1999 eruptions), burning clouds (2000 eruptions), and lahars, i.e., mud flows or volcanic landslides (1922 eruptions). With 15 eruptions between the 1800s and 2000 [36,59], Mount Cameroon gives a recurrence of an eruption on average every 17 years. Volcanic and seismic hazards are the best monitored in Cameroon, especially near the Chariot of Gods (equipped with telemetered seismographs). While earthquakes do not occur necessarily always with volcanism, the correlation between earthquakes and volcanic activity is very high in Cameroon. This makes the prediction of eruptions and earthquakes adequate and allows a better understanding of the evolution of volcanism at Mount Cameroon near the coast. Nevertheless, the tendency is an increase in volcanic and seismic manifestations. Of the four volcanic hazards, lahars have historically been reported as justifying the great rift on the western flank of Mount Cameroon [36], which suggests that heavy rains fell on this slope during this historic eruption. Similarly, the abundance of rainfall, ambient humidity, and gravity largely explain the occurrence of landslides around the Cameroon Mountains and the coastal fringe.

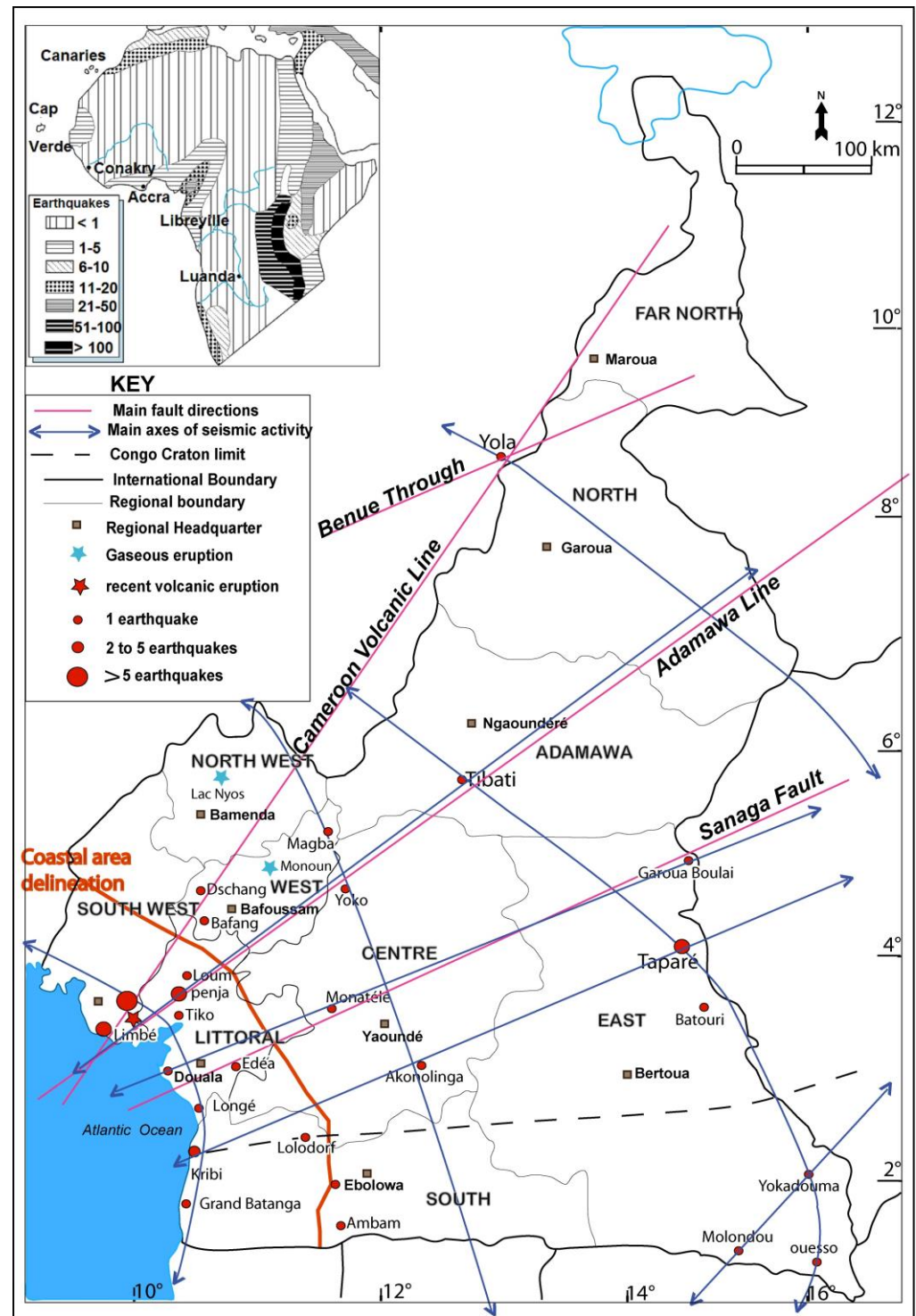


**Figure 8.** Cameroon earthquake map (source: Tchindjang [31]).

### 3.1.3. Coastal Landslide Hazards

Landslides appeared as a recent phenomenon in Cameroon since 1950. Indeed, most studies focused on geomorphological slope dynamics tried to evoke the occurrence and dominance of landslides in the slope dynamics. These phenomena were observed in random spots in favor of heavy rainfalls or within the trenches of major roadworks. Still, the term slope dynamics is broader and includes landslides themselves, rockfalls, subsidence, creeping, mud flows, etc. According to Ayonghe et al. [70–72], more than 300 landslides have been felt (historical and oral memory) or recorded in Cameroon since 1954. More than

450 common triggering mechanisms for landslides in Cameroon include one or a combination of heavy rainfall, earthquakes, volcanic eruptions, and anthropogenic factors like urbanization, deforestation, and domestic/industrial sewage seeps. Most of the landslides occurred in localities along the CVL [36,73,74] and between June and September, which is the rainiest period of the year in Cameroon.

#### 3.1.4. Hydrometeorological or Climatic Hazards

Coasts in Africa are sometimes subject to rapid change. In the context of climate change, it is essential to characterize situations of hazard and vulnerability in coastal zones. Coastal areas are the areas of greatest hazards in the world and are the parts most affected by climate change. Studies at a global level show that there is a positive trend in the frequency of warm extremes and a decrease in the frequency of cold extremes [75]. In relation to rainfall, it has increased in medium and high latitudes but decreased in the tropics and subtropics [76,77], resulting elsewhere in floods, storm surges, etc.

### 3.2. *Climate Change Evolution and Impacts on Vulnerability in Coastal Areas*

#### 3.2.1. Coastal Flood Hazards in Cameroon

Of the natural hazards that can affect the coastal zone and increase vulnerability, flooding is the first and by far the most important. The concept of “flooding” explicitly includes “sea-based flooding in coastal areas” and river flooding. River flooding is caused by excessive runoff brought by heavy rains, storm surges, or coastal flooding and is often exacerbated by storm runoff from the upper watershed. Marine submersion, such as the one of Limbe in 2001 [58], is a temporary or episodic flooding of the coastal zone by the sea. It is caused by severe weather and tide conditions. Extreme events like atmospheric depression, wind, swell, and rain, along with strong tidal coefficients that cause the water level to rise significantly, usually cause this terrible event. It is the result of surges in ocean water caused by cyclones, storms (Limbe in 2001), and tsunamis. River flooding is considered permanent flooding resulting in the permanent degradation of land from coastal wetlands and deltas. It is the most frequent, and it causes more damage than permanent inundation. Flood risk is the combination of two factors, hazard and vulnerability. Flood hazard is very common in coastal areas. But, this hazard will be less important in uninhabited and non-urban areas. Coastal cities like Limbe, Douala, Tiko, and others better perceive flood hazards. The first record of this phenomenon in Cameroon dates back to 1980.

#### 3.2.2. Coastal Erosion in Cameroon

In coastal regions, erosion entails the removal of sediments by waves, tides, and currents. Sediment balance primarily influences coastal erosion, a multifactorial natural phenomenon. It occurs on a littoral section when the sediment losses (erosion and retreat) are greater than the contributions (accretion or fattening). The movements of sedimentary balance are connected to the effects of continental (rain, frost, and wind) and marine processes (swells, tides, and marine currents). However, people can also upset this balance [78]. Erosion rates reach up to 1.15 m/year in Cape Cameroon, while sediment deposition is minimal due to tidal currents and wave action in the Cameroon estuary. But the effects of flooding are more important because, in this zone, muddy coasts predominate. In such a context, it is difficult to have a very accurate estimate of the effects of erosion. Mbevo [31] succeeded in assessing coastal erosion at Cape Cameroon with 1.15 m/year [79].

#### 3.2.3. Sea Level Change Assessment in Cameroon

Sea level rise (SLR) is considered one of the oft-cited effects of global warming (rise in global temperature due to the enhanced emission of greenhouse gases). We observed it in Idenau Bibundi, where it poses a threat to coastal facilities and causes erosion. For

those living on small islands (Manoka and Cape Cameroon), the vulnerability is high [73]. According to the IPCC [76], the global average of SLR over the 1993–2003 period was about 3.1 mm per year. Increased rainfall and increased sea currents due to rising sea levels will increase sedimentation. Future sea level rise can cause huge impacts on Cameroon's coastlines, including mangrove degradation. We should not neglect the risks of partial or total flooding due to an accelerated rise in sea level. Between 1948 and 2003, Cameroon experienced an SLR rate of 1.8 to 2.2 mm per year. The projections for 2050 place it between 9 and 38 cm and then 86 cm in 2100 [80], while in the world, the UN stressed 20 cm by 2050 and 56 cm by 2100 with 2.7° warming against 8 cm by 2050 and 38 cm by 2100 with 1.5° [75,76,81].

### 3.2.4. Coastal Vulnerability

Vulnerability represents the degree of exposure of human lives, assets, and systems to a disaster. Vulnerability also concerns the incapacity to anticipate, to face, to withstand, and to recover from the impact of a calamitous event [82–85]. Vulnerability can be physical, social, political, and economic. Vulnerability “depends on the threats posed by hazards to a society” [86]. Vulnerability depends on a combination of factors on perception (it covers and expresses the consequences of the phenomenon on the assets (human–environment–nature damage) and the preparedness (the ability of societies to respond and overcome crises) face to the disaster. This perception included different forms of knowledge (like information, social beliefs, values, etc.) towards an object or event (e.g., risk), and related to behaviors in a person or a group of people (inhabitants, decision-makers, and local authorities).

Blaikie et al. [84] show that vulnerability can be considered in terms of five components: initial well-being, self-protection, social protection, livelihood resilience, and social capital; each crucially linked to the likely severity of the impact of a given hazard. These components are all determined by political, economic, or social processes. But in this paper, vulnerability combined four parameters (structural damage, bodily injury, functional loss, and hazard perception) which largely included the above components defined by [82]. We shall access it with the above typology.

### Geohazard vulnerability

#### *Seismic and volcanic hazard vulnerabilities*

Earthquakes in Cameroon are less dangerous. But in the context of increasing population in coastal regions, it could become harmful. As Cameroon Mountains are concerned, eruptive activity is also associated with the occurrence of volcanic earthquakes, some of which are strong enough to rock houses [62] even though these houses are built without respecting earthquake-resistant standards. However, the human concentration along the coast (Limbe, Tiko, Douala, and Kribi) is more than 3,000,000 inhabitants. It does not exclude greater damage even in the case of low magnitude, because there is no seismic construction on these coasts and therefore, it is the people who expose themselves to this hazard. For example, in 1999, the tremors accompanying the Mount Cameroon eruption affected some poorly built houses in Buea and were felt from Douala to Nkongsamba, more than 150 km from the coast to the hinterland. One can notice that the lava flows, though destructive, have never killed people but destroyed their property. The only damaging killing event recorded on Mount Cameroon is the mud flow that followed the 1922 eruption and killed 100 people [87]. The 1999 Cameroon Mountains eruption provoked an interruption of road traffic on the West Coast to Idenau, Bibundi, and Debunscha and burned out more than 900 ha of oil palm plantation at Bakingili. Thus, lava flows, ash falls, pyroclastic falls, mud flows, volcanic landslides, lahars, rock fall, and relative volcanic gas emissions are common threats posed by the volcano on its inhabited and agricultural southeast, east, and northern flanks. It provoked a road deviation of less than 1 km (Figure 9).



**Figure 9.** Lava flows from the 1999 Cameroon Mountains eruption. It cut the West Coast highway and stopped just at 50 m from the ocean. A deviation was built to allow continuous road traffic. (Source: Tchindjang, April, 2007.)

#### *Coastal vulnerability to landslides*

There have been almost more than 300 recorded landslides (historical and oral memory) in Cameroon since 1954, with more than 200 people killed and much damage (devastation of farmlands, excavation, destruction of houses, road infrastructure, water tower, etc.) [70,88]. In our personal records, landslides have killed at least 100 people every year for the past 20 years in Cameroon. Devastating landslides have occurred in some cities around the coast (Limbe and Douala). Regarding Cameroon's coastal areas and considering historical sources, the authors identified some observed landslides. It is worth mentioning that, unfortunately, the works conducted do not mention the volumes of materials moved. Most of the observed landslides are produced in September (57%), August and July (14 and 28%, respectively), June (9.52%), and October (4.76%). Landslides generally destroy crops, buildings, and residential homes (Figure 10) or cause the loss of lives.

