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Evaluation of the Economic Impact of Coastal Erosion in Dakar Region

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ABSTRACT

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Besides the environmental impacts, climate change negatively affects the economic value of coastal zones. Coastal erosion, which is one of its impacts, causes damage to people living along the coast. The narrowing of the beach due to erosion leads to socio-economic damage by reducing the areas where economic activities are carried out. As a result, livelihoods, human settlements, and economic activities such as fishing, tourism, and industry are disrupted. The evaluation of the economic impacts of coastal erosion is timely and relevant. This study aims to economically investigate the most affected coastal areas in Dakar region in 2030 and 2040. It also allows for the identification of localities that need protective infrastructure to prevent economic losses from coastal erosion. The assessment is done by estimating the economic value of the beach using multilinear regression, an econometric forecasting model. Software such as R, Excel, ArcGIS, and Digital Shoreline Analysis System were used in this study. The results show that, due to coastal erosion, the district municipalities along the coast of Dakar will record a loss estimated at 38,507,856,000 FCFA in 2030 and 57,822,698,000 FCFA in 2040. The results of this study suggest that the parameters such as Beach Width, Lost Areas, Coastal Length, Dynamic Rate, Littoral Areas, Built Areas, Proximity to Town, Coastal Vulnerability Index, Number of Buildings, Number of Hotels, Number of Industries, Number of Fishing Points, and Road Length play an important role on littoral value. Coastal erosion will be among the most threatening disasters in the Dakar region if the "do nothing" option is adopted as an adaptation measure.

ADDITIONAL INDEX WORDS: *Economic activities, vulnerability, coastal management.*

INTRODUCTION

Dakar region, like most of the world's capitals, is not safe from the impacts of climate change and coastal erosion because of its geographical position and its low-lying (Pouye *et al.*, 2022). Advanced sea resulting from the rise in sea level is affecting the coasts. Dakar's current and expected coastal dynamic shows that there is indeed an advanced sea due to variations in oceanic waters aggravated by the effects of hydrodynamic agents such as waves, tides, and wind. Therefore, this situation reduces coastal areas; human displacement toward inland; disruption of economic activities such as fishing, recreation, hotel, and industry activities. Man accentuates these threats through sand mining, pollution, and illegal settlements (Pouye, 2016). According to Niang *et al.* (2012), scenario-based studies have predicted land losses in Dakar by 2050. These losses will be estimated at 0.21 to 1.79 km^2, *i.e.* 3.8 to 28.5% of the total beach area. By 2100, they will be between 0.77 and 3.95 km^2, *i.e.* 12.2 to 62.8% of the total beach area.

This coastal erosion causes significant economic losses, the estimation of which is complex. Knowledge of the economic value of the beach was minimal, beyond that suggested by property values. There needs to be more scientific information on the economic value of the beach to assess the effectiveness of investing exorbitant amounts of money in beach erosion management (Edwards and Gable, 1991). So far, this economic value of beach erosion was sometimes assessed by the cost of protective infrastructures without considering income losses (Alexandrakis, Manasakis, and Kampanis, 2015). Therefore, with the use of econometric models, this challenge is resolved. This evaluation is no longer linked to the protection infrastructures but to the revenues generated by economic activity such as tourism and the economic value of coastal properties. In a study, Alexandrakis, Manasakis, and Kampanis (2015) estimated the value of eroded beaches through the hedonic pricing model, where the beach value is determined by its width and tourism business. Some studies argued that the value of the properties is relative to beach width. Brown and Polakowski (1977), in a study, indicate that the value of a

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Table 1. *Localities, data, and methods used in this study.*

Localities	Code	Variables	Code	Methods
Bambilor	NC 1	Littoral Price (LP)/m^2 (FCFA)	LP	https://www.fao.org
Tivaouane	NC 2			
Malika	NC 3	Lost Areas (LA) (m^2)	LA	Satellite images/ArcGIS/DSAS
Yeumbeul	NC 4			
Wakhinane	NC 5	Coastal Length (CL) (m)	CL	Satellite images/ArcGIS
Ndiareme	NC 6			
Sam	NC 7	Dynamic Rate (DR) (m/year)	DR	Satellite images/ArcGIS/DSAS
Golf Sud	NC 8			
Camberene	NC 9	Littoral Areas (LA) (m^2)	LA_s	Satellite images/ArcGIS
Parcelles	NC 10			
Yoff	NC 11	Built Areas (BA) (m^2)	BA	https://download.geofabrik.de/africa/senegal-and-gambia-latest-free.shp.zip
Ngor	WC 1			
Ouakam	WC 2	Proximity to Town (PR) (m)	PR	Satellite images/ArcGIS
Mermoz	WC 3			
Fann	WC 4	CVI	CVI	Satellite images/ Hydrodynamic data/ArcGIS
Gueule Tapee	WC 5	Littoral Width (LW) (m)	LW	Satellite images/ArcGIS/GPS Visualizer
Medina	WC 6			
Plateau	WC 7	Number of Buildings (NB)	NB	https://download.geofabrik.de/africa/senegal-and-gambia-latest-free.shp.zip
Hann	SC 1			
Dalifor	SC 2	Number of Hotels (NH)	NH	https://download.geofabrik.de/africa/senegal-and-gambia-latest-free.shp.zip
Thiaroye	SC 3			
Diamageun	SC 4	Number of Industries (NI)	NI	https://download.geofabrik.de/africa/senegal-and-gambia-latest-free.shp.zip
Mbao	SC 5			
Rufisque Ouest	SC 6	Number Fishing Points (NFP)	NFP	Google Earth Pro
Rufisque Est	SC 7			
Yenn	SC 8	Road Length (RL) (m)	RL	https://download.geofabrik.de/africa/senegal-and-gambia-latest-free.shp.zip

