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Mapping and valuation of ecosystems and economic activities along the coast of Cameroon: implications of future sea level rise

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Abstract

The vulnerability of the coastal zone of Cameroon to flooding from sea level rise (SLR) was quantified using Geographic Information System (GIS) flooding analysis. The main economic activities and ecosystems along this area were identified using secondary data. Valuations of non-market values of ecosystems were based on the ecosystem service product method. The low-lying coastal areas were found to be physically and socio-economically susceptible to impacts of SLR due to their high ecological and economic value. A digitised land use/land cover (LULC) classification was produced from low resolution topographic maps and Google Earth images of the area. The digital elevation model (DEM) used was acquired by the shuttle radar topography mission. Evaluation of potential land loss due to inundation was based on empirical approaches using minimum and maximum scenarios of 2 and 10 m flooding. These were estimated considering the best available SLR data for the area, mean high water levels and wave heights during storms. The estimated SLR range from 2.3 m to 9.2 m for the low and high scenarios, respectively, by 2050 and from 2.6 m to 9.7 m for the low and high scenarios, respectively, by the year 2100. Results indicate that 112 km^2 (1.2 %) and 1,216 km^2 (12.6 %) of the coastal area will be lost from a 2 m (equivalent to a low scenario by 2050) and 10 m (equivalent to a high scenario by 2100) flooding, respectively. 0.3 % to 6.3 % of ecosystems worth US$ 12.13 billion/yr could be at risk of flooding by the years 2050 and 2100. The areas under a serious threat contain mangroves, sea and airport, residential and industrial areas of Douala. Main plantation crops of banana and palms will be slightly affected. The identification of the socio-economic impacts of projected SLR on vulnerable coastlines and populations is important for timely actions to be taken in mitigating the effects of natural disasters in the coastal zone.

1 Introduction

A common opinion among contemporary climate scientists is that increasing green house gas (GHG) emissions will raise the average atmospheric temperature by 1.1 C to 6.4 °C over the next century (IPCC 2007). This will lead to thermal expansion of the oceans, rapid melting of ice sheets, and, consequently, sea level rise (SLR). Bindoff et al. (2007) project a global SLR ranging from 0.18 to 0.59 m by the year 2100 taking into consideration various GHG emissions scenarios. Over the 20th century tide gauge's records indicated a global mean SLR rate of 1.7 ± 0.24 mm/yr (Church & White 2006, Holgate & Woodworth 2004), while satellite altimetry data show an accelerated rise of 3.1 ± 0.7 mm/yr for the period 1993-2003 (Solomon et al. 2007, as reviewed by Katsman et al. 2008).

According to Martinez et al. (2007), 41 % of the world's population live within 100 km of the coast and a large proportion of them live closer to the shoreline. Bijlsma et al. (1996), Nicholls et al. (1999) and Martinez et al. (2007) estimated that the gross domestic product (GDP) growth in coastal zones and its environs exceeds the national average in many countries. This turns the coastal zones to important areas for settlement and these zones play a vital role in the economic well-being of many nations.

The last three decades have witnessed economic growth along the coasts of the world (Agardy et al. 2005, Costanza et al. 1997, Turner et al. 1996). Ecosystems in particular are an integral part of the coastal zone and this implies that they are of significant value to both the economy of the country and the livelihoods of local residents. Therefore, it is quite important to evaluate the goods and services that they provide as they have been identified as a central link between society and the structure and function of natural systems. Furthermore, the sustainability and conservation of coastal ecosystems have been highlighted to foster its functioning (Agardy et al. 2005, Costanza et al. 1997, EFTEC 2005, Martinez et al. 2007, WWF 2000). However, only a modest SLR could lead to flooding in low-lying regions, accelerate coastal erosion, inundate wetlands and lead to the relocation of coastal communities and infrastructure. According to IRIN (2008) and Brooks et al. (2006), the entire West African's coastline extending from the orange dunes in Mauritania to the dense tropical forests in Cameroon will be submerged by the end of the century as a direct consequence of climate change. Unabated degradation of coastal ecosystems and habitats caused as a result of natural and anthropogenic activities could lead to their reduced capacity to support the basic human needs of food, fuel and shelter. Associated impacts of coastal hazards could have serious consequences on socio-economic activities.

The aim of this paper is to assess how much of Cameroon's economy might be affected by SLR and to identify the areas and activities at risk of flooding. Specific objectives are:

1. to identify the main economic activities located on the Cameroonian coast and quantify their contribution to the country's economy,
2. to map the existing ecosystems along the coasts of Cameroon and quantify their non-market value based on the ecosystem product service approach as described by Costanza et al. (1997), and
3. to assess economic assets (ecosystems and economic activities) which are at risk most, based on existing estimates of SLR.

Description of the study area

The 402 km long coastline of Cameroon extends from Rio-del-Rey estuary (4° 40 N) at the border to Nigeria to the Campo basin (2° 20 N) at the border to Equatorial Guinea (Figure 1). According to the Centre for International Climate and Environmental Research Oslo (CICERO 2000), 70 % of the country's national industries are located in the coastal area. There are a lot of different coastal ecosystems and they are highly exploited (Gabche et al. 2000), including estuaries (Rio-del-Rey, Cameroon and Ntem estuaries), mangroves, sand dunes, mud and sand flats, lagoons, deltas, coastal shelves, bays and lakes (Figure 1; Folack et al. 1999, Folack & Gabche 2007, Gabche 1997, Gabche & Smith 2002, Sayer et al. 1992, UNEP 1984). These are separated from the Atlantic forest by a marshy complex of brackish waters in the northern portion. On the other hand, the south-eastern part of the coast presents an alternation of rocky and sandy beaches and cliffs.

2 Methods

A comprehensive literature review from primary and secondary sources was carried out to identify the main economic activities developed along these coasts. The area extent of these coastal ecosystems was obtained from the 'World Mangroves Atlas' (Spalding et al. 1997) and 'Coastal Ecosystems' (Burke et al. 2001). The area extents on estuaries, lakes and rivers are from Dupra et al. (2001) and Folack & Njifonjou (1995) while data on coastal forests were obtained from MINEF (1997) and Oates et al. (2004). Valuation of the non-market value of the coastal ecosystems services was done according to the estimations of Costanza et al. (1997).