A coastal hazard assessment should relate the hazard magnitude to its likelihood of occurring, and the source and significance of uncertainties should be identified. Coastal natural hazards come from the conjunction between vulnerability and natural events. Table 8 shows the severity of geohazards.

**Table 8.** Vulnerability to geohazards along the Cameroon coast.

| Type of Hazards/<br>Parameters | Personal<br>Injuries<br>(X1) | Functional<br>Losses<br>(X2) | Structural<br>Damages<br>(X3) | Hazard<br>Perception<br>(X4) | Severity<br>(X1 + X2 + X3 + 3 + X4)/4 | Frequency | Final<br>Vulnerability |
|--------------------------------|------------------------------|------------------------------|-------------------------------|------------------------------|---------------------------------------|-----------|------------------------|
| Earthquake                     | 1                            | 1                            | 2                             | 4                            | 2                                     | 1         | 2                      |
| Volcanic<br>eruption           | 5                            | 5                            | 5                             | 4                            | 4.75                                  | 2         | 9.50                   |
| Landslides                     | 5                            | 5                            | 5                             | 5                            | 5                                     | 3         | 15                     |

As shown by the table on coastal geohazard severity, landslides appear more critical and dangerous, and coastal populations with their assets remain more vulnerable. Also, the earthquake is minor and people remain less vulnerable. Volcanism around the coast is nearly moderate and destroys goods (plantations and road cutting), but it is tolerable. However, in case of a high concentration of population, it will become unacceptable in coastal cities. Landslides around coastal cities are really destructive for goods (plantations and road cuts) and human lives, and sometimes unacceptable because of the high concentration of population and their assets.



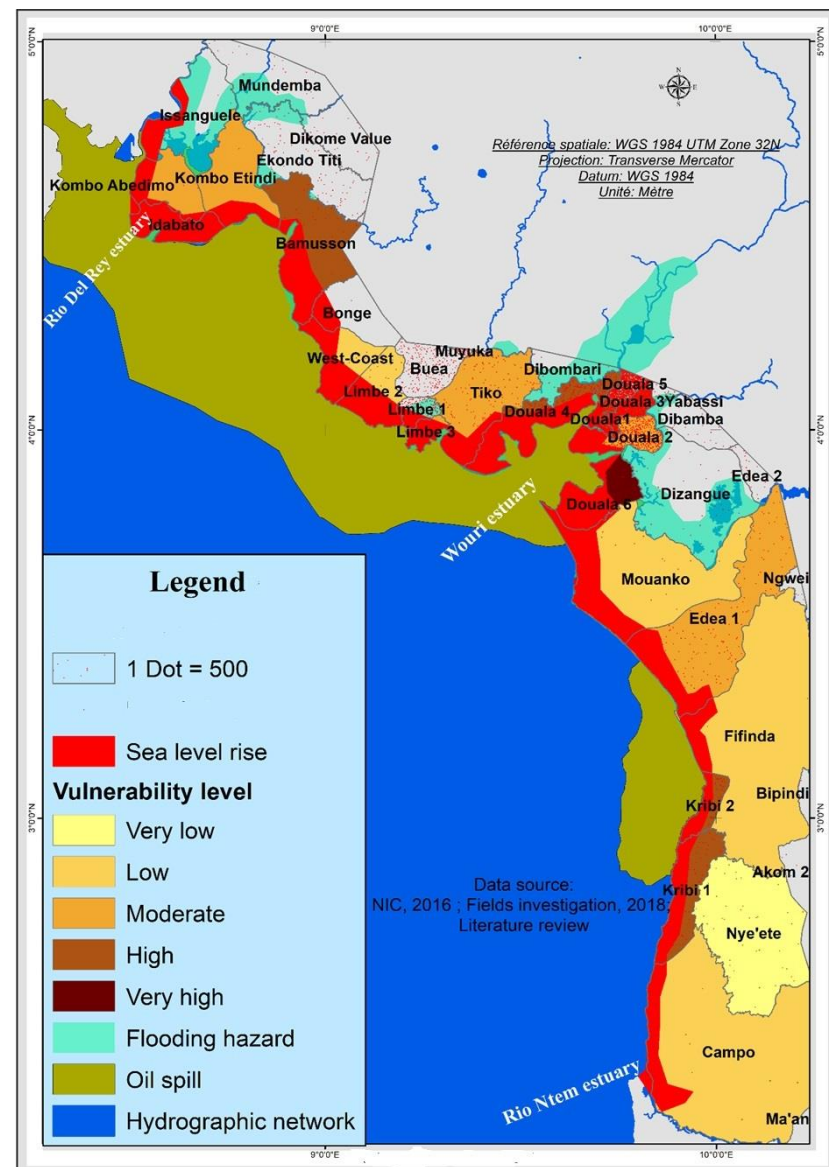
**Figure 10.** Landslide manifestations in the coastal areas of Cameroon. At the top left, food crops on the slopes at Bimbria. Right, a landslide with the destruction of crops (banana trees in Bimbria). Here is a change in land use on the Mutengene road with the introduction of maize (a very ravenous plant) and banana plantations that gradually bite the slopes and replace the forest. (Source, Tchindjang, December 2012.) In the middle, a hillslope is affected by a mass movement in Limbe city, and one can see houses and property exposed to damage. The last photos showed the way the municipality and agro-industries are fighting against landslides through rocky gabions.

#### *Coastal Urbanization and vulnerability.*

Urbanization, with its corollaries, are factors closely related to the many facets of human activities that, in one way or another, contribute to increasing the threat by the declining of vegetation cover. Population growth has been identified with the extension of urban space, the use of drains and watercourses as a dumping ground, the absence of planning that engenders shanty townships, cultural burdens, and poverty. Cameroon's urban population has grown from 2.2 million in 1976 to 16 million in 2021, for a total of 27 million inhabitants. Table 9 shows the distribution of population parameters between coastal cities. It is completed by Figure 11, which illustrates the population level of vulnerability.

**Table 9.** Population, density, and urbanization rate in the main coastal cities of Cameroon.

| Parameters                           | Limbe   | Kribi   | Tiko    | Douala    |
|--------------------------------------|---------|---------|---------|-----------|
| Country area pays (Sq)               |         | 475,650 |         |           |
| Total population                     | 200,000 | 120,000 | 134,649 | 4,063,000 |
| Urban population                     | 112,641 | 120,000 | 95,885  | 3,063,000 |
| Urban area (Sq)                      | 12.9    | 1885    | 9.8     | 210       |
| Urban density (inh/km <sup>2</sup> ) | 8731    | 64      | 9041    | 14,586    |
| Data year record                     | 2021    | 2021    | 2021    | 2021      |
| Urbanization rate                    | 60      | 65      | 55      | 85        |

**Figure 11.** Coastal population level of vulnerability.*Coastal vulnerability to hydrometeorological or climatic hazards.*

Flood hazards are better perceived in coastal cities like Limbe, Douala, Tiko, Idenau, Debunscha, etc. Its occurrence is related to heavy rainfall that hit the coast. The causes are aggravated by anarchic occupation in prohibited areas by building and also deforestation. In urbanized areas, the functional components prone to flooding are buildings, equipment, houses, roads, and tracks. In rural areas, it takes with it the habitat, cultures, and protected

areas. Cameroon, because of several natural and human factors, is a country with flood risk in many of its regions. However, the coastal region appears more vulnerable because it is more predisposed due to its flat topography, whose various human factors contribute to the aggravation.

Among the vulnerabilities identified and faced by coastal regions are habitat destruction and the loss of biological diversity, the latter often being a consequence of the former, since it is true that the coastal area concentrates multiple pressures: changes made to soils and landscapes by certain agricultural practices, excessive urbanization, and destruction of wetlands, therefore, environments conducive to rest and reproduction of species. Added to this are the pollution of terrestrial and coastal sea environments, the overexploitation of fishery resources, and the risks generated by climate change on biodiversity that are now starting to be assessed. The loss of coastal biodiversity is proven: the coastal risk, here, is that of an acceleration or the worsening of the observed trend.

### 3.2.5. Climate as a Determinant Forcing Factor

Climate is a determining element in the evolution of Cameroonian coastal environments and societies because the strong spatio-temporal variability of the two parameters (temperatures and precipitation) is characterized by an alternation of dry and humid rain sequences correlated since 1971 with increasing temperatures and a marked rise over the last two decades (2000–2020), as can be read in Figures 12 and 13.

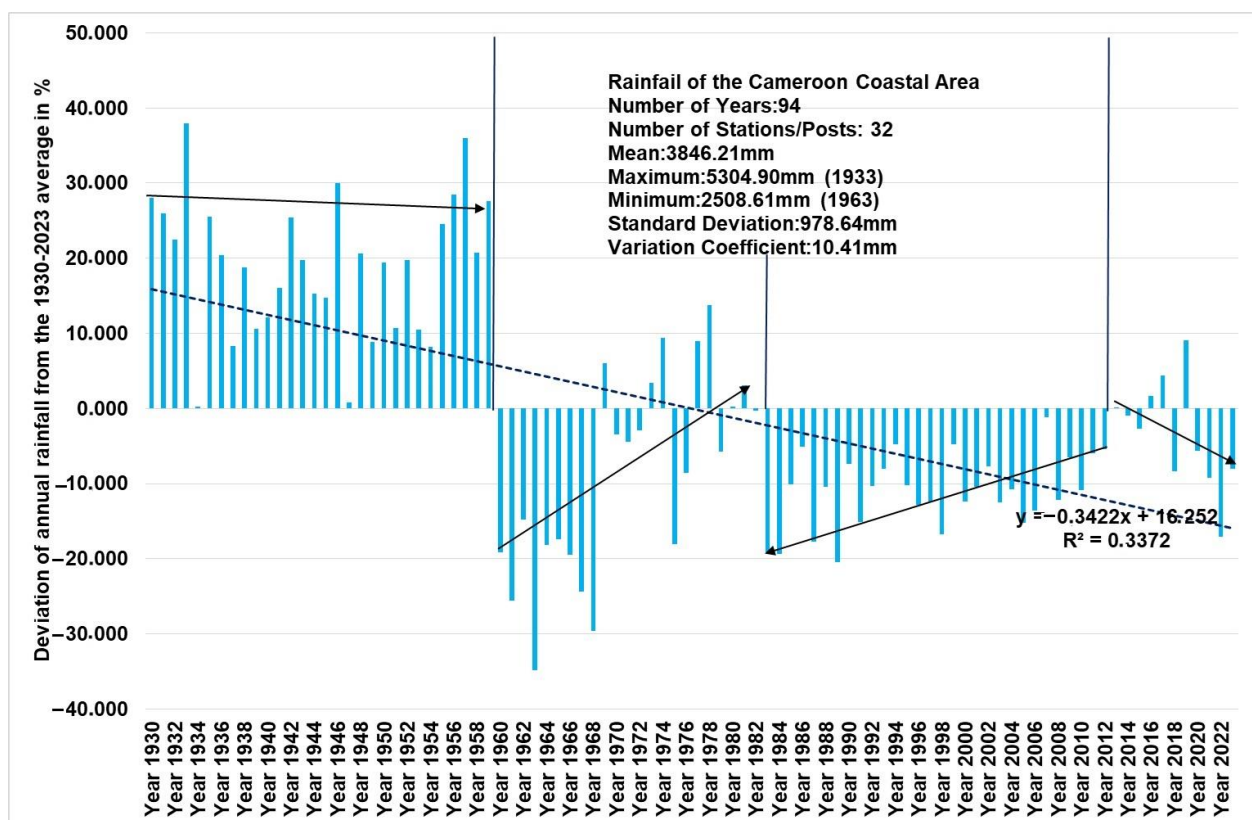


Figure 12. Evolution of the total mean rainfall in the Cameroon coast.