CVI = Coastal Vulnerability Index; DSAS = Digital Shoreline Analysis System

property decreases with distance from the water. The effect of beach quality, as determined by beach width, on property values in two South Carolina coastal towns is investigated by Pompe and Rinehart (1995). In addition, in a study, Landry, Keeler, and Kriesel (2003) emphasized the complexity of the relationship between property value, the erosion rate, and distance from erosion reference. Property owners appreciate shorter distances to the reference erosion feature for recreational and amenity reasons. They also value the protection against storm surges and the risk of erosion, fostered by a larger beach width, a more considerable distance to the reference erosion feature, and a decreased erosion rate.

The importance of assessing the economic value of beaches is to evaluate coastal management policies and projects (Lew and Larson, 2008). It may identify coastal areas needing protective infrastructure based on physical and socio-environmental vulnerability, coastal dynamism rate, and beach width reduction. Further, this study uses an econometric model (multilinear regression) which points out the impacts of Littoral Width, Lost Areas, Coastal Length, Dynamic Rate, Littoral Areas, Built Areas, Proximity to Town, Coastal Vulnerability Index (CVI), Number of Buildings, Number of Hotels, Number of Industries, Number Fishing Points, and Road Length on beach value along the coast of Dakar region (Table 1). Geographic Information System techniques were used to determine independent variables through spatial data.

Study Area

The study area is the district municipalities along the coast of Dakar region (Figure 1), which is located in west Africa between 17° 10 and 17° 32 west longitude and 14° 53 and 14° 35 north latitude. It covers an area of about 550 km², *e.g.*, 0.28% of the national territory. It is bordered to the east by the Thiès region and to the north, west, and south by the Atlantic Ocean (Pouye, 2016). As the capital of Senegal, Dakar region hosts about 3,938,358 inhabitants, *e.g.*, 22.8% of the total population (ANSD, 2020). Dakar region hosts over 50% of economic activities and most of the administrative infrastructures.

Consequently, the concentration of the population is becoming denser and denser, increasing the need for urbanization and land allotments (ANSD, 2021). This concentration of population causes problems in the marine environment. The urbanization of the coastline has become a thoughtless phenomenon that reflects the importance of the proximity of water. The dynamics of coastal occupation show two types of evolution: on the one hand, the advance of dwellings towards the sea, and on the other hand, the advance of the sea towards the dwellings. In addition, several economic activities, such as fishing, tourism, and industry, are carried out along the coast of Dakar, which gives the beach an increasing economic value (Pouye, 2016). According to Amuzu *et al.* (2018), several people live along the coast, contributing to the Gross Domestic Product (GDP) through economic activities such as tourism and fishing. In West Africa, the contribution of fishing to the GDP in Senegal decreased from 1.7% in 2012 to 1.4% in 2015. In Dakar region, the Bay of Hann, Rufisque, Soumbedioune, Thiaroye, and Yoff is the prominent localities where fishing activities represent an essential part of economic income. Nevertheless, because of over-exploitation of marine resources, pollution, and environmental degradation, weakness of the institutional framework managing the sector, insufficient human resources, lack of adequate financing, inadequate fiscal environment,