Estimates of sea level change for the coast of Cameroon were calculated using data obtained from TOPEX/Poseidon and Jason satellite altimeters for the period 1993-2004 (NASA 2008), and tide gauge from Takoradi, Ghana for the period 1930-1965 (PSMSL 2008a). The statistical package Minitab 15 was used to analyse the datasets. Only recently, a tide gauge was installed at the coast of Cameroon. Therefore, the Takoradi data are the best available record that can be applied to estimate sea level changes in Cameroon because being the only tide gauge station in Africa with long-term sea level record (GLOSS 2008) it is, like Cameroon, located in the Gulf of Guinea (GOG) and has, therefore, similar oceanographic characteristics (Aman et al. 2007).

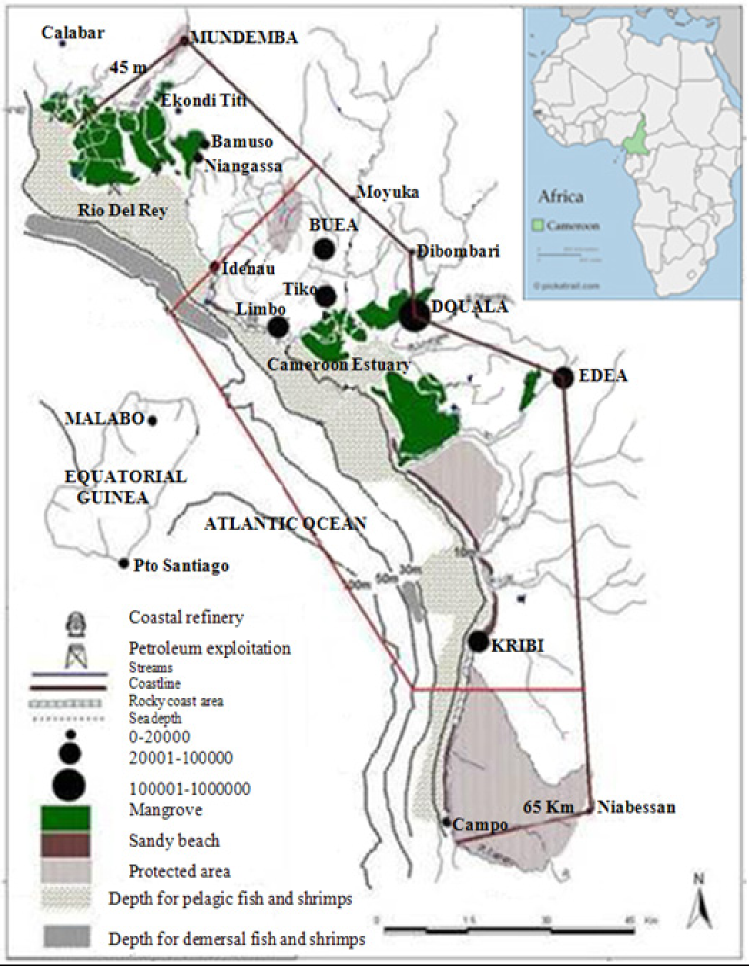

Figure 1: Ecosystems along the coast of Cameroon (adapted from Gabche 2002)

2.1 Coastal topography and land use/land cover pattern

Low resolution topographic maps (NIS 2004), satellite imagery (Go Spatial Ltd 2008), and raster images were extracted from Google Earth. Google Earth images of desired locations were saved and exported to ArcGIS 9.2. These were georeferenced and then digitised to produce shapefiles of coastal Cameroon. This included topography, bathymetry, and land use/land cover, location of main industries, and mapping of coastal ecosystems. It permitted the identification, location and extent of ecosystem biomes along the coasts of Cameroon.

ArcGIS 9.2 (ESRI 2007) was used to map the distribution of coastal economic assets (including ecosystems) to assess the areas at risk for different scenarios of SLR. The software was also used to quantify the potential impacts of SLR on the coastal environments and the country's economy using DEM Raster image (Go Spatial Ltd 2008). You might want to include here an estimate of uncertainties and the effects of the low resolution topographic data.

2.2 Flooding scenarios and socio-economic impacts

Flooding scenarios and areas at risk were calculated by using the equation of Hoozemans et al. (1993) as follows:

$$Dft = MHW + S + Wf + Pf$$

While Dft is the flooding level, MHW refers to the mean high water level; S is the relative SLR, Wf is the height of storm waves and Pf is the SLR as a result of the lowering of the barometric pressure, which is zero (UNESCO 1985). Hoozemans et al. define a risk zone as the land area between the coastline and the "maximum" design water level. This calculation indicates a preliminary extent of the area at risk of flooding.

The data on the tides and surges along the Cameroon coasts were obtained from Hydrographer of the Navy (2008). A value of minimum mean high water (MHW_{min}) of 0.6 m, the mean wave height of storm waves (1.6 m) and the low estimate value of SLR (0.07 m by 2050 and 0.20 m by 2100) was used to obtain the minimum flooding levels. On the other hand, the maximum mean high water (MHW_{max}) value of 2.6 m with a return period of 1/100 years, giving the storm wave height of 6.20 m, and a high estimate of SLR (0.39 m and 0.86 m by the years 2050 and 2100 respectively) indicated the maximum flooding levels.

3 Results: mapping of economic activities and ecosystems

Areas of special ecological importance, plantation crops and economic activities of the different sectors developed along the coasts of Cameroon are shown in Figure 2. Mangroves are the most common coastal ecosystems and usually occur in areas of conservation between Kribi and Campo, around Douala and along the northernmost coastal area.