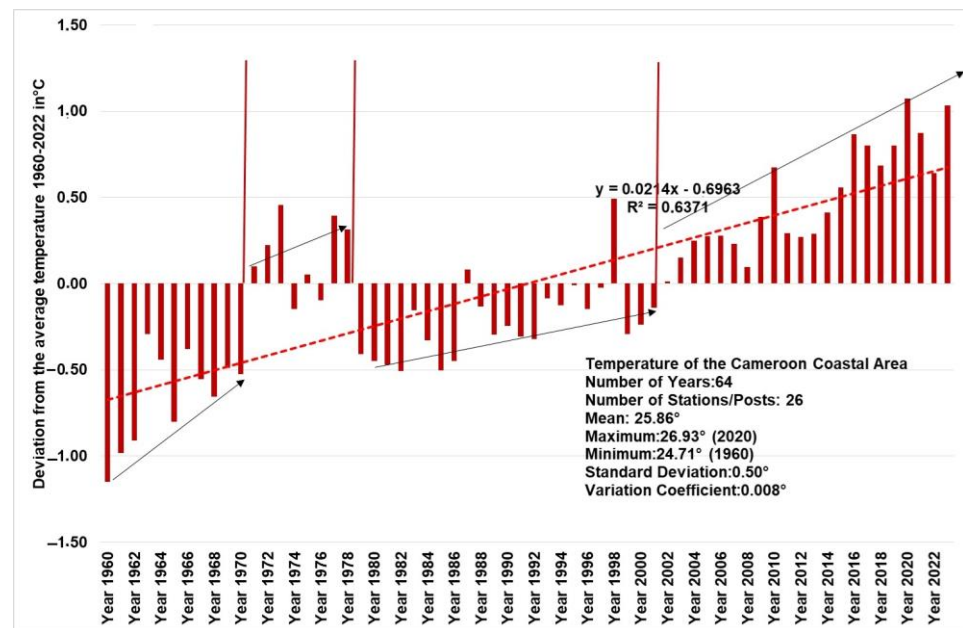


**Figure 13.** Evolution of the temperature on the Cameroon coast.

As for annual precipitation in the coastal zone (Figure 12), for nearly 32 stations in 94 years, the analysis of Figure 12 reveals four major periods, characteristic of the evolution of climatic conditions in the Cameroonian coastal region (1930–2023). The period 1930–1959 is a wet sequence characterized by abundant rainfall without dry sequences and records of more than 35% in 1933 and 1957. The second period goes from 1960 to 1983 and is marked at the beginning by a dry sequence from 1960 to 1968 with a pronounced deficit of –30% of annual precipitation in 1963 and 1968 followed by an alternating dry sequence/wet sequence from 1969 to 1982. The anomalies are largely negative because it includes the two drought sequences that marked Tropical Africa (1972–1973 and 1983–1984). The third period goes from 1983 to 2012 (30 years) and it is essentially negative with challenges of up to –20% of annual precipitation. The last period goes from 2013 to 2023 and is characterized at the beginning by an alternating wet sequence/dry sequence to end the last 4 years (2020–2023) with a negative sequence reflecting a continuous deficit in precipitation since 1930 as illustrated in the trend curve. These prolonged and intense rainfall deficits and their strong spatial variability (32 stations) have consequences on eco- and socio-ecosystems. Indeed, these profound deficits affect coastal societies (the destruction and degradation of mangroves, vulnerability of fishing, and significant socio-spatial changes) through recurring floods which threaten the lives of more than a million inhabitants.

Apart from rainfall with its crucial influence on vital human activities, temperature was also taken into account in the analysis of climatic conditions in the Cameroonian coastal zone. The temperature was analyzed from 1960 to 2023 at 26 stations in the coastal zone. Figure 13, which illustrates it, shows four periods. The first period goes from 1960 to 1970 and shows a decrease in temperatures of 0.50 to 1°. The second goes from 1971 to 1978 with an increase in temperatures of 0.50° compared to the average. The third, longer sequence goes from 1979 to 2001, and is characterized by a decrease in temperatures of –0.50° in 23 years. The last period goes from 2002 to 2023 and is characterized by an increase in temperatures of around 0.20 to 1.1°. It actually corresponds to the period where in Cameroon, the populations consulted and surveyed located the beginning of felt global warming. The temperature curve reflects an overall increase in temperatures at a time when rainfall is increasingly lacking. This increase in average temperatures is a confirmation of the warming trend observed on the African continental and global

scale. Consequently, the importance of the variability of climatic conditions (rainfall and temperature) in the Cameroonian coastal zone has had undeniable repercussions on the dynamics of ecosystems (coastal forest and mangrove) and productive systems.

With climate change as shown in both figures, floods become more frequent due to violent storms concentrated in time and space. Its results on soil saturation are because of excess water especially in shallows, and depressed areas where the water table is already close enough to the surface. Moreover, even though floods remain frequent in Cameroon's coastal cities, the populations have most of the time developed techniques to reduce as much as possible the loss of life by drowning. However, they are generally the victims of secondary risks such as the contamination of water and food. With its strong predisposition to flood risks, the coastal zone undergoes recurrent floods that are aggravated by climate changes. It causes death despite the strong predisposition, and community response times align with established early warning systems but remain insufficient in high-risk zones. One can observe the displacement of certain populations of risk zones in Douala when the rains are accompanied by a beginning of rising water. Nevertheless, flooding often causes significant damage, especially since a single loss of life, however isolated, always causes enormous pain to the family and the state.

Observations show that floods have plunged many families into significant damages that are difficult to quantify. It is noted that most of the time in Douala, the victims only withdraw in case of extreme danger but come back later; a definitive departure here is often the result of a forced eviction by the public authorities. High quest for land (as in Douala with migrations) and poverty result in people cutting off the coastal hill slopes and unconsolidated pyroclastic cones (in Limbe) prone to landslides to build houses. Landslides and floods killed about 10 (mostly slum-dwelling) people every year in the city between 1990 and 2024 and destroyed many buildings, roads, bridges, and lifelines (electricity and water). In the past 30 years, floods have affected more than 120,000 people and killed more than 200 people in coastal cities.

Coastal erosion has some significant effects on humans and their assets among which are the following: (i) leaching of the coast by waves that transport sediments from upstream to downstream of the basin which will cause the destruction of sandy beaches in mangroves (Cape Cameroon, Kangué, [31]) (ii) increased erosion which will also deport mangrove substrates offshore (at sea), reducing the size of these mangroves with 1162.25 ha losses in 30 years at Cape Cameroon [79]. The disappearance of trees will accelerate erosion, which will result in the case of Cameroon in a total recession of mangroves. Figure 14 illustrates the effects of coastal erosion on the Limbe and Kribi coasts.

There is a close link between coastal erosion and sea level rise. Also, coastal erosion nowadays has become a human-induced hazard due to the way policymakers manage coastlands. SLR will, in Cameroon coastal cities, affect most of the coast components like beaches, estuaries, deltas, mangroves, and industrial plantations (Figure 15). In addition, rising temperatures result in increased evapotranspiration, leading to more frequent and more violent storms. The most devastating cases occurred in 2000, 2003, and 2007 in the South-west Coastal Highlands, with losses estimated at USD 450,000 [38,39,73].

Douala city remained more vulnerable to floods that caused damage and destroyed homes, businesses, schools, hospitals, etc. The same observations can be transposed without the risk of being wrong at Limbe, Tiko, Idenau, and Bibundi.

In terms of social vulnerability, the analysis of CRED data focused on the bodily injury that characterizes all the damage caused to human beings by floods. These are the numbers of injured, homeless, affected, and dead. Like all the other hazards, floods cause considerable injuries and death around the world. These harms are a function of their

intensity, scale, and the resistance or resilience of the populations that face them. Table 10 recaps the vulnerability assessment.



**Figure 14.** Effects of coastal erosion on Limbe and Kribi Coast (source: Tchindjang, 2012 and 2017).



**Figure 15.** Sea level rises threatening roads and oil palm plantations in the West Coast district of Cameroon (source; Tchindjang, December 2012).

Floods are harmful and catastrophic and people remain more vulnerable while coastal erosion around coastal areas is critical and destructive for people's goods (plantations and road cuts), but non-tolerable. However, with a high concentration of population, coastal erosion could become unacceptable in coastal cities. The same with sea level rise, which appears moderate.

**Table 10.** Vulnerability to coastal erosion, SLR, and floods.

| Type of Hazards/<br>Parameters | Personal<br>Injuries<br>(X1) | Functional<br>Losses<br>(X2) | Structural<br>Damages<br>(X3) | Hazard<br>Perception<br>(X4) | Severity<br>(X + X2 + X3<br>+ X4)/4 | Frequency | Final<br>Vulnerability |
|--------------------------------|------------------------------|------------------------------|-------------------------------|------------------------------|-------------------------------------|-----------|------------------------|
| Floods                         | 5                            | 3                            | 4                             | 4                            | 4                                   | 5         | 20                     |
| Coastal<br>erosion             | 2                            | 3                            | 3                             | 5                            | 3.25                                | 5         | 16.25                  |
| Sea level rise                 | 2                            | 3                            | 3                             | 5                            | 3.25                                | 4         | 13                     |

### 3.2.6. Impacts of Meteorological Hazards on Livelihoods

However, coastal areas remain mostly vulnerable to floods and erosion. Douala, Yoyo, Limbe, Bimbia, Tiko, Idenau, and Debunscha are constantly exposed to these hazards. The building of huts and houses requires the establishment of an insurance system that still does not exist. Assistance at this level, as is currently the case, consists of tents of fortunes, which do not secure the lives of victims. Infrastructures and equipment are expensive, and their destruction cuts the populations of the concerned localities of their neighbors, thus making difficult exchanges, to say the least; it is the case during catastrophic floods. Climate change will have impacts on the distribution of energy and industries. They will lead to floods, floods, soil erosion, and saltwater infiltration. These factors will have detrimental consequences on the independent maritime ports of Limbe (and its annexes of Idenau-Bibundi, Tiko, and Debunscha), Douala, and Kribi. Most of the industries are located in these highly industrialized and urbanized areas where hazardous events cause population displacement and the resettlement of psychologically affected victims.

Urbanization is a phenomenon whose influence on population growth, migration, fertility, etc., can no longer be ignored. The fact that a city like Limbe is industrialized (SONARA) and could be one hour from Douala, the economic capital, remains a challenge. Most of the cities are aligned along the coast, less than 30 km away, while in the hinterland, this distance goes from 30 to 100 km. Urban development and public works affected land use and nibbled the space devoted to agriculture while causing migration.

Floods and erosion have been clearly identified by the south-western populations as climate-related threats. There is a clear tendency for households in the region to combine fishing and agriculture instead of specializing in one of these sectors. This diversification certainly helps households to better adapt to climate hazards. Thus, alongside these agrosylvopastoral and piscicultural activities, there are other income-generating activities, such as handicrafts and petty trading, which should be encouraged. Even in the absence of regularly recorded data, each threat must be taken into account with its characteristics and the degree of exposure of populations and their properties, especially if one wants to consider the way in which climatic hazards affect the resources available (Table 11).

It can be seen from this table that climatic hazards, in terms of exposure, hurt small farmers (106.25), fishermen (93.95), and traders (93.95). They destroy soils (75) and crops (100), and affect fisheries (56.25), trade (81.25), transport (93.95), tourism (93.95), and water supply (81.25). In terms of the impact index, floods come first (69.18), followed by intense rains (63.56), rising sea levels (58.68), and then erosion (54).

These three specific hazards (floods, coastal erosion, and sea level rise) on the coast will experience an increase in intensity and magnitude by 2030, as illustrated in Table 12. Not only are floods recurrent (Limbe, Douala, Idenau, Debunscha, Kribi, Nkongsamba, etc.), but also certain coastal localities (Idenau, Bibundi, Cap Cameroun, etc.) are threatened by sea level rise, a consequence of global warming. These dangers are added to land movements and active deforestation in fishing areas. Such a situation leads to a reduction in mangroves, the presence of which protected the coastline and constituted a spawning

ground for biological life in the oceans. More than two million people are threatened in this region by these climatic events. The most catastrophic floods were recorded in 2001 in Limbe, 2010, 2015, and 2020 in Douala. Added to this, the winds destroyed 100 huts in a fishing camp in 2019 in Manoka.

**Table 11.** Impacts of climate hazards on livelihoods in coastal regions.

| Parameters                | Floods | Storms,<br>Intensive<br>Rainfall | Erosion | Sea Level<br>Rise | Total  | Average | Exposition<br>Index |
|---------------------------|--------|----------------------------------|---------|-------------------|--------|---------|---------------------|
| Ecosystem services (1)    |        |                                  |         |                   |        |         |                     |
| Soil water                | 2      | 2                                | 3       | 3                 | 10     | 2.5     | 62.5                |
| Water supply              | 3      | 3                                | 3       | 4                 | 13     | 3.25    | 81.25               |
| Forestry, reforestation   | 3      | 4                                | 3       | 3                 | 13     | 3,25    | 81.25               |
| Soils                     | 3      | 3                                | 3       | 3                 | 12     | 3       | 75                  |
| Total                     | 11     | 12                               | 12      | 13                | 48     | 12      | 300                 |
| Average 1                 | 2.75   | 3                                | 3       | 3.25              | 12     | 3       | 75                  |
| Livelihood activities (2) |        |                                  |         |                   |        |         |                     |
| Food crop                 | 5      | 4                                | 3       | 4                 | 16     | 4       | 100                 |
| Livestock                 | 3      | 3                                | 2       | 3                 | 11     | 2.75    | 68.75               |
| Fishing                   | 2      | 2                                | 2       | 3                 | 9      | 2,25    | 56.25               |
| Trade                     | 4      | 3                                | 3       | 3                 | 13     | 3,25    | 81.25               |
| Handicraft                | 3      | 3                                | 2       | 2                 | 10     | 2,50    | 62.5                |
| Casual labors             | 4      | 3                                | 3       | 3                 | 13     | 3.25    | 81.25               |
| Road transportation       | 4      | 5                                | 3       | 3                 | 15     | 3.75    | 93.95               |
| Tourism                   | 5      | 4                                | 3       | 3                 | 15     | 3,75    | 93.95               |
| Total                     | 30     | 27                               | 21      | 24                | 102    | 25.5    | 637.9               |
| Average 2                 | 3.75   | 3.38                             | 2.63    | 3                 | 12.75  | 3.19    | 79.74               |
| Livelihood actors (3)     |        |                                  |         |                   |        |         |                     |
| Small farmers             | 5      | 5                                | 3       | 4                 | 17     | 4,25    | 106.25              |
| Fishers                   | 5      | 4                                | 3       | 3                 | 15     | 3.75    | 93.95               |
| Traders                   | 5      | 3                                | 4       | 3                 | 15     | 3.75    | 93.95               |
| Others                    | 3      | 3                                | 3       | 3                 | 12     | 3       | 75                  |
| Total                     | 18     | 15                               | 13      | 13                | 59     | 14.75   | 369.15              |
| Average 3                 | 4.5    | 3.75                             | 3.25    | 3.25              | 14.75  | 3.68    | 92.28               |
| General total             | 59     | 54                               | 46      | 50                | 209    | 52.25   | 1307.05             |
| General average           | 3.69   | 3.39                             | 2.88    | 3.13              | 13.06  | 3.27    | 81.69               |
| Impact index              | 69.18  | 63.56                            | 54      | 58.68             | 244.88 | 61.31   | 1531.68             |

**Table 12.** Hazards linked to the coastal environment in Cameroon.

| Cities                                  | Douala |      | Kribi |      | Limbe |      | Idenau/Bibundi |      |
|-----------------------------------------|--------|------|-------|------|-------|------|----------------|------|
| Hazards                                 | 2020   | 2030 | 2020  | 2030 | 2020  | 2030 | 2020           | 2030 |
| Floods                                  |        |      |       |      |       |      |                |      |
| Coastal erosion                         |        |      |       |      |       |      |                |      |
| Sea level<br>rise/marine<br>submergence |        |      |       |      |       |      |                |      |

N.B. For the gravity scale, please refer to Table 4.