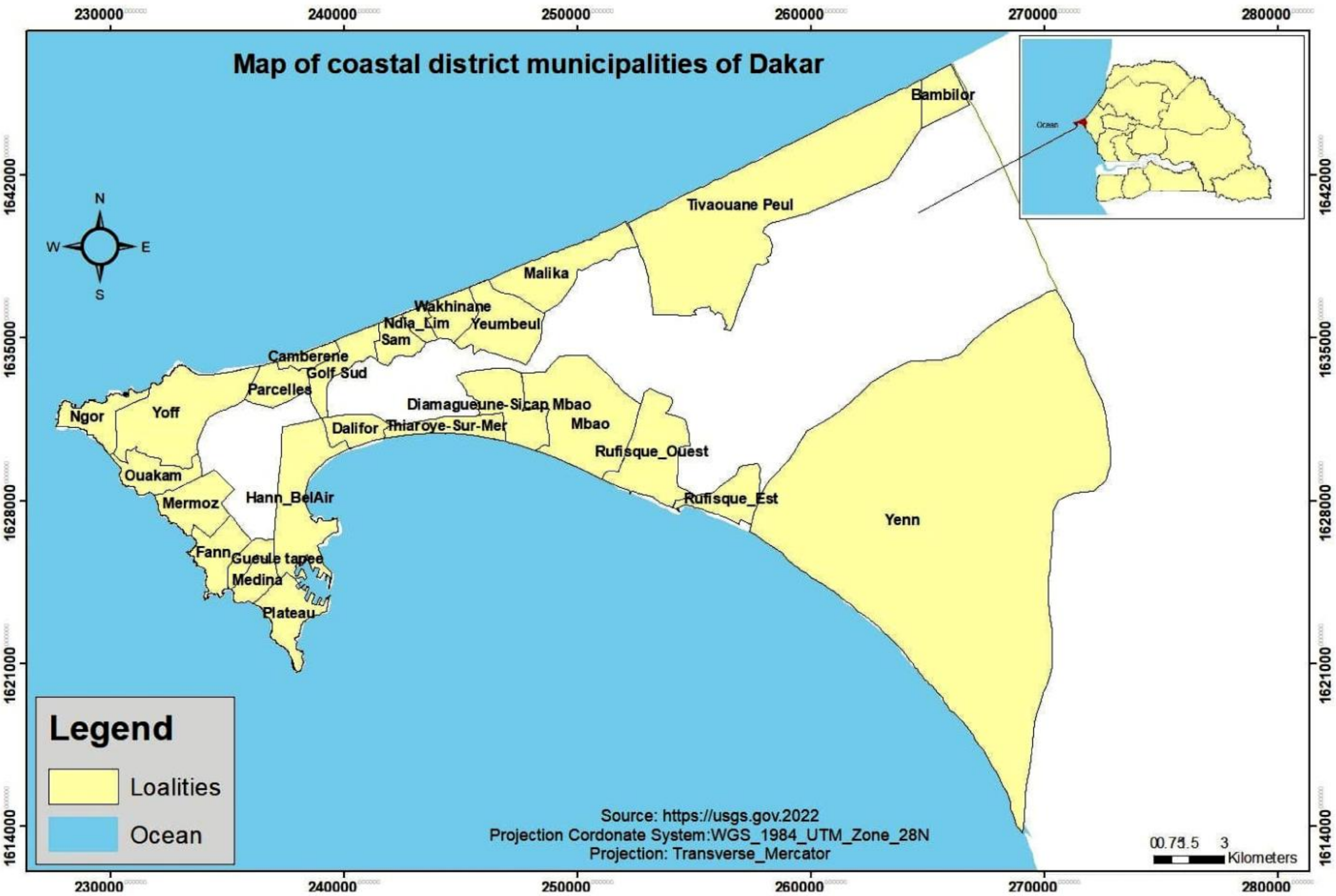


Figure 1. Location map of the district municipalities along the coast of Dakar region.

weakness of information system and research capacities, sustainable fishing is not guaranteed (ANSD, 2018). Far from being negligible, industries along the coast also play an essential role in the national economy. Tourism is among the most important economic activities which generate income in the national economy. In a report (ANSD, 2021), it is stated that tourism is the second largest provider of income. Due to its geoclimatic situation, Dakar region occupies a central place in tourism activities and the hotel sector. In addition, Dakar is a platform linking Europe, Africa, and America, which gives it a prime position in business tourism in West Africa. Since coastal zones constitute the most strategic areas for industry, tourism, transport, and fishery, the high profitability of these economic activities is challenged by erosion through the reduction of littoral zones and incomes.

Data Source

This study uses two categories of data: physical and socio-economic data. The following table presents the study area, data, and methods, and assigned code for localities and variables, where NC means northern coast, WC is the western coast, and SC is the southern coast.

Beach Width Estimation

The distance between the settlement and the sea is considered as beach width. It is valuable in assessing economic littoral value. It is one of the indicators which informs about the level of exposure of local communities to coastal erosion. It provides information regarding the number of square meters of the coast of each district municipality. It was determined using satellite images, Google Earth, GPS visualizer, and ArcGIS. The high urban population growth in Dakar is the consequence of the rapid occupation of the coast, which reflects the importance of the settlement's proximity to the sea. The coastal occupation dynamic shows two types of evolution: the advance of the dwellings toward the sea and, on the other hand, the advance of the sea towards the dwellings. The total beach width in district municipalities in 2020, 2030, and 2040 is estimated respectively at 4496, 3364, and 3085 m (Figure 2). However, due to erosion, the beach width is generally reduced.

Lost Areas

Lost areas are estimated using the coastline of 2020 and the one of 2030 and 2040. It indicates that on dynamic coastline rate and the level of risk. Malika records the highest rates of beach loss, 309,561 m^2 in 2030 and 467,882 m^2 in 2040. In