Figure 2 shows that a large proportion of the industries and ports are found in the low-lying region of Douala (sea port, airport, textiles, and wood and chemical product plants) with few industries located in the Kribi area (mainly rubber and palm plantations), which includes also a sea port used for the exportation of crude oil from Chad (Chad-Cameroon pipeline). The northern region of the coasts along the Tiko, Limbe (formerly Victoria) and Idenau is covered by banana, rubber and palm plantations. These plantations have very large product processing plants. There is a large soap and detergent factory, air- and sea port in Tiko. The Limbe deep sea port is associated with a petrochemical refinery which refines crude petroleum for nationwide consumption and exportation. The location of many industries along this area acts as a melting pot of the country's economy. The fact that this is a low-lying and flood risk area implies that efforts must be made to mitigate any problems resulting from a SLR.

Industries, ecosystems, and plantations account for 70 % of the GDP of the country. The fishery sector, which falls under agriculture, make up 19 % of the economy's GDP. Douala, which is the economic capital of the country, contributes 21.9 % GDP from trade, hotels, and restaurants. This is closely followed by the water and gas sector which represents 18.2 % of the GDP. The mining sector (10.6 % of GDP) has witnessed some drop as a result of depletion of hydrocarbons. Export crops of banana, rubber and palms contribute 1.4 % of the GDP.

3.1 Results of the valuation of ecosystems

Results of the valuations of the habitat types adapted from the data described by Costanza et al. (1997) are presented in Table 1. This summarises annual values of natural resources in American dollars (US$) as currently used in environmental assessments. A total value of US$ 12.13 billion/yr was obtained from the valuation of Cameroon's coastal ecosystems.

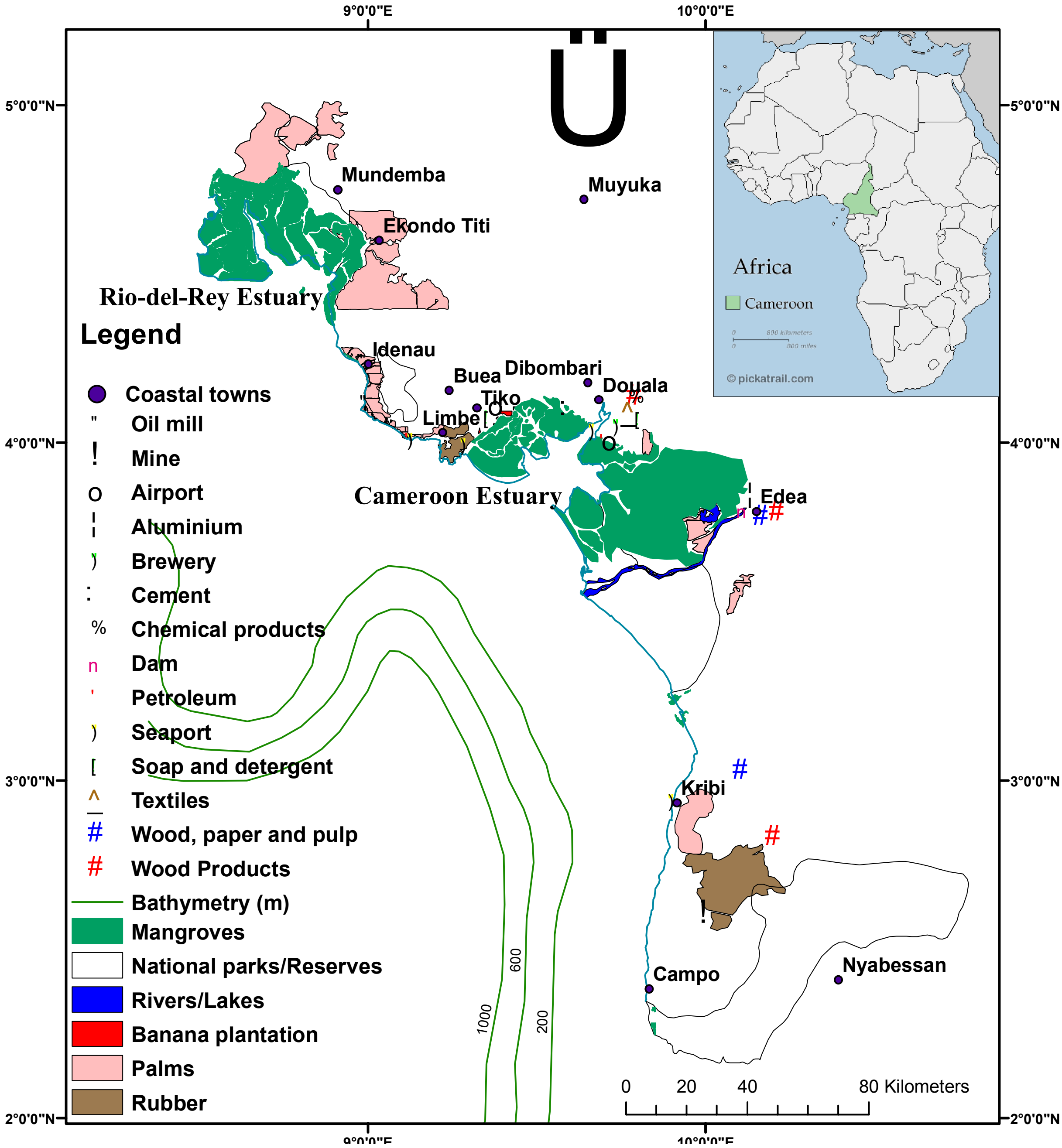

Figure 2: Ecosystem types, main economic activities, cash crops, and urban areas along the coast of Cameroon

Table 1: Estimated average value of annual ecosystem services for the coasts of Cameroon (Burke et al. 2001, Costanza et al. 1997, Gabche & Smith 2002, Oates et al. 2004)

Biome	Area (km^2)	Area (ha)	Value (US$/ha/yr)	Total value (US$/yr)
Estuaries	2,850	285,000	22,832	4,891,756,000
Shelves	13,100	1,310,000	1,610	1,706,600,000
Forests/reserves	5,834.6	583,464	969	565,376,616
Mangroves	2,494	249,400	9,990	2,491,506,000
Lakes/rivers	2,910	291,000	8,498	2,472,918,000
Total	**27,638.6**	**2,763,864**	**43,899**	**12,128,156,616**