### 3.2.7. Anthropogenic-Induced Coastal Hazards in Cameroon

There are intense anthropogenic activities on sandy and soft coasts that give way to erosion, which is accentuated by the destruction of coastal vegetation and the disorderly exploitation of sand on the coast and shoreline. The destruction of the vegetation cover in the coastal zone is also a consequence of the uncontrolled occupation of peri-urban areas

and the anarchic construction of houses near the shore. In addition, one can notice the large-scale destruction of mangrove forests for a variety of reasons (firewood production, fish smoking, and building materials), all of which, with the extraction and collection of sand, accelerate the growth of mangrove forests. Coastal erosion facilitates the occurrence of floods. The best assessment of the phenomenon was observed at Kribi, where there is a rise in water due to the construction of the deep-water port of Kribi at Lobe Falls. Kribi is chosen to illustrate coastal erosion in shoreline dynamics.

#### Kribi Coastline dynamics

The shores evolve by erosion and sedimentation. The results of the literature search revealed that the fattening and the degrading of the coastline are caused by both anthropogenic forcings and marine weather. In fact, the shorelines of the Cameroonian coast are influenced by terrestrial, marine, and atmospheric processes that interact and participate in its evolution. In general, a forcing is an action that acts on (forces) a dynamic system (ocean, atmosphere, or human activities) and can disturb its equilibrium state. Marine weather forcing dynamics are animated by several currents that mobilize sediments and influence the sediment budget.

On the Cameroonian coast, coastal erosion is most active at Kribi [57] and in the Wouri estuary [79,89,90]. Also, the analysis shows a strong alternation of transects in erosion and those in accretion over the entire length [57]. The coastal strip where Cap Cameroun is located is the most eroded. A summary of the statistics of the dynamics of the coastline at Kribi is provided and can be extended to the whole Cameroonian coast (Figure 16).

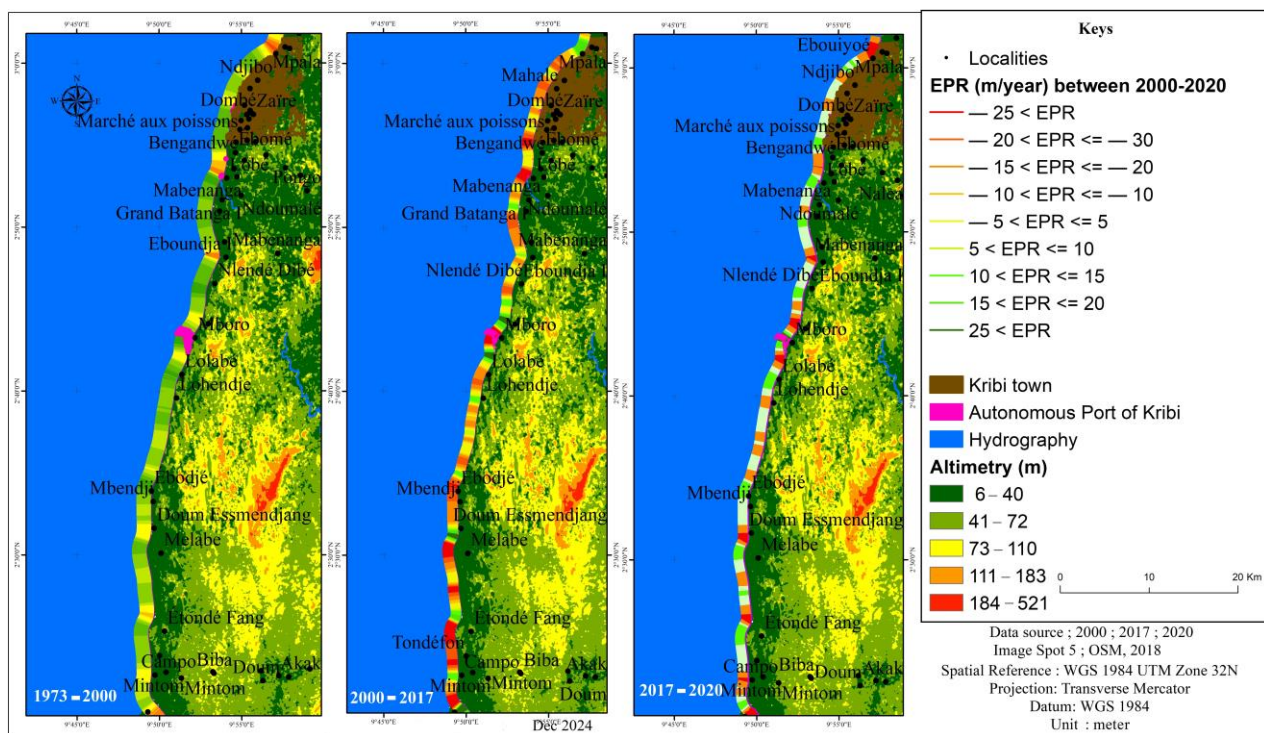


**Figure 16.** Summary of coastal erosion on the Kribian coast in EPR (m/year).

The IPCC and SETEC et al. [75,76,91] forecast on a global scale and the modeling on the scale of the Kribi region coastline make it possible to estimate for the horizon 2100 (i) a rise in temperature on a global scale between +2 °C and +5.5 °C depending on the scenarios (Table A2); (ii) a rise in sea level, where the maximum level will reach +3.14 m in the Kribi region; (iii) an increase in wave height and wind speed of approximately +0.8 m

and +2m/s in the Kribi region; (iv) erosion of the coastline with a retreat of 15 to 50 m in the Kribi region as shown by Figure 17.

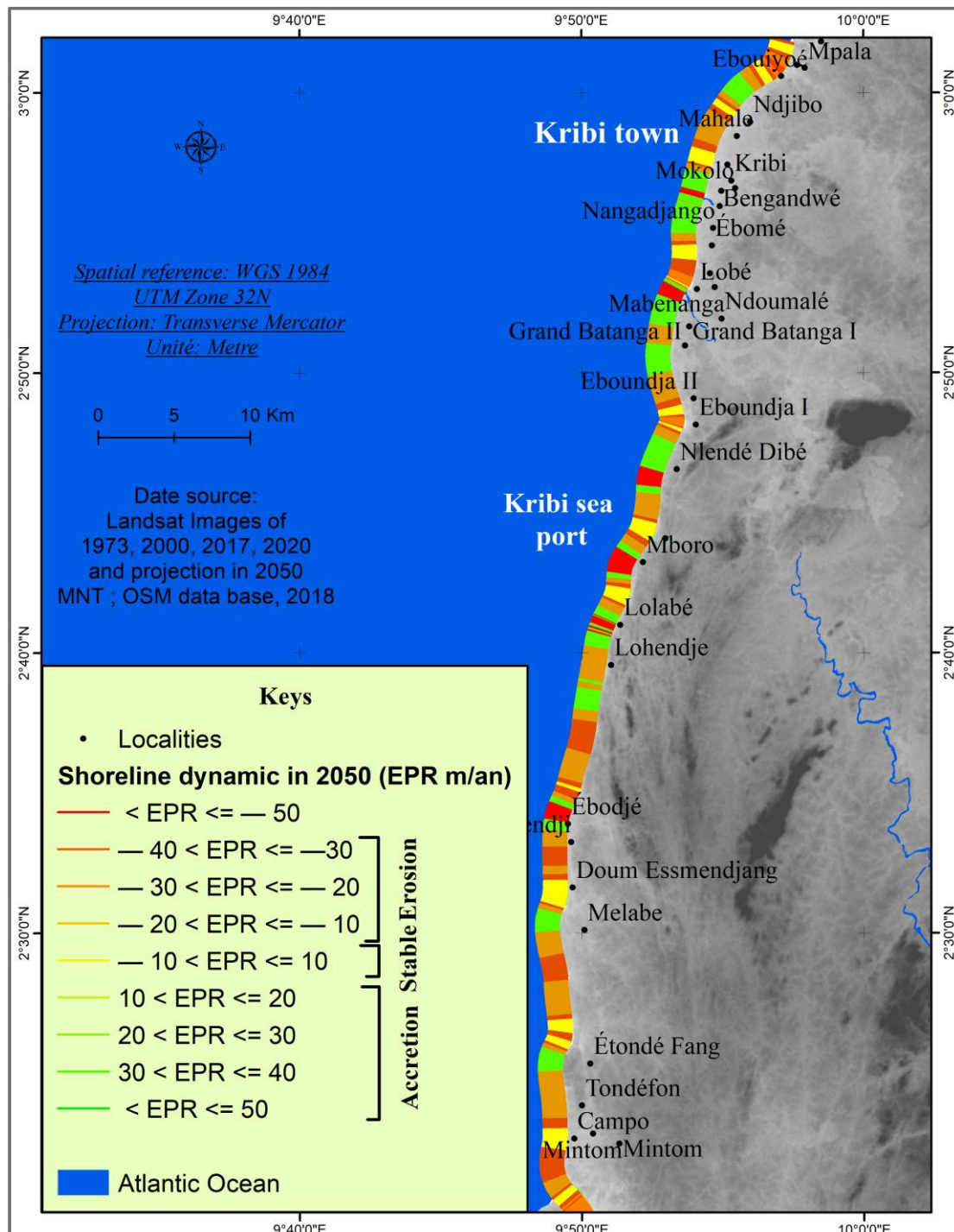


**Figure 17.** Predictive mapping of the coastline dynamics on the Kribian coast, in 2050, following the BETA prediction model, in DSAS.

#### *Anthropogenic influence on coastal dynamics*

Anthropogenic forcings included greenhouse gas emissions, aerosol emissions, deforestation, and more generally, the modification of plant surfaces. According to Royal Haskoning [92], land use in the Kribi area has changed significantly, with a 15% decrease in the total forest cover in recent decades. The degradation of 20% observed in 1973 is now

estimated at 46%, an increase of 26% in 40 years. This strong degradation is mainly due to the pressure exerted by human activities: agro-industries (SOCAPALM, HEVECAM, etc.), wood processing industries (WIJMA, MMG, etc.), village agriculture, drying of fishing products, work building, etc. [92]. Human activities influence coastal processes. Field surveys of resource persons reveal a number of activities (Figure 18) with direct effect on the Kribian coast.



**Figure 18.** Sand extraction at the Lobé Falls and erosion linked to human activities (fishing, housing, etc.) on the shore at Londji and Ebodje (source: Tchindjang, 2013–2018).

Most of the things that people do in modern Kribian coastal development are meant to keep the coast stable by protecting it from water movement and marine erosion and keeping the access channels at the ports in good shape. For this purpose, people set up buildings such as dikes, rockfill cords (Figure 19), and anti-erosion walls with varying degrees of success.



**Figure 19.** Gabions or cords of rockfill and sandbags at Lobe Falls and Ebodje. Rockfill berms are one of the most common measures for stabilizing the coastline. However, this is a mixed success with the rising sea currents (source: Tchindjang, 2017–2019).

### Risks related to oil spills and pollution

Oil spills are considered as major accidents of modernity and have had a significant impact on marine pollution, atmospheric pollution, and GHG emissions [93]. For more than 50 years—and in the greatest silence at times—oil spills have occurred in the Gulf of Guinea and are completely overshadowed by the literature. The oil spill of the Gulf of Guinea runs silently every day in the oil fields of Nigeria, Cameroon, and elsewhere in Africa. Figures 20 and 21 illustrate the impacts of these oil spills on a scale of 1 to 5.