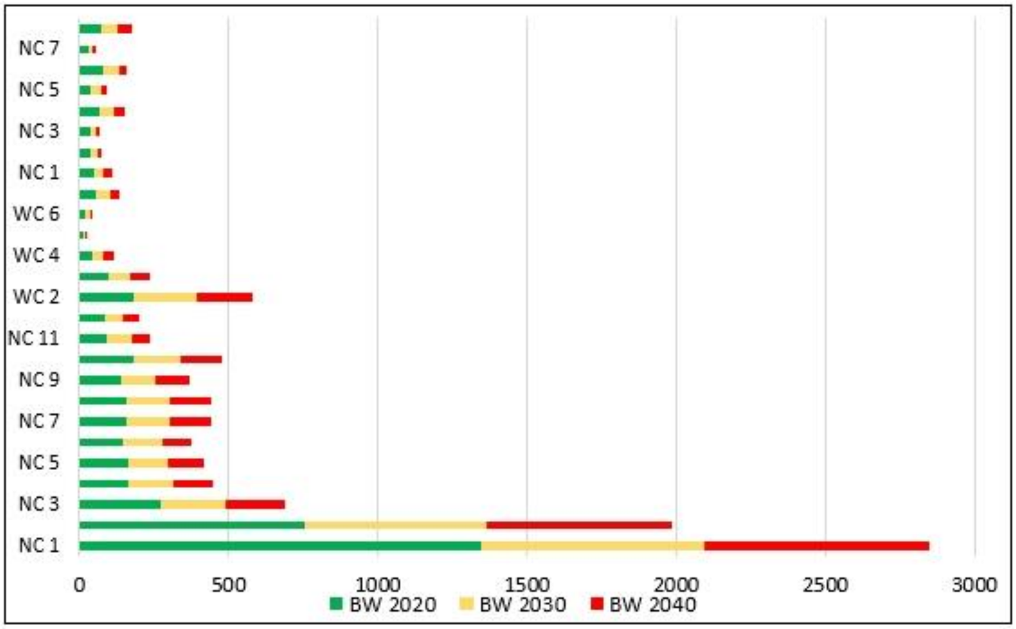


Figure 2. Beach width in the district municipalities in Dakar region in 2020, 2030, and 2040 showing the reduction of the beach width due to coastal occupation.

Tivaouvane Peul, there is estimated to be a loss of area of about 336,160 and 463,823 m^2, respectively, in 2030 and 2040 (Figure 3).

Shoreline Retreat in Each District Municipality

The rate of shoreline retreat between 1990 and 2020 is evaluated. For that, the distance of shoreline movement is divided by the time elapsed between the oldest and the youngest shorelines using the Digital Shoreline Analysis System (DSAS) software which is an extension of ArcGIS 10.7. The advantage of this statistical method is that the dynamic rate is computed easily through the end point rate (EPR) (Himmelstoss *et al.*, 2018):

$$EPR = \mathrm{NSM} / \mathrm{ET} \tag{1}$$

where

- EPR = End point rate statistical method is computed by dividing the Net Shoreline Movement (NSM) by the time elapsed between the oldest and the youngest shorelines.

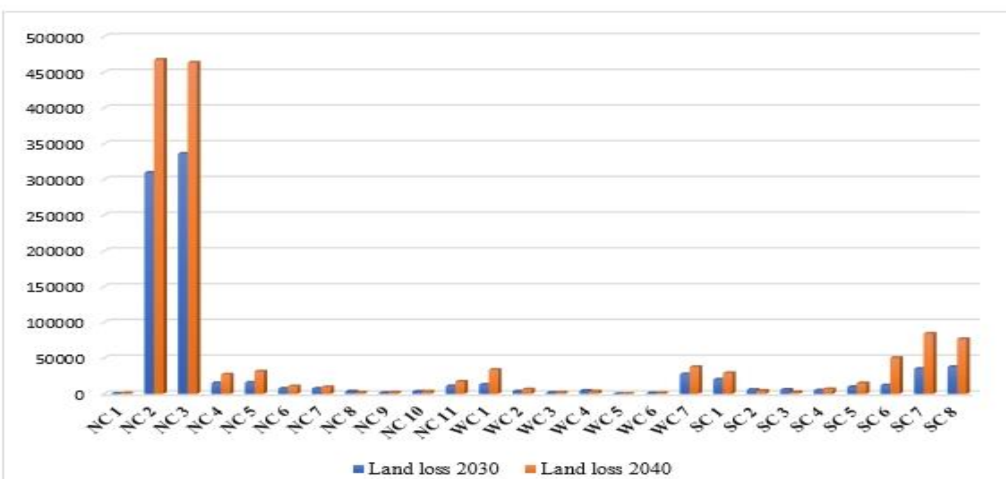
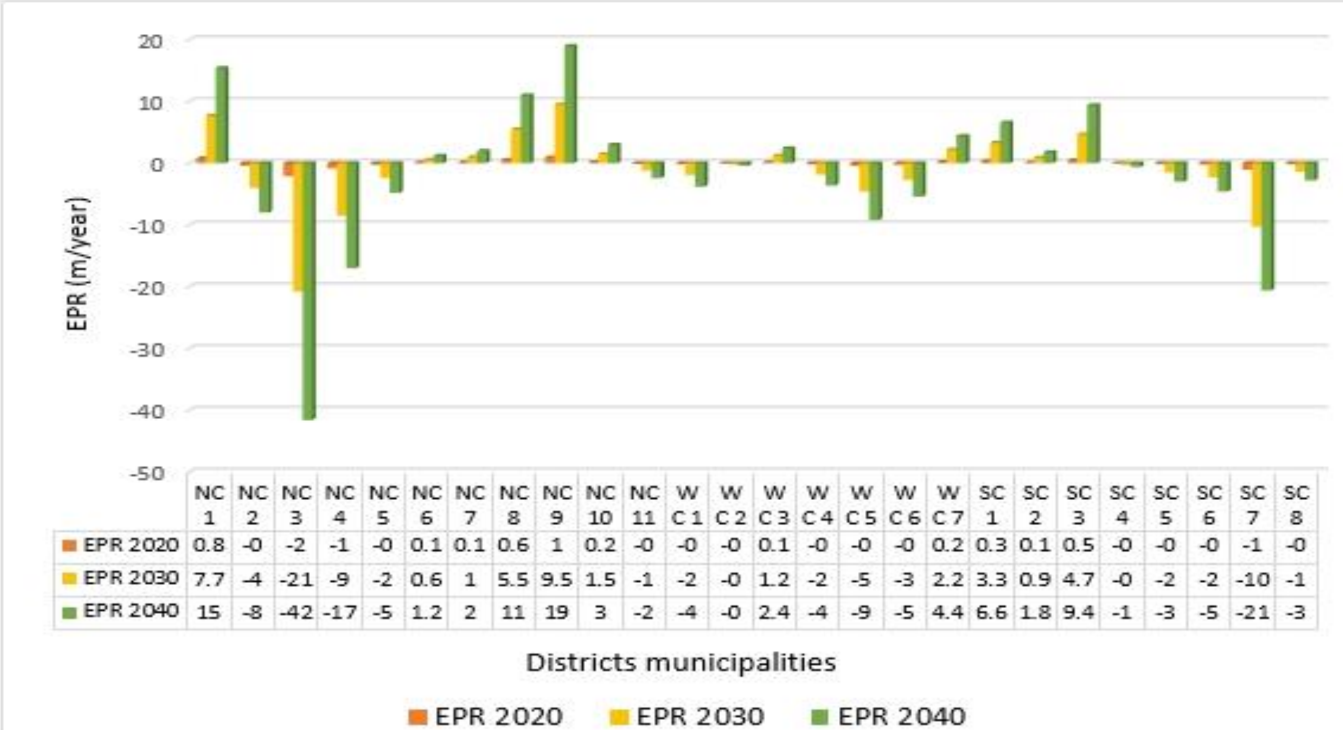