3.2 Sea level rise rates of change

Data from TOPEX/Poseidon and Jason satellite (NASA 2008) show that Cameroon has relative rates of SLR of 2 to 2.4 mm/yr. Results of Glacial Isostatic Adjustment (GIA) from Calabar, Nigeria (PSMSL 2008b), which is the tide gauge closest to the study area with longer recorded and analysed data, when subtracted from Cameroon's estimated SLR figures from satellites, gave a corrected rate of sea-level change of 1.8 to 2.2 mm/yr for the period 1948-2003. However, the results of the Revised Local Reference Level (RLRL) data from PSMSL (2008a) showed a relative rate of SLR of 3.1 mm/yr with a range of lower 95 % confidence levels and upper 95 % confidence levels of 2.3 and 3.8 mm/yr respectively. Corrected satellites data and confirmed results of estimated SLR are shown in Table 2. They range from 9 to 38 cm by the years 2050 and 2100, respectively. This falls within the medium range scenario by the IPCC (Table 2) ranging from 20 to 86 cm by 2100 for the IS92a GHG emissions scenario, which is the medium emission scenario by the IPCC, with a best estimate of 49 cm.

Recent satellite data indicate a rate of 3.1 mm/yr for the same period (Cazenave & Nerem 2004, Holgate 2007). The global average range (1.74 ± 0.24 mm/yr) for the 20th century has been published by Bindoff et al. (2007). Differences between the global average range and the estimated tide gauge range for Cameroon are probably caused by knowledge gaps on the processes that generate local changes in sea-surface temperature, ocean siphoning, and continental levelling (Gehrels & Long 2008). The present study used projections by Warrick et al. (1996) for example the IPCC medium emissions scenario for GHG IS92a. This is because estimated SLR for the coasts of Cameroon falls within their range (20 to 86 cm with the best estimate of 49 cm), and, secondly, there is a lack of knowledge with respect to anthropogenic activities that could affect SLR and inadequate monitoring of tide gauges' data along the coasts of Cameroon. The same IPCC range was used in Cameroon and Morocco to assess preliminary impacts of SLR (CICERO 2000, Snoussi et al. 2008, Snoussi et al. 2006).

Table 2: Estimated SLR (cm) for the coast of Cameroon from satellite and GIA data set records and RLRL from Takoradi tide gauge and global meal sea level estimates (Warrick et al. 1996)

Scenarios	SLR (cm), satellite and GIA data with a range of 1.8 to 2.2 mm/yr		SLR (cm) Takoradi with a range of 2.3 to 3.8 mm/yr		Global SLR (cm)		
					Low	Medium	High
2050	9	11	11.5	19	7	20	39
2100	18	22	23	38	20	49	86

3.3 Flooding scenarios and socio-economic assessment

A minimum high water indicated flooding levels of 2.4 m while maximum high water values indicated flooding levels of 9.7 m as shown in Table 3. Consequently, two levels of flooding were considered: a minimum and a maximum flooding scenario based on the different estimated rates of SLR.

Table 3: Minimum and maximum flooding scenario by the years 2050 and 2100, respectively

Scenarios	Minimum flooding levels (m) Low estimate of SLR	Maximum flooding levels (m) High estimate of SLR
2050	2.27	9.19
2100	2.4	9.66