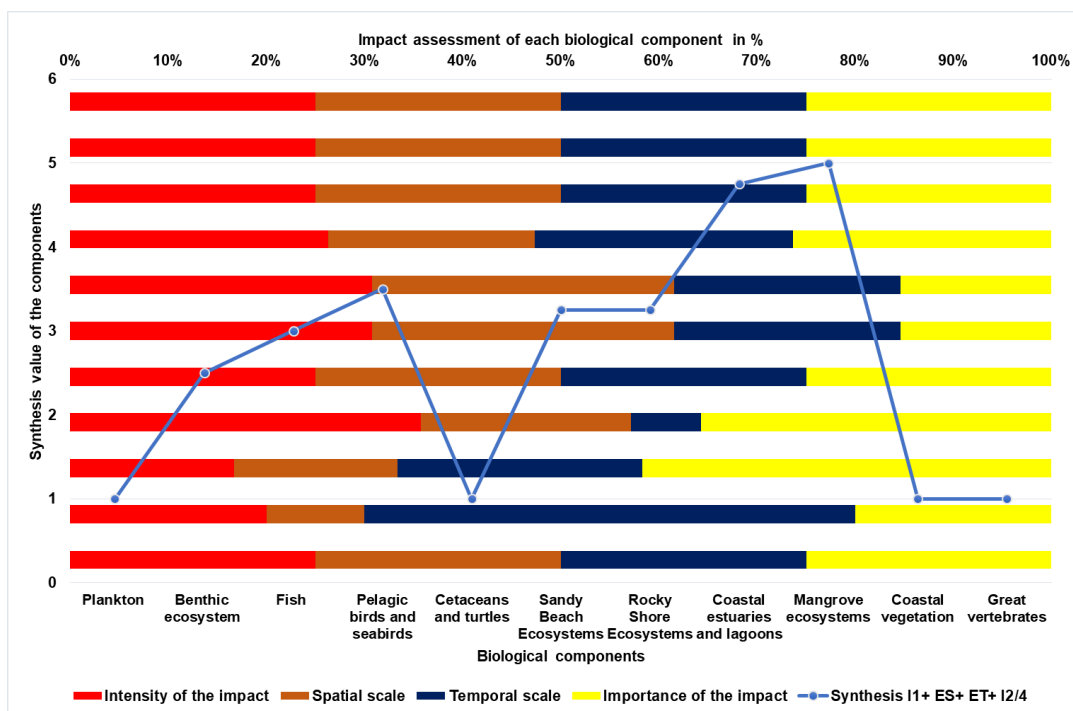


Figure 20. Summary of the impact assessment of large oil spill on the biological environment.

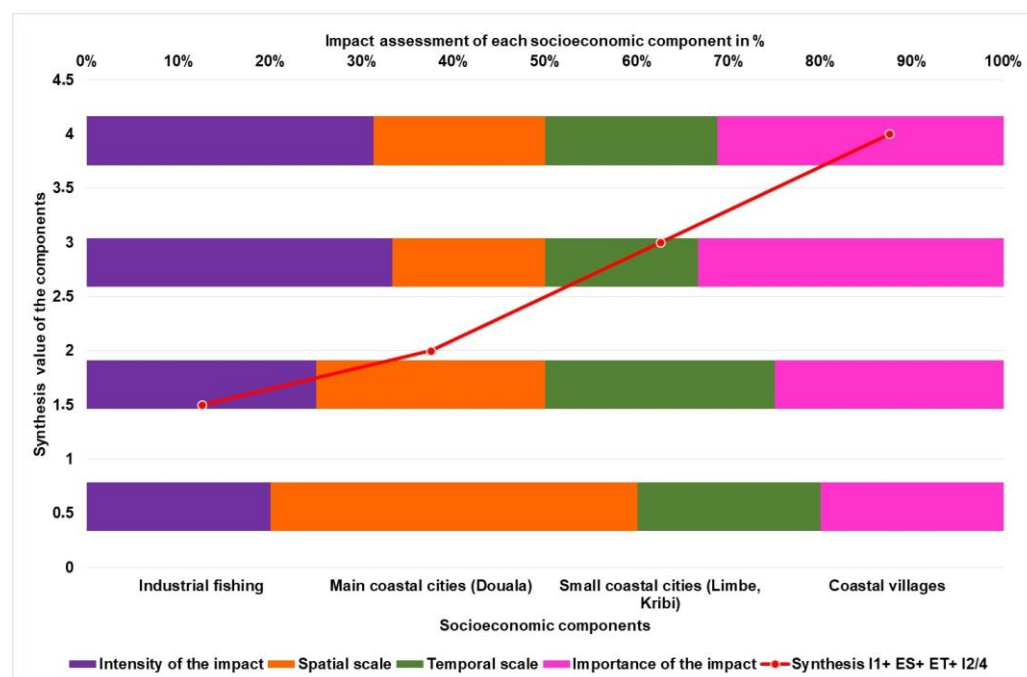


Figure 21. Summary of the impact assessment of a large hydrocarbon spill on the socioeconomic environment.

If mangrove ecosystems, coastal estuaries and lagoons, rocky shore ecosystems, and sandy beaches (tar balls) are affected, then the pelagic birds and fish will suffer a great deal from these oil spills. The same is true of small towns and small coastal villages on the human level (Figure 21).

The dumping of oil at sea or at the port is a global environmental problem. In the context of the almost continuous growth in the maritime transport of petroleum products, the issue of related risks has become evident in recent years. Indeed, any accidental spill at sea or in port is likely to cause pollution defined as follows: “Pollution is an unfavorable modification of the environment; a natural byproduct of human action, through direct or indirect effects altering the criteria for the distribution of energy flows, radiation levels, the physicochemical natural environment and the abundance of living species”. These changes can affect humans directly or through agricultural resources, fishing, water, and biological products. The environment’s recreational opportunities and physical objects can also be changed. The impact of oil spill/pollution and ship movement on the coastal areas (ecosystems and populations) has been assessed. Ship movements show a great threat to marine tortoises (4/5) and mangrove estuaries (3/5). The pollution from land ranks Douala coast as highly pollutant with a score of 5/5 due to high wave industrial activities and population density. Douala is followed by Kribi (4/5), West Coast and Manoka (3.5/5), and Rio del Rey (3/5), but, Campo is environmentally pollution-free (1.5/5). These outputs are illustrated by Figures A3 and A4.

### 3.3. Overall Coastal Vulnerability Indices

Based on Figure 6, we assess the coastal vulnerability indices with 6 indicators in the coastal physical index, 10 indicators in the social coastal vulnerability index, and 13 indicators in the economic coastal vulnerability index. Figures 22–24 illustrate the results.

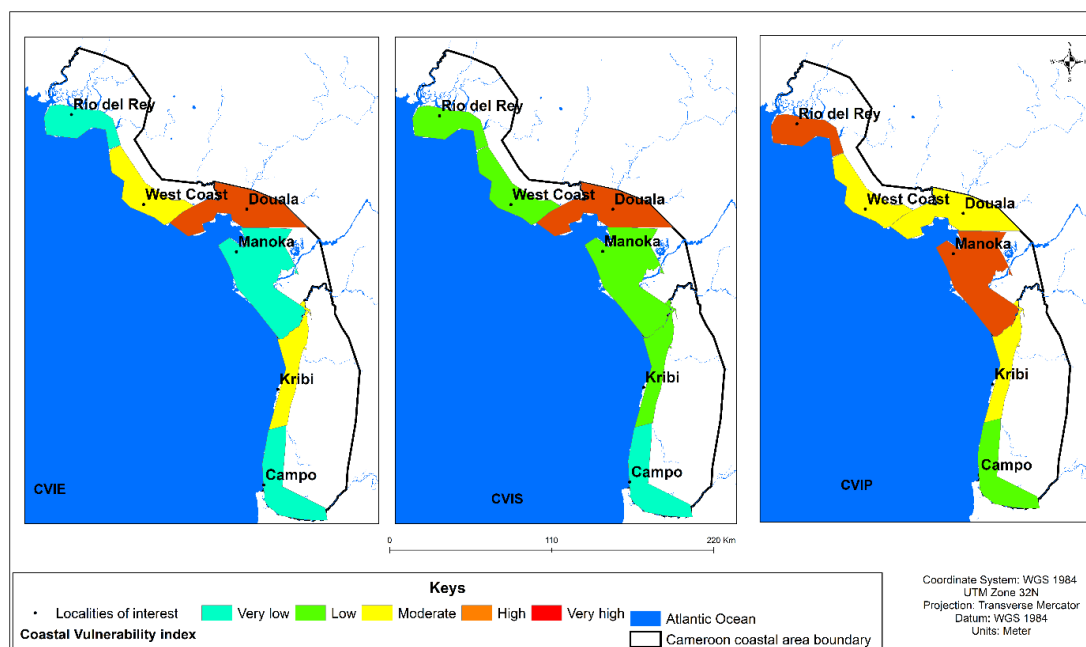


**Figure 22.** Coastal vulnerability indices in Cameroon: physical coastal vulnerability index (CVIP), social coastal vulnerability index (CVIS), and economic coastal vulnerability index (CVIE).

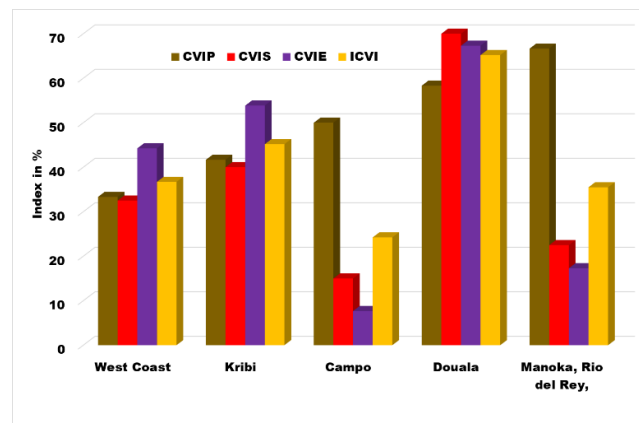


Figure 23. Overall coastal vulnerability indices in %.

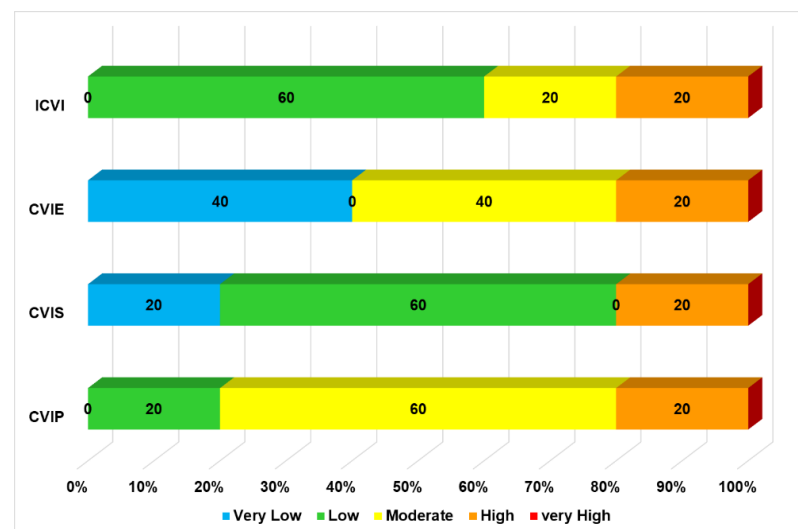


Figure 24. Overall vulnerability indices by gravity.

As shown in Table 12, the Cameroon coastal system is projected to be increasingly at risk due to global climate change through 2030 and beyond. Coastal vulnerability assessment was also performed using indices (Figure 23) and a multi-hazard approach (floods, coastal erosion, and changes in sea level, storms, salinity, waves, and sedimentation patterns).

### 3.3.1. Physical Coastal Vulnerability Index (CVIP)

There are significant variations in the physical vulnerability index along the Cameroonian coast. Campo, Manoka, and Douala (Figure 24) appear more vulnerable (between 50 and 70%) even though, on average, the entire Cameroon coast falls under the moderate physical vulnerability index category (60%) against 20% on high vulnerability and 20% on low vulnerability (Figures 22 and 24).

### 3.3.2. Social Coastal Vulnerability Index (CVIS)

Apart from Douala (70%), most of the area surveyed falls under the 15–40% social vulnerability index (Figures 22 and 23). These sites are in decreasing order: Kribi, West Coast, Manoka, Rio del Rey, and Campo (Figure 24). Douala's position as a metropolitan city explains such a record. Overall, the whole Cameroonian coast has low vulnerability in 60% of the area, high vulnerability in 20%, and very low vulnerability in 20% (Figures 22 and 24).

### 3.3.3. Economic Coastal Vulnerability Index (CVIE)

Economic vulnerability appears more important in Douala (65%), Kribi (40%), and the West Coast (30%) (Figure 23). This reflects the importance of economic activity in these areas and cities. Campo and Manoka–Rio del Rey appear to have poor scores (15–20%). The overall coastal vulnerability is 40% moderate, 20% high, and 40% very low (Figures 22 and 24). Many informal activities along the Cameroonian coast have led to this situation.