Figure 3. Estimated areas lost in the district municipalities of the Dakar region in 2030 and 2040 due to coastal erosion.



	NC 1	NC 2	NC 3	NC 4	NC 5	NC 6	NC 7	NC 8	NC 9	NC 10	NC 11	W C 1	W C 2	W C 3	W C 4	W C 5	W C 6	W C 7	SC 1	SC 2	SC 3	SC 4	SC 5	SC 6	SC 7	SC 8
EPR 2020	0.8	-0	-2	-1	-0	0.1	0.1	0.6	1	0.2	-0	-0	-0	0.1	-0	-0	-0	0.2	0.3	0.1	0.5	-0	-0	-0	-1	-0
EPR 2030	7.7	-4	-21	-9	-2	0.6	1	5.5	9.5	1.5	-1	-2	-0	1.2	-2	-5	-3	2.2	3.3	0.9	4.7	-0	-2	-2	-10	-1
EPR 2040	15	-8	-42	-17	-5	1.2	2	11	19	3	-2	-4	-0	2.4	-4	-9	-5	4.4	6.6	1.8	9.4	-1	-3	-5	-21	-3

Figure 4. Evolution of accreting or eroding coastlines in district municipalities in Dakar region in 2020, 2030, and 2040.

- NSM = Net Shoreline Movement is the distance between the most recent shorelines and the oldest shorelines for each transect and is measured in meters (m).
- ET = Elapsed time between 1990 and 2020 (Himmelstoss *et al*., 2018 and Pouye *et al*., 2022).

The analysis of the coastline dynamics in district municipalities shows two principal trends: erosion and accretion. Since the hydrodynamic, geologic, geomorphologic, and topographic conditions are not the same on the northern, western, and southern coasts, it is evident that the localities do not record the same rate (Pouye *et al*., 2022). Therefore, 15 out of 26 district municipalities recorded negative dynamic rates in 2020, 2030, and 2040. Malika has the highest rate of 22 m/year, 221 m/year, and 242 m/year in 2020, 2030, and 2040, respectively. These rates have been exacerbated by the sand mining activities that have taken place over the years (Figure 4).

Coastal Length

The coastal length for each district municipality is determined using satellite images and measurement tools in ArcGIS.

Proximity to Town

The proximity of a location to the city is a valuable variable for its economic value. In most cases, the closer a settlement is to the city, the higher its economic value. The proximity of settlements to the city is determined using the ArcGIS analysis tool.

Littoral Pricing per m^2

The prices of the littoral used in this study are based on those defined by Decree No. 2010-400 of 23 March 2010 on the scale of rental prices for the occupation of the state's private real estate domain. Indeed, the occupation of the state's private real estate domain gives rise to the payment of an annual fee proportional to the property's market value. However, a scale fixing the price of these outbuildings has yet to be established beforehand. To fill this gap, the text of Decree No. 88-074 of 18 January 1988 fixing the price scale for bare land and built-up land, applicable for determining the rent of premises for residential use and for calculating compensation for expropriation in the public interest, has always served as a reference scale. However, apart from the fact that it was not designed for this purpose, the said scale has needed more revaluation since its adoption in 1988, despite the increased value acquired by the land in the various areas of the national territory. In order to correct this situation, it was, therefore, necessary to establish a scale for setting the fee for occupying the state's private real estate domain (FAO, 2010).