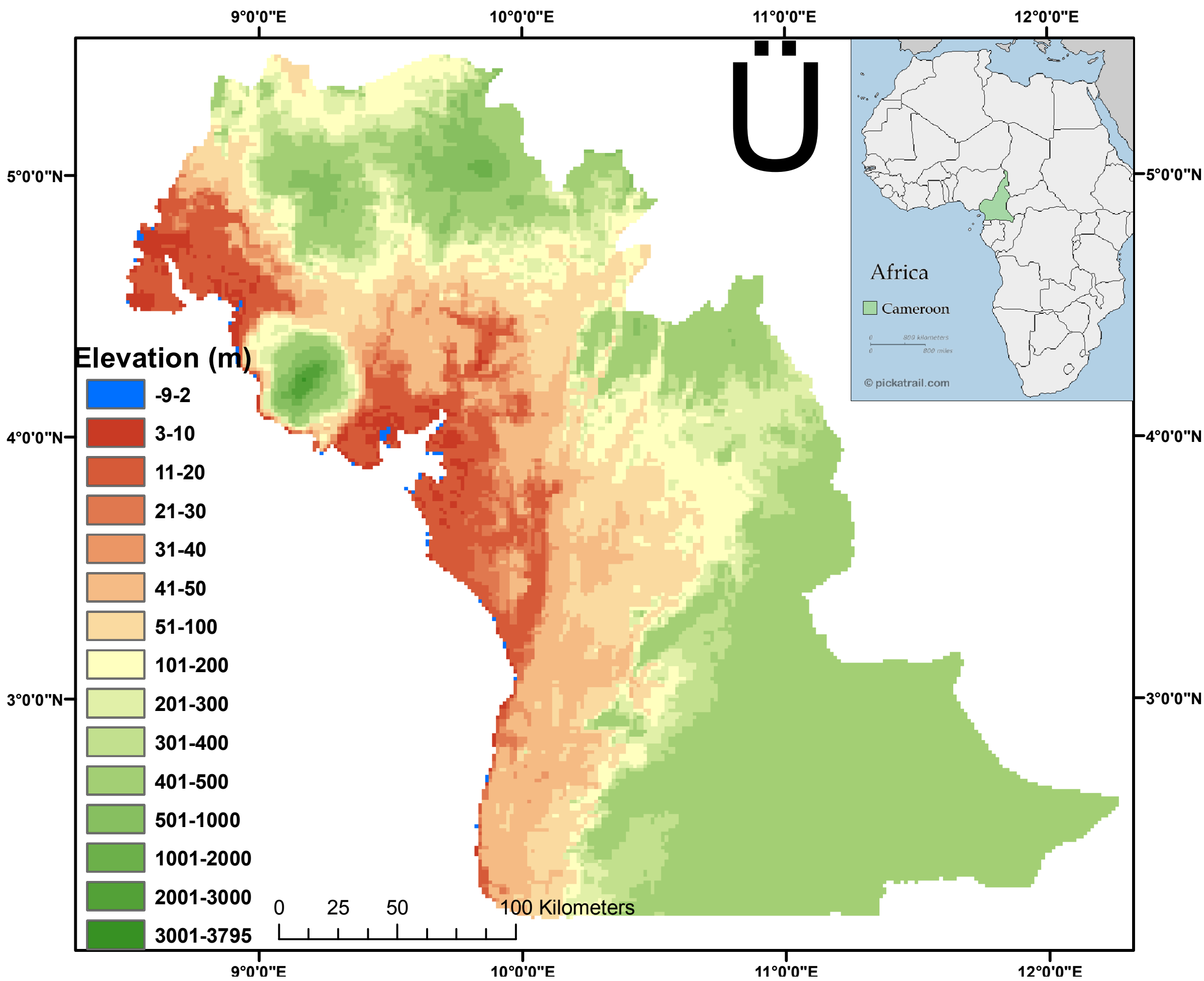

Figure 3: Minimum flooding levels (2 m): elevation and areas at risk by the year 2050 along the coast of Cameroon

Figure 3 indicates that with a 2 m flooding scenario, 1.2 % of the coastal area (112.32 km^2 of the land) will be lost. A maximum flooding scenario of 10 m would lead to a land loss of 1,216 km^2 (12.6 %) of the whole coastal area (Figure 4).

Data on potential land loss due to 2 and 10 m high flooding scenarios are presented in Table 4. From these data it can be observed that for a 2 m flooding, 28.35 km^2, 3.46 km^2, and 4.26 km^2 of the mangroves of Rio-del-Rey and the Douala area, Edea and Ndongone forest reserves and rivers and lakes respectively will be destroyed. This indicates a 1.14 %, 0.05 % and 0.15 % decrease in the values of the services rendered to the country by these ecosystems along the coasts of Cameroon. Results from GIS environment analysis showed that land loss from urban settlement will be 2.33 km^2. Furthermore, 0.36 km^2 and 0.32 km^2 of land will be destroyed due to flooding of palm plantations and the Douala sea port. However, the airport, refinery, rubber and Banana plantation will not be affected.

For 10 m flooding, ecosystems at risk include 657 km^2 of estuarine mangroves. This represents a reduction of 26.25 % in the values of services provided by this biome. Over 170 km^2 of protected coastal areas will be damaged, costing a reduction of 2.9 % of its services**.** A reduction of 3.7 % of the rivers' and lakes' value will be incurred when 103.33 km^2 of these biomes are lost caused by a 10 m flooding.

Analysis of the environment using GIS also indicated that urban areas are at risk of flooding. The Douala air- and sea ports, which are important to the handling and transport of goods to and from the country, will be severely affected by flooding. In case of a 2 m flooding the Douala sea port will be slightly affected while a 10 m flooding could cause damages on over 80 % of the land area of the sea and airport.