### 3.3.4. Integrated Coastal Vulnerability Index (ICVI)

The integrated coastal vulnerability index (CVI) ranks the Douala coast as highly vulnerable with a score of 63/100 due to high wave activities and population density. Douala is followed by the Kribi with a score of 43/100 due to the Kribi deep sea port, which provides facilities for Kribi industrialization. The West Coast holds the third rank (35/100) because of its active cabotage and small fishing and commercial activities. Kribi is nearly followed by Manoka–Rio del Rey with (33/100). Campo with only 21/100 is a rural coast without any facilities (Figures 24 and 25). The overall integrated vulnerability shows that 60% of the Cameroonian coast is low against 20% moderate and 20% high (Figure 24).

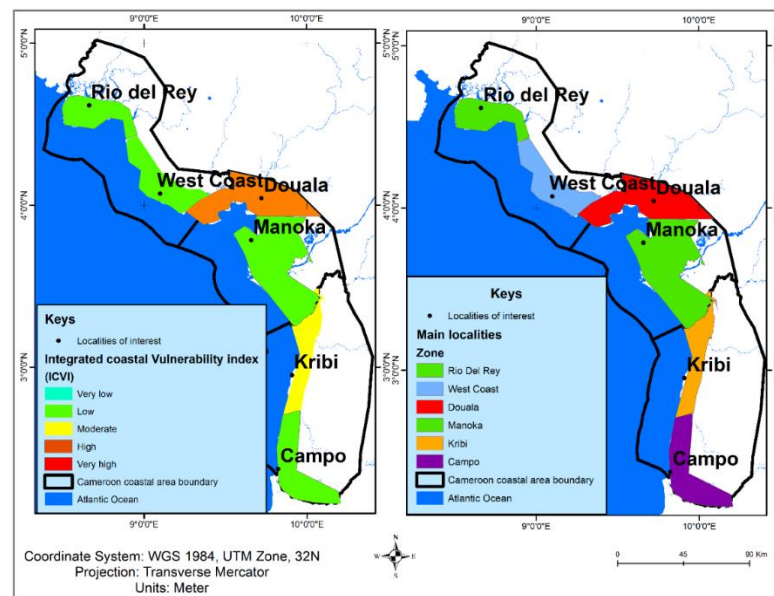


**Figure 25.** Integrated coastal vulnerability index.

### *Synthesis of coastal vulnerability indices on the Cameroonian coast*

Based on the maps and the score and ranking above, we succeeded in giving a more detailed description of the locations that are vulnerable to flood hazards, coastal erosion, and sea level rise in the coastal areas of Cameroon. As such, the Douala estuary appears more vulnerable, followed by the Kribian coast, West Coast, Manoka–Rio del Rey, and at least Campo (Figure 25). Douala with a CVIP of 58.33%, a CVIS of 70%, a CVIE of 67.31%, and an ICVI of 65.21, is extremely vulnerable due to its unique combination of estuarine coastal geomorphology, low slope, and a high erosion trend, which is primarily influenced by energetic wave actions.

Douala is followed by Kribi (41.67% CVIP, 40% CVIS, 53.85% CVIE, and 45.17% ICVI), which is highly vulnerable. This position is due to the recent construction of the Kribi deep sea port and many related activities. Kribi has a mixed coast (soft/rocky) which means that economic activities have a great influence (erosion modification of the shoreline) in this section of the Cameroonian coast. West Coast, with small cities (Limbe, Idenau, Debusncha,

etc.), comes in third position of the coastal areas moderately vulnerable (33.33% CVIP, 32.50% CVIS, 44.23% CVIE, and 36.69% ICVI). It is an area of active coastal cabotage with mixed geomorphological coast and a great monsoon influence (storms and huge rainfall distributed through the year with an average between 4000 and 8000 mm).

Manoka–Rio del Rey comes in third position with a great physical index score (66.67% CVIP) and very low score in CVIS (22.5%) and CVIE (17.31), because the areas are poorly inhabited and this limits economic activities. The integrated vulnerability index is 35.49%. The last area is Campo (very low vulnerability index), which can be seen as a soft coast and a dominance of rural primary activities (agriculture and fishing). The score ranked 50% CVIP, 15% CVIS, 7.69% CVIE, and 24.23% ICVI (Figure 26).

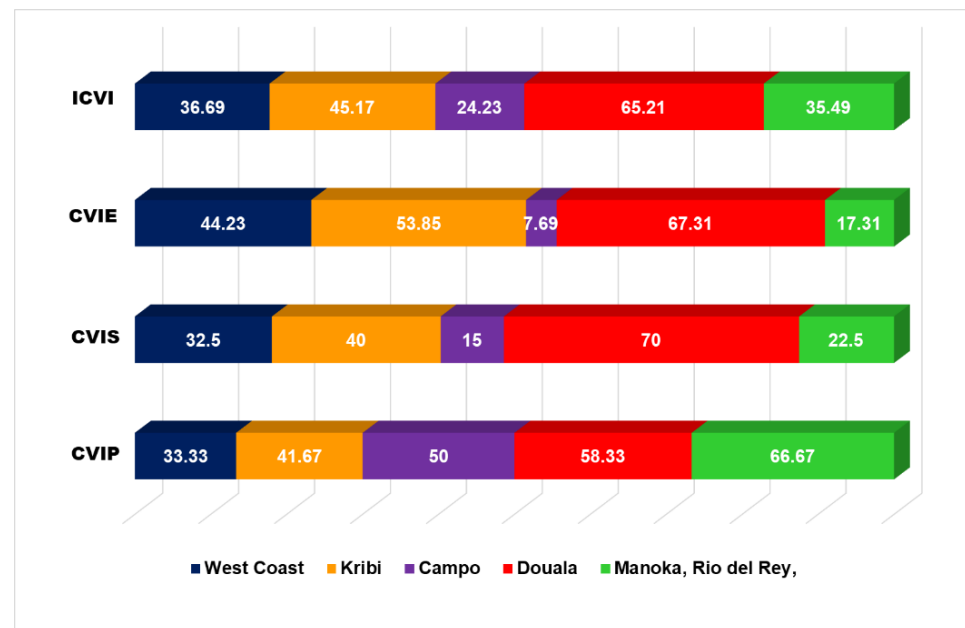


**Figure 26.** Vulnerability index scores by area.

### 3.4. The Way Forward?

Floods are a major hazard worldwide, especially in coastal environments where cyclones, storms, torrential rains, and severe monsoon storms occur. Enhancing flood forecasting and prevention continues to be a crucial tool. Furthermore, it is preferable to have better information about vulnerable populations and properties in flood-prone areas. However, in many African coastal countries, the management of this flood risk shows the predominance of the defense works, both on the political display side and the expectations of the populations. In fact, beyond the political orientations related to risks (contingency plans), all the construction of smart cities in Africa must take into account several elements that go from ecology to technology and planning, as shown in Figure 27.

Contemporary urban ecology is an integrated, rich, and complex discipline in which environmental resources combine built and natural spaces, urban organizations, and human activities. Even though ecology has the potential to become a political concept, its primary goal is the restoration of nature's rights. Therefore, ecology holds significant importance as it mitigates the damage resulting from the ecological crisis by safeguarding the environment and natural systems. This, in turn, helps to protect society and communities [94], which is beneficial for their growth and survival.

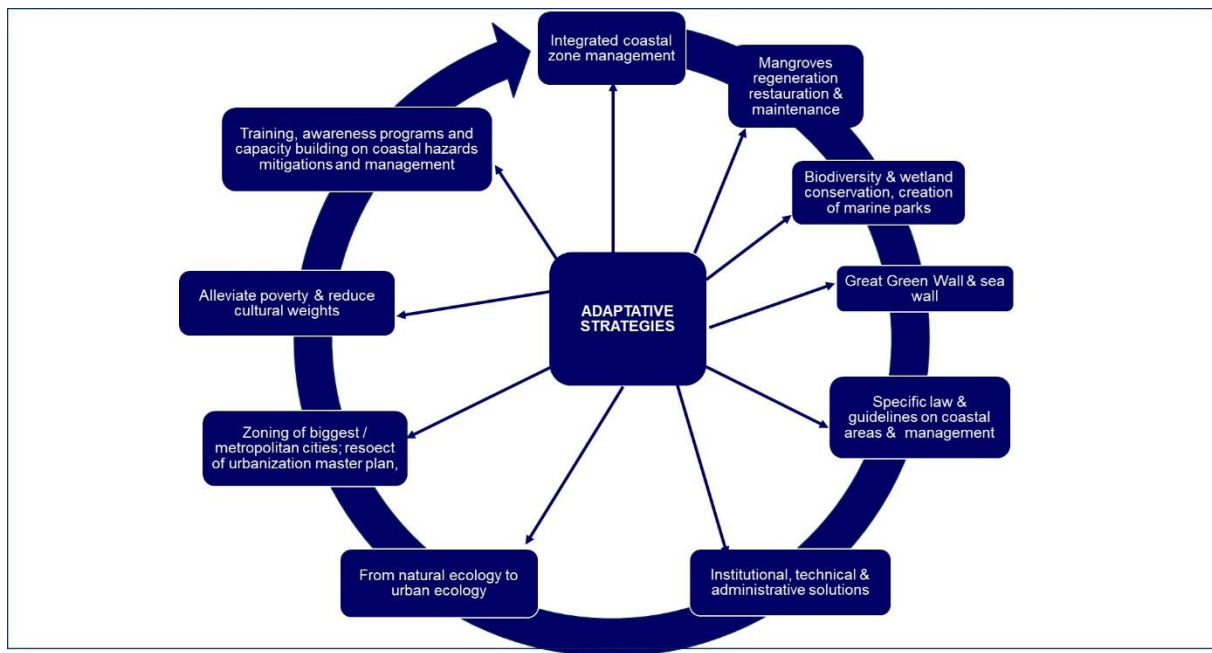


**Figure 27.** Proposed local adaptive strategies for coastal management in Cameroon.

Integrating such restoration with environmental awareness and disaster preparedness plans is crucial for a landscape resilience approach. This integrated approach can save the city and the poor people who reside there by leading them to abandon the impacted spaces. The ecological option inevitably leads to the zoning of Cameroonian coastal cities. The reforestation and demassification of the city must be incorporated into new planning documents. This can be carried out by creating green spaces; separating resettlement areas, residential areas, and industrial areas; maintaining and cleaning drains by removing trash and ice build-ups to keep water flowing; and developing watersheds upstream and downstream of rivers that cross the city. Cameroon must learn to balance its urbanization. Based on the findings of an erosion of the coastline of 35 m/year, Benin has managed to curb the expansion of Cotonou in favor of other cities (Parakou, Abomey-Calavi, etc.). This hopeful solution can help reduce the scale of disasters in the main city [95].

At the institutional level, governance and risk management must appear as a key element of national policy. Disaster risk governance refers to the way in which national and sub-national actors (including governments, parliamentarians, civil servants, the media, the private sector, and civil society organizations) are willing to coordinate their activities and actions and manage disaster risk reduction [11]. Should we not help people in coastal cities cope with floods, given the recurrence of this hazard and scenarios in different countries? Of course, most African countries, including Cameroon, have incorporated risk and disaster elements into their recent policies through contingency plans stemming from the Hyogo Framework (2005–2015) and the Sendai (2015–2030) Disaster Reduction Framework [96,97]. But is it enough?

If, in the face of climate change, avoiding floods becomes an impossible task for the different countries, well-designed urban planning documents incorporating risk reduction plans can support the reduction in the scale of human and material damage. We must publish, disseminate, and make these documents available to city dwellers, encouraging them to respect unbuilt areas and free the beds of watercourses. All communal or local development plans will have to integrate the problem of climate change and floods. Only as a last resort in disaster preparedness can we produce disaster relief plans. In addition, training people to prepare for disasters reduces the extent and cost of damage.

Among other anthropogenic factors, there is the absence or non-compliance with urban master plans, the choice of investments, and land use planning that are often against the protection of the environment, especially in the coastal strip [98]. If urban planning is an art, a conception, and a science, urbanization remains the way to give a body to this art according to the social culture of the medium or even the country, the nature of the available building materials, the topography on the ground, the financial range available to the actors, and, more or less, the pace of increase in the birth rate of populations, demography, etc.

The use of watercourses as a landfill is recurrent in African urban centers, especially in precarious neighborhoods. The sanitation system regularly dumps solid garbage into the watercourse beds and drains. It is clear that these rivers discharge large quantities of waste at sea. Most of the time, coastal cities' drainage systems and sewer pipes are broken, clogged, or blocked by trash. This is because the unsafe neighborhoods that line the drains and pipes date back to the colonial era or were just obtaining their independence. This is most noticeable in Yopougon, Abidjan [99].

Above all, we must free ourselves from constructionist laws to rethink the coastline. In Cameroon and many African countries, there are no laws on the coast or mountains. The main coastal cities of Cameroon (Douala, Limbe, Tiko, Idenau, and Kribi) should experience catastrophic floods that could cost a billion dollars a year from 2020 to 2050. In this situation, not having any laws seems like a weakness because the coastal environments can be used for many things, which leads to the recognition of specificity and coastal territories.