Littoral and Building Areas

Superficies occupied by littoral and building were estimated using shapefiles of settlements along the coast. A buffer of 200 m from the coastline was considered. The surface area of buildings in 2030 is estimated at 803,119 m^2, whereas in 2040, it is expected to be 911,783 m^2. Regarding the coastal surface area in 2030, the number of 16,433,400 m^2 is

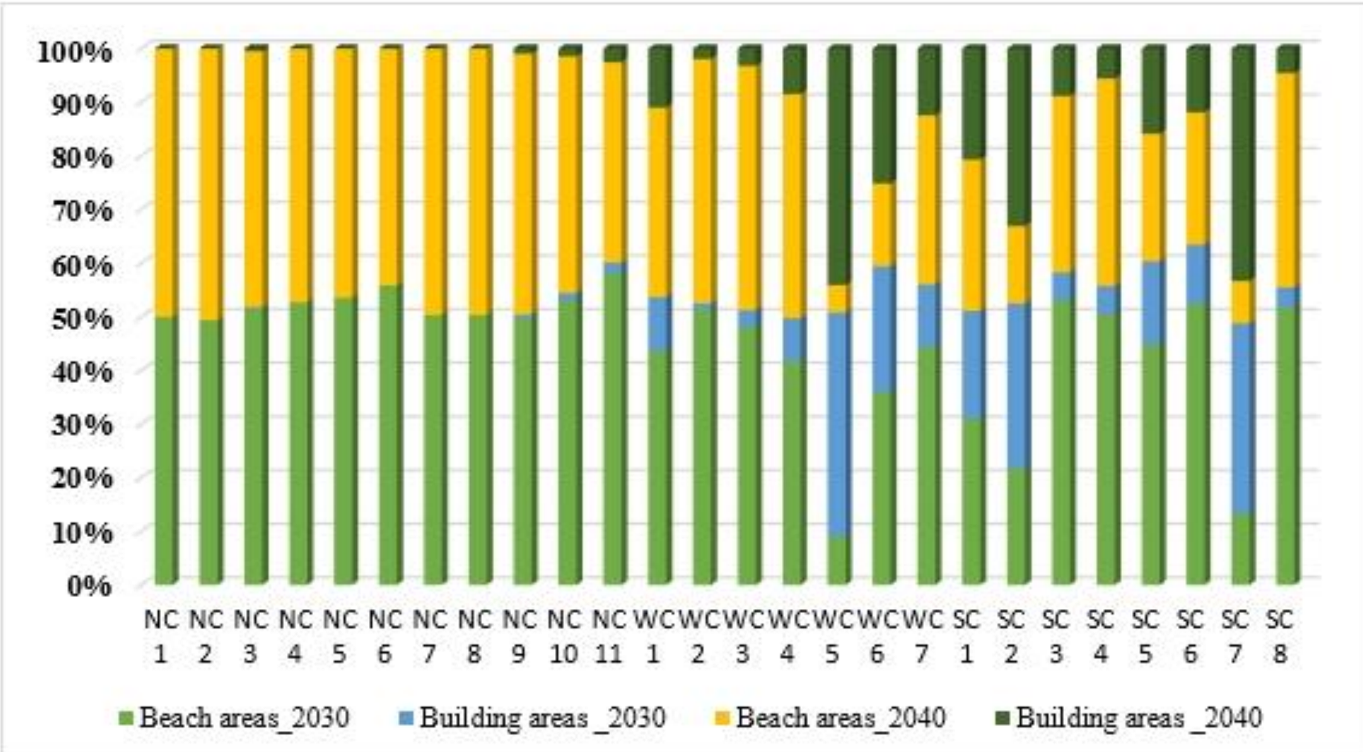


Figure 5. Beach reduction due to construction along the Dakar coast in 2030 and 2040.

estimated instead of 15,481,413 m^2 in 2040, with a difference of 951,987 m^2 which is the expected loss of surface area between 2030 and 2040 (Figure 5).

Number of Buildings, Hotels, Industries, Fishing Points, and Road Length

The buildings, hotels, industries, fishing points, and road lengths located in the buffer zones of the coastline are counted for each district municipality. The counting was done using the Open Street Map shapefile data in ArcGIS (Figure 6). These variables help determine the economic value of a coastal zone.

Coastal Vulnerability Index

The CVI is calculated using the square root of the product of variables (slope, geomorphology, geology, existing protective infrastructures, sea level change, shoreline displacement, mean tidal range, swell range, mean wave height, and distance between settlement and sea) divided by the total number of variables. Then, variables are ranked from 1 to 5 and divided by the total number of variables. These variables are the key driving factors of the physical coastal vulnerability and are quantitative and qualitative. Variables have different units. The CVI of each district municipality is determined and used as an independent variable to highlight its importance in the economic values of coastal width:

$$\mathbf{CVI} = \sqrt{\frac{(\mathbf{a} * \mathbf{b} * \mathbf{c} * \mathbf{d} * \mathbf{e} * \mathbf{f} * \mathbf{g} * \mathbf{h} * \mathbf{i} * \mathbf{j})}{\mathbf{10}}} \quad (2)$$

where a = slope; b = geomorphology; c = geology; d = existing protective infrastructures; e = sea level change; f = shoreline displacement; g = mean tidal range; h = swell range; i = mean wave height; j = distance between settlement and sea.

Variable Used for the CVI Computation

This study uses ten variables: slope, geomorphology, geology, existing protective infrastructures, relative sea level, shoreline displacement, tidal range, swell range, wave height and distance between the settlement and sea.