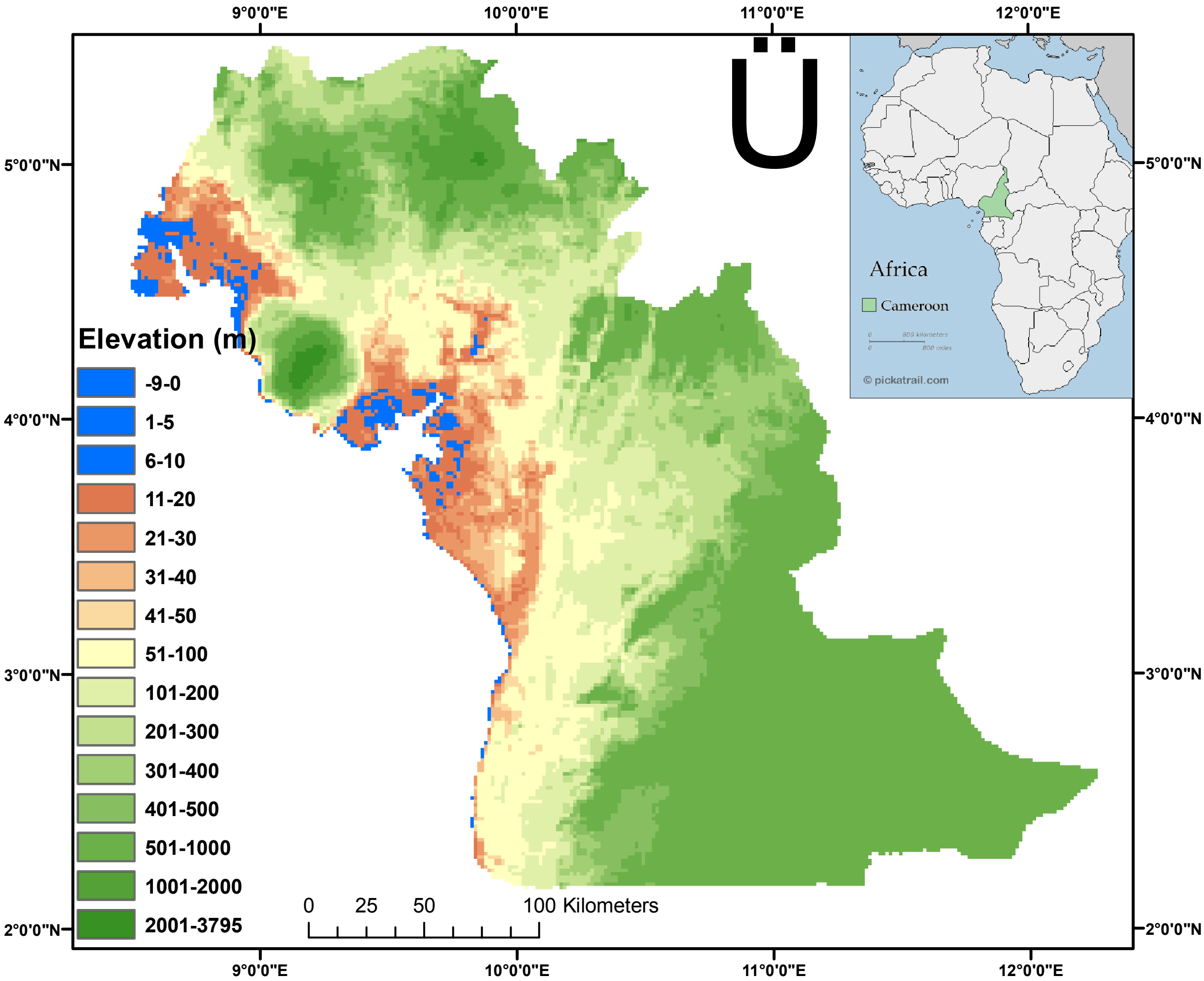

Figure 4: Maximum flooding levels (10 m): elevation and areas at risk by the year 2100 along the coast of Cameroon

Table 4: Potential land loss from 2 and 10 m flooding

Cartographic units	Flooded area with minimum level (2 m) in km²	Flooded area with minimum level (10 m) in km²	% services at risk	
			2 m	10 m
Mangroves	28.35	657	1.14	26.34
Protected areas	3.46	171.72	0.05	2.9
Rivers/lakes	4.26	103.33	0.15	3.7
Urban areas	2.33	87.69	0.22	6.32
Refineries	-	-	-	-
Airports	-	3.91	-	84.78
Seaports	0.319147	3.93	7.03	86.56
Palm plantations	0.360	67.67	1.16	4.43
Banana plantations	-	5.49	-	3.62
Rubber plantations	-	2.04	-	2.54

4 Discussion

The industrial base of the Cameroonian economy is concentrated around the coastal regions. According to Scheren et al. (2002), industrial activities are concentrated around urban centres along the coast where 60-80 % of the industrial production takes place since these coasts host major harbours. A large proportion of these industries are found in the low-lying coastal region of Douala (sea port, airport, textiles, wood and chemical plants, fishing industries, and processing plants) (Asangwe 2007, Asangwe 2000, Gabche et al. 2000). For instance, Gabche et al. (2000) indicated that the Wouri coastal area has the highest population density of near-shore shrimp fish catch (ca. 940 per km^2, 1987) and approximately 27 % of the population were artisanal fishermen. They also reported that 80 % of Cameroon's industrial fisheries were established in this region which clearly is in danger in the wake of a SLR.

Industrial production within the GOG, as described by Scheren et al. (2002), is categorized into elementary products (agro-food processing, textile and leather, soap and detergent, beverages and construction), and processing of raw materials exploited in the region (e. g. petroleum, aluminium, and sand and gravel mining). The petroleum industry in Cameroon is located in the coastal towns of Limbe, where a refinery is situated, and Kribi, which is an outlet for the Chad-Cameroon pipeline. In 2006, Cameroon was the sixth largest oil producer in sub-Saharan Africa with about 63,000 barrels per day (Alemagi 2007). Revenue generated from the oil sector contributes significantly to the socio-economic well-being of the nation and accounts for more than 10 % of the country's GDP. The situation for the country's economy may be more complicated because activities that generate funds, as represented by the GDP of 2006 (AFDB 2008), are highly dependent on the stability of the coastal region for their smooth running (sea port, airport, industries etc).

Agriculture is an important sector for the economy of Cameroon. It is the second largest employer in the country after the public service (NIS 2004). The main industrial plantations (rubber, palms, and banana) are located along the coasts and they contribute significantly to the GDP of the country. It is generally agreed that coastal areas generate more than half of the GDP of most nations (Nicholls & Klein 2000, Nicholls & Lowe 2004). This is the case in Cameroon as well, where a majority of the industries is located along the coasts and at risk of flooding due to SLR. Data from this study show that over 10 % of the revenue generated from rubber, palms, and banana crops plantation could be at risk from a 10 m flooding scenario, leading to a decrease in the GDP contributions from the agricultural sector. The economy of the country could, therefore, be seriously undermined by a 10 m flooding scenario by the year 2100. The fact that this is a low-lying and flood risk area implies that efforts must be made to mitigate any problems resulting from a SLR.

4.1 Valuation of ecosystems

This study shows that ecosystems (mainly mangroves and estuaries) and areas of conservation are an integral part of the coastal zone. Their significant role to both the economy of the country and the livelihoods of local residents in Cameroon and the GOG has been highlighted by several authors (Chukwuone et al. 2009, CICERO 2000, Din et al. 2008, Gabche et al. 2000, Price et al. 2000, Ukwe et al. 2003).

The summary of annual values of natural resources, as currently used in environmental assessments and as determined by Costanza et al. (1997), gives a substantial value of US$ 12.13 billion/yr for the coastal ecosystems of Cameroon. The results of this study is higher than the national value of US$ 8.3 billion/yr estimated by Price et al. (2000). Differences between these estimates are explained due to the fact that coastal forests were not included in their valuation estimates. Furthermore, the area extent of estuaries as determined by Price et al. (2000) was smaller (1,605 km^2) than in the present study (2,850 km^2). Estimates of the area extent used in the present study were taken from Gabche & Smith (2002). However, there is a lack of consensus on the exact area extend of the estuarine system. Dupra et al. (2001) stipulated an area estimate of 3,300 km^2 for the Rio-del-Rey system and 2,850 km^2 for the

Cameroon estuarine system. Therefore, there is a need for a consensus on the area extent of the estuarine systems in Cameroon. Despite these differences and shortcomings, bioeconomic valuation is still considered a valuable tool for providing at least a preliminary economic assessment of coastal habitats (Price et al. 2000).