In addition to primatiality and macrocephaly in some of the biggest cities like Douala, constructionists should avoid the obvious consequence of the excessive anthropization of the coastline. Instead of thinking about disaster preparedness and making it the subject of rigorous policy, states choose the technocratic solution by multiplying buildings, infrastructure, and other amenities along the marine shoreline, which itself is subject to modifications. The retreat of the coastline has two important social and economic dimensions. On the one hand, the intense concentration of populations on the coast can lead to the destruction of habitats and traffic infrastructure, ultimately causing the territorial organization of the most exposed coastlines to be disrupted. On the other hand, it may necessitate significant expenditures for either prevention (fighting against coastal erosion) or repairs. Coastalization, overuse, and over-occupancy usually lead to the degradation of the physical environment, resulting in flooding.

Populations from rural or poor countries can identify cultural weights (mentality, perception, and representations) in the urban housing construction style. They seem accustomed to promiscuity and horizontal houses suitable for large families. This situation is also accompanied by promises and slogans of political campaigns in Africa: "A citizen, a roof", something almost impossible in the city today. Such a situation inevitably leads to a degradation of the urban space (swamps, rivers, etc.) and to the excessive extension of cities. The phenomenon does not seem to be mastered by the public authorities who lose control of it from an environmental point of view (we have seen it around the Douala international airport where, despite the zoning and the construction of the fence, people continue to install in mangroves and creeks). The consequences, obviously harmful, are enormous for urban and peri-urban agriculture (especially market gardening) and for the health of occupants (water-borne and malaria diseases).

Another set of proposed actions is in line with the integrated coastal zone management (ICZM) document from Rio in 1992, which lays out strategies for development and management actions that will be used in the Kribi–Campo coastal strip. It is accepted that the most plausible solution is that of integrating the local population or, better, reconciling the local communities to the decisions taken by the public authorities in the development of the coastal area and the management and protection of existing natural resources. Supporting

this idea, some authors [100–104] show that making an ICZM plan requires a few key steps, including realizing that planning is needed, diagnosing the area, defining the plan's spatial area, figuring out what the problems are, getting everyone involved, and getting the national and local governments to work together. However, it suggests that people should be more aware of climate change and have better skills to deal with it. Focusing on socioeconomic adaptability, ecologically based adaptation measures, and governance for resilience can achieve this.

In Cameroon, managing and reducing risks has become a complex task. To lower the risk of disasters, along with educating the public, making a media plan, and obtaining partners from the Department of Civil Protection and administrative authorities to help celebrate International Disaster Reduction Day and World Civil Defense Day, the National Risks Observatory (NRO) will be given more tools and a system for sending weather data will be put in place.

In fact, our results are useful for organizing port activities and helping Cameroonian port managers understand the vulnerability of the environment and the challenges of protecting nature and populations. First of all, as practical information for policy recommendations, we think that the Cameroonian government, given the importance of coastal areas and the threats they face, should enact a law on coastal management. The government created the Kribi–Campo Manyange na Elombo Marine Park in 2019, but it is insufficient, and to make sure that the coastal biodiversity is protected, it is essential to set up a law on humid zones and recognize the entire Cameroon coastal area as a humid zone. The implementation of the urban master plan should be the next step. The next step is the sensitization of coastal populations and their preparedness with an operational early warning system. For further protective action, a study on vulnerability has been carried out in 2020 and needs to be published to help the population and managers. Table A1 presents the projections for the coastal region from 2021 to 2100.

Kribi is an area hosting one of the most high conservation value forests (HCV). Activities such as port, fishing, agriculture, and industries threaten Kribi, necessitating the promotion of a land–sea conservation approach. This way of thinking is based on integrating different areas of science into ecosystem-based frameworks. It focuses on protecting land and sea in a planned way by finding links between economies and ecosystems (because of endemism) and making the most of the costs and benefits of actions at different levels and in different ways that ecosystems respond [105,106].

Given the fact that Cameroon has signed the International Convention for the Control and Management of Ballast Water and Sediments in order to take part in the fight against the introduction of invasive alien species (IAS), it was necessary with the implementation of the port activities to study the state of IAS. Thus, the study of maritime traffic through the port of Kribi between June 2019 and June 2020 [91] made it possible to identify three species likely to be present in the ballast water of ships and presenting a moderate to high risk of arrival: the red algae *Gracilaria salicornia*; the polychaete worm *Ficopomatus enigmaticus*; and the bivalve *Arcuatula senhousia*. So, an extension of traffic would tend to increase the risk of introducing IAS. This risk will be particularly increased with ships coming from so-called “hot spot” ports which present the greatest risk of introducing IAS on the globe [107]. In view of their life traits, these three species are likely to survive and adapt to the environmental conditions that characterize the habitats present on the coast of the Kribi sub-region. The three species are likely to colonize soft bottoms, hard bottoms, and the mangroves. It means that local species will be threatened and it needs strong policies and recommendations among which the following:

- A specific policy on coastal areas that integrates risk management and ecosystems-based approaches and policies.
- The creation of not only marine parks, but also great humid zones along the coastal region which possess at least 10 national parks
- The promotion of green spaces and the reforestation of mangroves together with support to ecotourism projects and a reasonable tourism development
- The protection of spawning grounds and avoidance of water turbidity, etc.
- Environmental education together with coast management and the transplantation of sea turtle eggs into secure enclosures as well as incentives to find an alternative to eating sea turtle meat. This goes in line with the fight against plastic pollution and the illegal dumping of waste into the sea.
- At the same time, the principle should stipulate how to dispose of the pollutants produced by oil and gas exploration and development in the coastal zone, as well as ship oil spills and ballast.
- There was a proposal for artificial reefs and if this is carried out, scientific monitoring must be set up after the immersion of the artificial reefs (an inspection of the structure of the modules, a qualitative and quantitative assessment of the species fixed and living around the modules, and monitoring of the sediments close to the modules (fattening zones and scouring)
- The last recommendation to address is that of environmental and spatial justice as the Kribi coast is concerned because the port project has been realized without the real participation of the local population and pygmies (indigenous people) who have been threatened and marginalized since the port implementation. The aim is related to the creation of a socioeconomic development model compatible with the protection of resources and marine heritage

#### 4. Conclusions

A coastal environment is an area with high interaction between nature and societies (land–sea interface) and is subject to multi-hazard interactions such as landslides, erosion, floods, coastline dynamics, sea level rise, and storm surges. The extent to which these occur are likely to increase under scenarios of climate change. All villages and cities located on the Atlantic coast face most of these hazards whose triggering factors are both natural and anthropogenic, among others: climate change, flat topography, and degree of proximity to the sea. As more and more people start to inhabit the coasts, their vulnerability to these hazards will also increase. Any assessment of coastal vulnerability must not only include the physical aspects of a particular coast but also its social and economic components. Only then can we make a holistic assessment of the coast's vulnerability to natural hazards. Because the coastal environment is so complicated, we used a multi-step process to figure out what was at risk and how vulnerable the coast was. This included mainly assessing hazards and vulnerability, using remote sensing and GIS to see how the shoreline was changing, making observations in the field, and using a critical grid to figure out how bad the hazards would be. We also looked at 29 different indicators to find out how vulnerable the coast was on different levels (6 for physical, 10 for social, and 13 for economic).

As a result, many cities and villages of the coastal regions of Cameroon appear doubly exposed to climatic risks. Not only are the floods recurrent (Limbe, Douala, Idenau, Debunscha, and Kribi), but localities are also threatened by rising sea levels as a result of climate change. These hazards are in addition to land movements and active deforestation in fishing areas. Such a situation leads to a decrease in the mangrove swamp, whose presence protected the coastline and was a spawning ground for the biological life of the oceans. These climatic events threaten more than 1,000,000 people in this region. The direct

impact of coastal erosion is the destruction of biodiversity and infrastructure. The shoreline evolves through erosion and sedimentation. The results of the present paper show the main coastal vulnerability of the whole Cameroon coast is moderate (60%). But in the details, due to some characteristics of areas, the city of Douala appears more vulnerable because of its size, urbanization rate, and population. Kribi is another city that, with the exploitation of the Kribi sea port and Kribi highway, has become more vulnerable than the cities of the West Coast (Limbe, Debunsha, and Tiko).

Also, the study shows that the shoreline evolves because of erosion and sedimentation caused by both anthropogenic forcings and marine weather. Moreover, coastal populations, due to a lack of preparedness, are highly vulnerable to some of these hazards when produced: floods, landslides, sea level rise, strong storms, and erosion. As far as floods are concerned, human responsibilities can be sought at the level of the occupation of flood plains, the use of watercourses as points of discharge, etc. It becomes difficult in such cases for Cameroon as well as any coastal African country to eradicate floods, but adaptation strategies are possible to mitigate them. Rethinking urban development in Cameroon without considering floods presents a significant challenge. It is up to states to develop effective strategies to mitigate its impacts.

The main new ideas are in the methodology, which includes many different methods that could be used in marine geology and hydrology, such as field observations, analyzing historical data, remote sensing technology, and GIS tools.

The second one is the number of variables/indicators used to calculate the coastal vulnerability index, i.e., 29 sub-indicators with 13 focused on economics. Economic vulnerability indices are not of particular use in the previous studies consulted. The more indicators there are, the better the study is; it is also pertinent for economists.

The next innovation is based on the scaling up or notation of the ship traffic impact on marine ecosystems and pollution, as well as the oil spill from petroleum coastal industries and land pollution on sea and biodiversity communities. This notation is necessary to support the implementation of specific policies on coastal management.

But we have not used the coastal hazard wheel to classify the type of coast. There is a deficiency in the current data regarding coastal urbanization in smaller cities such as Limbe, Idenau, and Tiko. Also, there has been a social crisis in the West Coast areas, which has limited investigations since 2017 as well as a poor implementation of ICZM despite its recognition since 2011.

**Author Contributions:** Conceptualization, M.T. and P.M.F.; methodology, M.T., P.M.F. and C.K.; software, M.T., P.M.F. and C.K.; validation, M.T., P.M.F. and C.K.; formal analysis, M.T.; investigation, M.T., P.M.F. and C.K.; resources, M.T.; data curation, M.T. and P.M.F.; writing—original draft preparation, M.T. and P.M.F.; writing—review and editing, M.T., P.M.F. and C.K.; visualization, M.T., P.M.F. and C.K.; supervision, M.T.; project administration, M.T. All authors have read and agreed to the published version of the manuscript.

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## Abbreviations

|          |                                                                                                                                                                |
|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| AfCFTA   | African Continental Free Trade Area                                                                                                                            |
| CDC      | Cameroon Development Corporation                                                                                                                               |
| CESER    | Conseils économiques sociaux et environnementaux de l'Atlantique                                                                                               |
| CVI      | coastal vulnerability index                                                                                                                                    |
| DSAS     | Digital Shoreline Analysis System                                                                                                                              |
| EPR      | End point rate                                                                                                                                                 |
| ETM      | Enhance Thematic Mapper                                                                                                                                        |
| IAS      | invasive alien species                                                                                                                                         |
| ICVI     | integrated coastal vulnerability index                                                                                                                         |
| ICZM     | integrated coastal zone management                                                                                                                             |
| IPCC     | Intergovernmental Panel on Climate Change                                                                                                                      |
| HCV      | high conservation value                                                                                                                                        |
| HEVECAM  | Hévéa du Cameroun – Cameroon Rubber Company                                                                                                                    |
| MINEPDED | Ministère de l'Environnement, de la Protection de la Nature et du Développement durable—Ministry of Environment, nature protection and Sustainable Development |
| NRO      | National Risks Observatory                                                                                                                                     |
| PAMOL    | Palm Oil Limited                                                                                                                                               |
| SLR      | sea level rise                                                                                                                                                 |
| SOCAPALM | Société Camerounaise des palmeraies – Cameroon Palm Plantation Corporation                                                                                     |
| SONARA   | Société Nationale de raffinage – National Refinery Corporation                                                                                                 |
| TM       | Thematic Mapper                                                                                                                                                |
| UN       | United Nations                                                                                                                                                 |
| UN-ISDR  | United Nations International Strategy for Disaster Reduction                                                                                                   |
| UNDRR    | United Nations Disaster Risks Reduction                                                                                                                        |
| USGS     | United States Geological Survey                                                                                                                                |
| WIOMSA   | Western Indian Ocean Marine Science Association                                                                                                                |