Slope

The susceptibility of the coast to immersion by flood and the quickness of shoreline retreat are influenced by the area's relief. This was changed later by the coastal slope (Kotinas *et al*., 2016). In this study, data about the slope of the Dakar region were obtained by downloading the Digital Elevation Model (DEM) through the Copernicus website (GLO_30 DEM) and using ArcGIS software. The slope is calculated by measuring the distance from each shoreline segment to the points with a contour over 4 m. The slope is obtained by dividing the rise by distance and multiplying by 100 (Equation (3); Kotinas *et al*., 2016). Three steps were performed for calculating coastal slope: a selection of coastal areas over 4 m altitude, segmentation of shoreline in small parts and distance from each part of the shoreline to the nearest points with an elevation of 4 m:

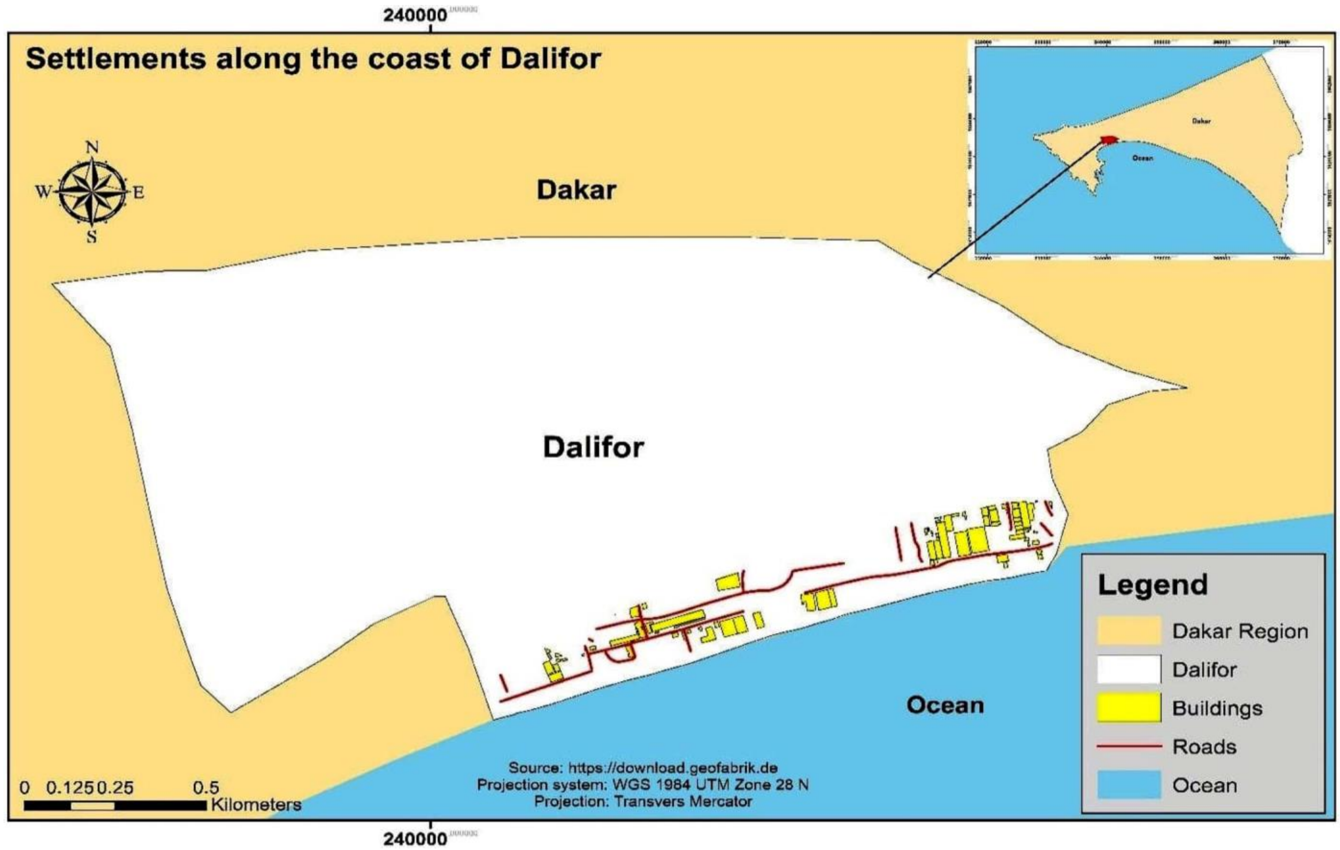


Figure 6. Identification of buildings, hotels, industries, fishing points, and the length of roads in the district municipalities of the Dakar region (case of Dalifor).

$$\textbf{Slope} = 4 / \text{Distance} * 100 \quad (3)$$

The coastal slope of the Dakar region is used to determine the level of exposure of the coast to inundation. The coastal slope of the Dakar region can be divided into three sections. On the northern coast, from Yoff to Malika, the slope is lower than 1%, whereas from Tivaouane Peuhl to Mbambilor, it does not exceed 4%. On the southern coast from Hann Bel-air to Rufisque, the slope is lower than 1%, whereas on the coast of the district municipality of Yene slope is comprised of between 0 to 39%. The slope of the western coast (from Ngor to Plateau) is between 3 to 41.9%. To integrate slope in coastal vulnerability assessment, a selection of coastal areas over 4 m altitude, segmentation of shoreline in small parts, and distance calculation were done using ArcGIS (Figure 7).