According to CICERO (2000), estuary mangroves and adjacent coastal waters play a significant part in Cameroon's fishery activities. It is estimated that industrial fishing for this area is worth US$ 488 billion (market prices in the year 2000). The importance of estuaries and mangroves for fishing activities can be explained by the fact that these areas serve as breeding, spawning, and nursery ground for most fish species in the area. Ogba & Utang (2007) and Ukwe et al. (2003) reported that mangrove forests provide nutritional inputs to parallel shallow channels and bay systems, which are the primary habitat to spawning and breeding grounds for many aquatic species of commercial importance in the GOG.

Mangrove forests and coastal forests also support local residents considerably in their provision for food like non-timber forest products (NTFP), firewood, charcoal, and construction (CICERO 2000, Din et al. 2008, EFTEC 2005, Feka & Manzano 2008). Logging of mangroves and NTFP in the Douala coastal region generates about US$ 5,152 million/yr according to Din et al. (2008). They regretted the fact that revenue from these activities is not considered in the country's financial policies. According to CICERO (2000), some of the mangrove forests are removed to allow agricultural expansion due to increasing agricultural land scarcity. However, overexploitation of these resources is often associated with environmental degradation and loss of ecosystem values and services which may hamper the sustainability of such ecosystems (Oates et al. 2004). Anthropogenic activities on the sustainability of coastal ecosystems are most prevalent around the Douala coastal region (Price et al. 2000) and these include the mangrove forests. Furthermore, sustainable forestry produces the highest economic return with regards to a global perspective in the 'best' use of land (Yaron 2001).

However, flooding scenarios of 10 m could hamper the benefits of the services provided by these ecosystems to the local residents, since 26 %, represented by US$ 658 million/yr, of estuarine mangroves are at risk. It is quite easy to understand the loss of estuarine mangrove ecosystems as these are closest to the sea and constitute most of the wetlands areas. 3.5 % (US$ 88 million/yr) and 2.9 % (US$ 17 million/yr) value of services provided by rivers/lakes and protected area/coastal forests respectively are at risk in a 10 m flooding scenario by the year 2100. According to Nicholls (2004), 5 to 20 % of coastal wetlands will be lost due to SLR worldwide by the year 2080. It was indicated that these losses are relatively small compared to direct and indirect human destruction. The destruction of marine habitats by inundation has been suggested to undermine livelihoods based on fishing for the Niger Delta coastal settlements (Ogba & Utang 2007). Other activities such as mining, logging activities, and NTFP could be affected by the 2 and 10 m flooding scenarios obtained in this study. However, the values of ecosystems at risk in a 2 m flooding scenario are minimal with a 1.14 %, 0.05 % and 0.15 % loss for mangroves, protected areas/coastal forests, and rivers/lakes respectively.

There is a legal framework for environmental management in Cameroon which protects all environments with valuable ecosystems (Alemagi 2007, Alemagi et al. 2006, MINEF 1997, MINEF 1995). Unfortunately, they are not being enforced, leading to unsustainable exploitation of these ecosystems.

Bioeconomic valuation for integrating information on ecological, economic and social aspects will improve the analysis of coastal systems beyond traditional commercial interests (commerce, fisheries and human populations; Martinez et al. 2007). An important aspect is the ability of these coastal systems to offer shoreline protection against extreme events like storms and hurricanes, storing and cycling nutrients, climate regulation, sustaining biodiversity and water capture (Martinez et al. 2007, NRC 2004). It is also estimated that water supply and disturbance regulation contribute close to two-thirds of the value calculated for the valuation of ecosystems services in Pantanal da Nhecolandia, Brazil (Seidl & Moraes 2000).

However, results obtained from this study showed that 0.3 % and 6.3 % of the values of these services could be at risk of 2 and 10 m flooding as a direct consequence of SLR by the years 2050 and 2100. The 2100 projections are within the range reported by Nicholls (2004) for the year 2080 for the percentages of ecosystems that could be at risk. In such situations, highly priced habitats for recreation and tourism could, therefore, be destroyed (Martinez et al. 2007). On the other hand, ecosystems will not be impacted seriously by the year 2050 as a result of a 2 m flooding. However, indirect effects, such as saltwater intrusion, changes in water or soil quality, rising water tables, loss of recreation, tourism and transport function etc., are possible and may result in a loss or degradation of valuable services.

4.2 Socio-economic assessment

An estimated 5.76 % of the total land area of Cameroon is coastal zone and 27 % of the population live less than 104 m above sea level in this area with an annual average growth of 2.21 %. Similarly, Nicholls et al. (2007) estimated that 23 % of the world's population live less than 100 m above sea level. Furthermore, the high population density of this area and its vital economic sectors make the potential socio-economic impacts on the Cameroon coast of particular concern. Nicholls (2002) highlighted that there are a lot of uncertainties, such as the number of people along the coasts that could be displaced as a result of flooding. Recent surveys show that flooding sensitivities of coastlines as a result of SLR do not only depend on natural factors of the shoreline's relative resistance to erosion, elevation, long term erosion/accretion trend, coastal slope, wave height, tidal range, storm frequency and rates of SLR, but also on the society as a whole to adopt preventive measure and to accommodate the dynamic nature of natural coastal processes. Preventive management measures are easier and less expensive to implement.

The identification of low-lying areas is one of the most important elements needed to assess the vulnerability of coastal regions and economies to projected SLR in the 21st century. CCSP (2009) stipulated that coastal elevation data (topographic maps or DEM) have been widely used to quantify the potential effects of predicted SLR, especially areas in coastal regions that could be flooded and their affected populations. Furthermore, recent reports have stressed the point that SLR impact assessments need to continue to include maps of areas subjected to flooding based on measurements of coastal elevations (Blomgren 1999, Coastal States Organization 2007, Seiden 2008).