## Appendix A

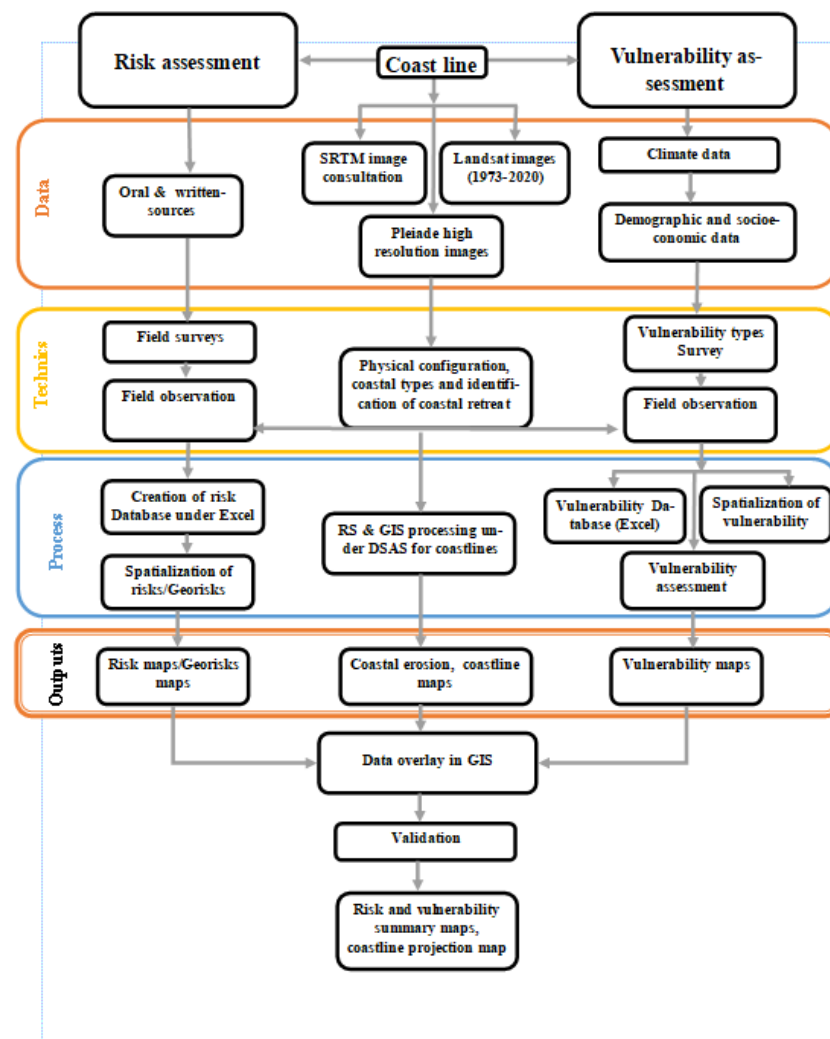
| Severity / gravity                                                                                                        | Frequency or probability (Likelihood) |                      |                       |                      |                      |                              |
|---------------------------------------------------------------------------------------------------------------------------|---------------------------------------|----------------------|-----------------------|----------------------|----------------------|------------------------------|
|                                                                                                                           |                                       | Rare / very unlikely | Unlikely              | Moderate             | Likely               | Very likely / almost certain |
|                                                                                                                           |                                       | 1                    | 2                     | 3                    | 4                    | 5                            |
| ↑                                                                                                                         | Very severe                           | 5                    | 10 tolerable / medium | 15 critical / high   | 20 catastrophic      | 25 extreme or catastrophic   |
|                                                                                                                           | 5                                     | Acceptable           |                       |                      |                      |                              |
|                                                                                                                           | Severe                                | 4                    | 8 tolerable / medium  | 12 critical / high   | 16 critical / high   | 20 catastrophic              |
|                                                                                                                           | 4                                     | Acceptable           |                       |                      |                      |                              |
|                                                                                                                           | Moderately severe                     | 3                    | 6                     | 9 tolerable / medium | 12 critical / high   | 15                           |
|                                                                                                                           | 3                                     | insignificant        | Acceptable            |                      |                      | critical / high              |
|                                                                                                                           | Less serious                          | 2                    | 4                     | 6                    | 8 tolerable / medium | 10                           |
| ↓                                                                                                                         | 2                                     | insignificant        | Acceptable            | Acceptable           |                      | tolerable / medium           |
|                                                                                                                           | Very low / negligible                 | 1                    | 2                     | 3                    | 4                    | 5                            |
| ↓                                                                                                                         | 1                                     | insianificant        | insianificant         | insianificant        | Acceptable           | Acceptable                   |
|                                                                                                                           | 1                                     |                      |                       |                      |                      |                              |
| 1—3 = Insignificant: won't cause serious injuries or illnesses                                                            |                                       |                      |                       |                      |                      |                              |
| 4—7 = Acceptable can cause injuries or illnesses, only to a mild extent                                                   |                                       |                      |                       |                      |                      |                              |
| 8—11 = Tolérable: can cause injuries or illnesses that may require medical or authorities attention but limited treatment |                                       |                      |                       |                      |                      |                              |
| 12—18 = Critical: can cause irreversible injuries or illnesses that require constant medical attention                    |                                       |                      |                       |                      |                      |                              |
| 19—25 = Catastrophic / Unacceptable : can result in fatality                                                              |                                       |                      |                       |                      |                      |                              |

Figure A1. Critical grid based on 5 × 5 risk assessment matrix.

**Table A1.** Characteristics of the processed images.

| Data             | Path and Row      | Resolution m | Code    | Sensors | Seasons | Aim                                     |
|------------------|-------------------|--------------|---------|---------|---------|-----------------------------------------|
|                  |                   |              | 1973    |         |         |                                         |
| 1 February 1973  | LM01_L1TP_200 058 | 30           | 8 bits  | Mss     | Dry     | Coastline extraction                    |
| 6 January 1973   | LM02_L1TP_200 057 | 30           | 8 bits  | Mss     | Dry     | Coastline extraction                    |
| 27 November 1973 | LM03_L1TP_201 057 | 30           | 8 bits  | Mss     | Dry     | Coastline extraction                    |
|                  |                   |              | 2000    |         |         |                                         |
| 6 November 2000  | LE7 186 058       | 30           | 8 bits  | ETM     | Dry     | Coastline extraction and classification |
| 5 March 2000     | LE7 186 058       | 30           | 8 bits  | ETM     | Dry     | Coastline extraction and classification |
| 16 January 2000  | LE7 186 058       | 30           | 8 bits  | ETM     | Dry     | Coastline extraction and classification |
|                  |                   |              | 2017    |         |         |                                         |
| 21 February 2017 | LC08 187 058      | 30/15        | 16 bits | L8      | Dry     | Classification                          |
| 31 March 2017    | LC08 187 058      | 30/15        | 16 bits | L8      | Dry     | Classification (Kribi)                  |
| 15 January 2017  | LC8 186 058       | 30/15        | 16 bits | L8      | Dry     | Coastline extraction                    |
|                  |                   |              | 2020    |         |         |                                         |
| 20 December 2020 | LC08 186 058      | 30/15        | 16 bits | L8      | Dry     | Coastline extraction                    |
| 27 December 2020 | LC08 186 058      | 30/15        | 16 bits | L8      | Dry     | Coastline extraction                    |

N.B. We shall add to this some Pleiades images (0.5 m resolution) which were used when working on the Kribi coast.

**Figure A2.** Methodology chart of the study.

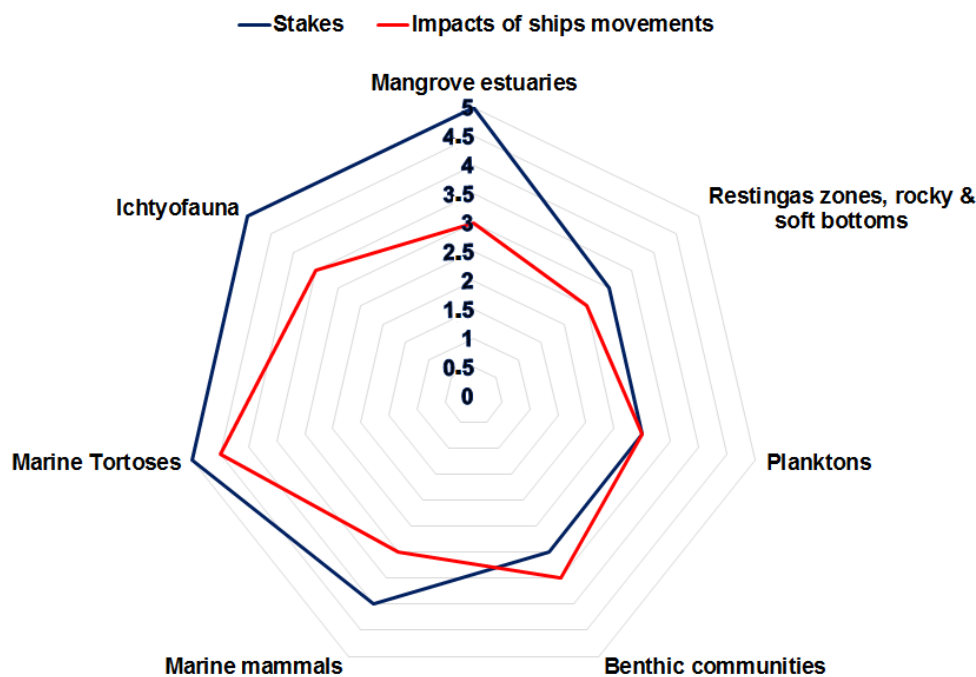


Figure A3. Impacts of the ship movements on the Cameroon coastal environment.

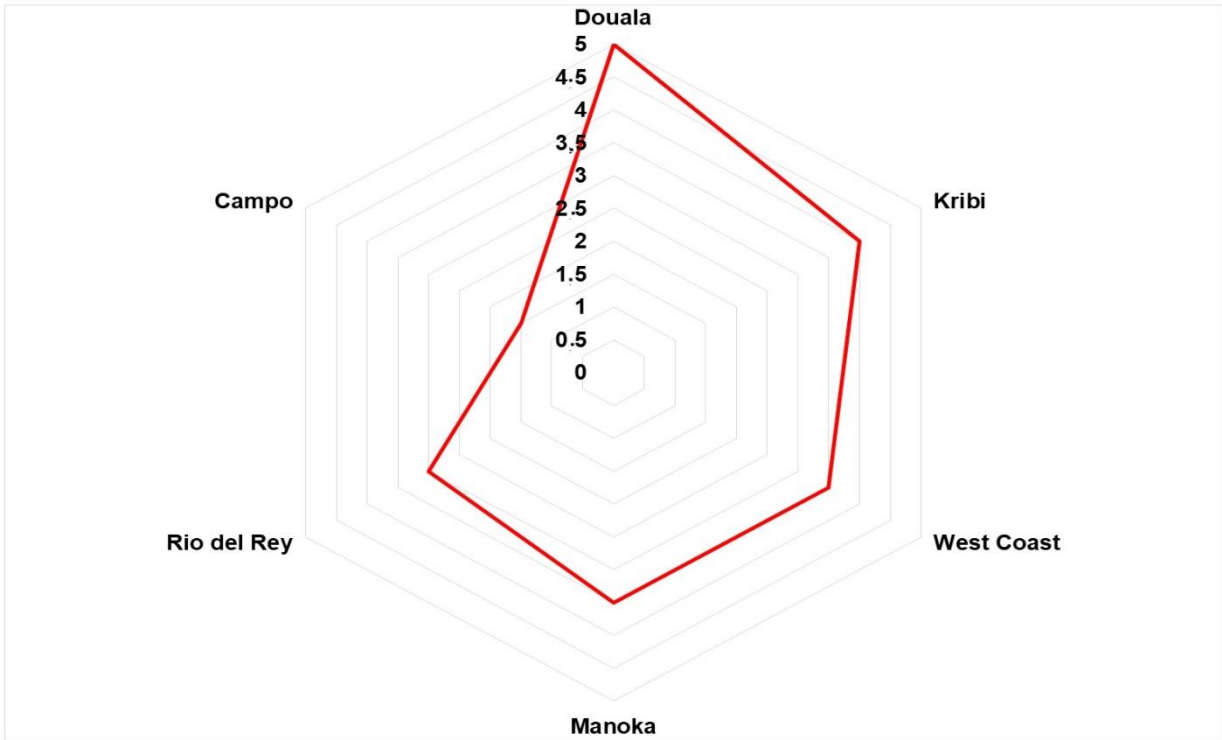


Figure A4. Impact of the pollution from land on the main coastal environment studied.

**Table A2.** Projections of the coastal climate parameters at different time horizons from 2021 to 2100.

| Projected Climate Parameters     | Scenarios | Time Horizons |           |            |            |
|----------------------------------|-----------|---------------|-----------|------------|------------|
|                                  |           | 2021–2040     | 2041–2060 | 2061–2080  | 2081–2100  |
| Rainfall trend scenario in %     | RCP 2.6   | −2 to 2       | 2 to 7    | 5 to 10    | −0 to 1    |
|                                  | RCP 4.5   | −1 to 1       | −1 to 1   | 1 to 5     | 1 to 4     |
|                                  | RCP 8.5   | 4 to 7        | 1 to 3    | 2 to 5     | 2 to 5     |
| Temperature trend scenario in °C | RCP 2.6   | 0.5 to 1      | 0.7 to 1  | 2 to 3     | 2 to 3     |
|                                  | RCP 4.5   | 0.5 to 1      | 1 to 1.5  | 2.5 to 3.5 | 2.5 to 3.5 |
|                                  | RCP 8.5   | 0.5 to 1      | 1 to 1.5  | 3 to 4     | 4 to 5     |

Source: MINEPDED, [73].

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