DEM combined with relative sea-level change for this study indicates that 112 km^2 and 1,216 km^2 of the coastal zone will be at risk from flooding scenarios by 2050 and 2100. This is equivalent to minimum and maximum losses of 0.02 to 0.3 % of the country's total land area and 1.2 to 12.6 % of the coastal area respectively by the years 2050 and 2100. Urban areas, especially Douala city, are at risk of flooding by 2050 and 2100. Douala's air and sea ports are the most vulnerable regions because more than 85 % of their land area could be undermined by the 10 m flooding scenario of this study. Studies by CICERO (2000) using the IPCC simple inundation model indicated that land loss as a result of SLR in the Cameroon estuary mangroves covers 49.5 km^2 for a SLR of 20 cm and 330 km^2 for a maximum SLR of 90 cm by the years 2050 and 2100. Land loss estimates for this study are based on the entire coastal zone of Cameroon.

Cameroon's economy heavily depends on its air and sea ports since most of its primary products (coffee, cocoa, banana, rubber, palm oil, petroleum, minerals and cotton) are exported through these ports. Importation of goods and services also passes through these ports. Furthermore, the landlocked countries Chad and Central African Republic depend on the sea port for the export and import of oil and other precious mineral stones. Flooding scenarios could, therefore, significantly reduce the GDP contribution of their economy.

Many studies have highlighted the fact that coastal areas are low-lying regions, which are vulnerable to natural and anthropogenic hazards (Bijlsma et al. 1996, Brooks et al. 2006, Demirkesen et al. 2008, Doornkamp 1998, Nicholls et al. 2007, Simeoni & Corbau 2008, Snoussi et al. 2008, Snoussi et al.

2006). DEM assessment of land lost within a 1 m high water mark has resulted in an 18,600 km^2 loss in Nigeria (Awosika et al. 1992), 2,165 km^2 in the Netherlands (IPCC 1996) and 1,700 km^2 in Poland (IPCC 1997).

A LULC map of the area showed that 82.33 % was covered with forest (including grassland, wooded greenland, shrubland, mangroves), 15.65 % with cropland, 1.3% with water and 0.73% with bareground and urban built up. This shows that the coastal area of Cameroon is still covered with natural forests and vegetation. A similar classification of the coastal areas of the world by Martinez et al. (2007) indicated that most African countries show a relatively well preserved ecosystem with ecosystem service products of moderate to high value (61-100 %). Given the importance that coastal ecosystems play in the sustainability of living and non-living resources, carbon sink, shoreline protection and the dissipation of energy from wind storms and flooding in the wake of SLR as a result of climate change, the management of such relatively preserved ecosystems in Cameroon, as a way of benefiting from these services and maintaining the values and functions, will be greatly beneficial to the economy of the nation, whose GDP is mainly dependent on the coastal ecosystems and activities developed along this area.

5 Conclusions and recommendation

Almost a fifth of the coastal area is low-lying. A large proportion of the low-lying area is located in the Douala coastal area and this is where a great proportion of the economic activities is concentrated. Being the economic capital of the country, it thus has a key role to play in the country's economy. The fact that almost all of Douala is located less than 70 m above sea-level calls for efficient management strategies to pre-empt any economic failure due to effects of flooding as a result of SLR.

The identification of the socio-economic impacts of projected SLR on vulnerable lands and populations is an important initial step for a country in mitigating the effects of natural disasters in the coastal zone (CCSP 2009, Subcommittee on Disaster Reduction 2008). The determination of the most vulnerable zones was obtained by overlaying the LULC map and DEM of the study area. Data from this study are equivalent to losses of 0.02 to 0.3 % of the total surface area and 1.2 to 12.6 % of the coastal area with elevations of 2 and 10 m flooding by 2050 and 2100. The coastal high risk flooding areas are the urban and industrial cities of Douala, Bonaberi, the airport, the sea port, mangrove swamps in Douala, the Douala-Edea reserve, the Ndongone reserve area and the Rio-del-Rey estuaries bordering on Nigeria to the North. The Seme beaches, mile six beach and Kribi beaches are sensitive to flooding and, therefore, land loss. Furthermore, important effects such as saltwater intrusion and changes in sediment balance are likely to affect the extent of affected areas, but are not included in this work.

Applying the IPCC methodology, assessing the impacts of SLR on the Cameroonian coast has enabled the quantification of the areas at risk, ecosystems and the economic assets vulnerable to flooding due to SLR. Global SLR scenarios are important, but it is the local SLR rates of change that matter in the assessment of impacts. Generally, flooding levels of 2 m by the year 2050 will not have an important impact on ecosystems and economic activities. Specifically agricultural lands are relatively preserved. However, important damages could be incurred on ecosystems and economic activities along the coasts of Cameroon with flooding scenarios of 10 m representing SLR of between 0.39 and 0.86 mm/yr by the years 2050 and 2100. Some limitations of the study were due to the resolution of the topographic data and also to the assumption that conditions of MHW and waves remain unchanged through time, but it gives us a preliminary estimate of the damages that could be incurred (assets and monetary) as a result of SLR along the coasts of Cameroon.

The use of ArcGIS 9.2 and DEM is, therefore, a very important tool for the assessment of flooding impact scenarios predicted to occur more frequently in the future because of climate change. Flooding could have irreversible adverse impacts on ecosystems and the livelihood of coastal settlers, since wetlands and infrastructure could be destroyed while coastal populations will be displaced.

A comprehensive and integrated coastal database should be drawn-up and implemented. This database should be dynamic, user-friendly and interactive based on the vulnerability assessment of the coastal zone. Elements of this database should include but not be limited to:

- Obtaining and modeling a long-term record of tidal levels along the coast of Cameroon, taking into consideration the coastal processes, beach morphodynamics and anthropogenic activities of the area so that vulnerability assessment is based on the local environment and not regional or global environment.
- A systematic mapping of important coastal habitats or ecosystems, using a combination of ground based surveys and high resolution aerial photographs or satellite images to be able to quantify changes through time both in land use type or area extent.
- Research and development of technologies to plan, design and implement adaptation strategies. The monitoring and evaluation of the performance of these technologies should also be envisaged.

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