Geomorphology

According to Sane and Yamagishi (2004), the accompanying geomorphological units are recognized in the graben. Coastal dunes arranged along the northern coast include two influential groups: the live coastal dunes spread out at the rear of the high seashore, and the youth dunes stand out behind the live coastal dunes. These are set up by N-S-oriented littoral drift. The Ogolian Erg is situated in the focal and northern parts of the Dakar region. It incorporates longitudinal dunes running in the NE-SW direction, isolated by dame interdune corridors. The substratum of the limestone plateau of the Bargny-Rufisque district is made out of limestone and marl of the Eocene age. In the graben, geomorphological units are portrayed by low topography, high porousness, and less resistant materials. The characteristics of the geomorphological units in the graben are one of the primary drivers of the vulnerability of Dakar to coastal erosion. The coastal geomorphology of the Dakar region is one of the conditions determining its susceptibility to erosion. It is characterized by sand on the whole north and south coast from Hann Bel-Air to Rufisque Ouest. Cobble beach and medium cliff coast describe the coast from Rufisque Est to Yene. The western coast is characterized by a cliff. Data about the geomorphology of the coast of the Dakar region have been collected through the USAID Project/RSI N 685–0233 (USAID, 1983). Many types of sediment have been identified: sandy beach, cobble beach, cliff, and medium cliff coast. These geomorphologic conditions have different resistivity to erosion. The geomorphologic data of the coasts of the Dakar region was integrated to the workspace. Each shoreline part is attributed to a geomorphologic feature by joining the information of the two layers (Split_Shore and Geomorphology.Shp) through the Spatial Join Tools (Figure 8).

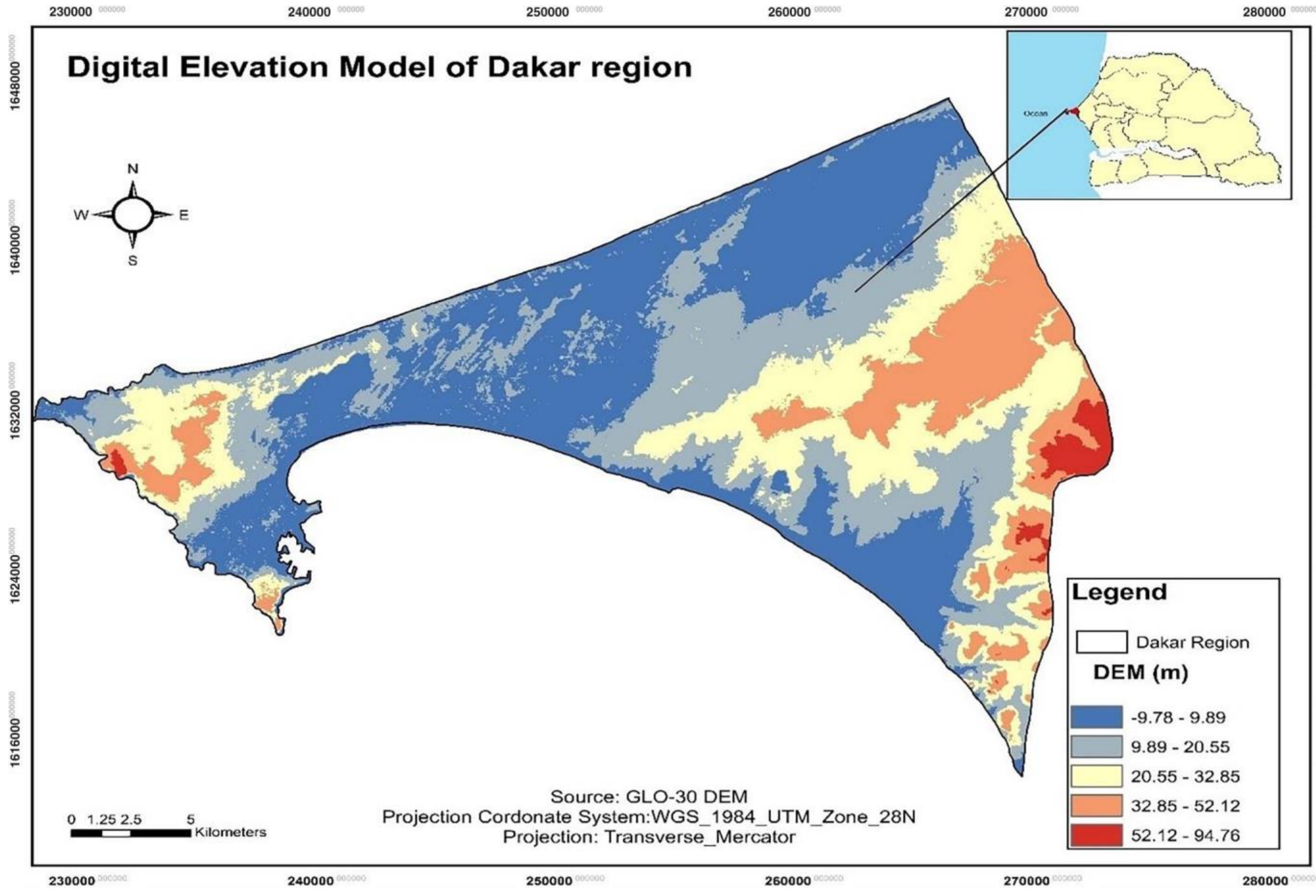


Figure 7. Digital elevation model of Dakar region used to determine the contribution of coastal slope in the Coastal Vulnerability Index (CVI).

Geology

Three different activities determine the geologic history of the Dakar region: volcanic actions, marine transgressions, and regressions, which are observed from the prequaternary period up to the quaternary period and mark traces are still visible. They are made up of mainly Nouakchott deposits (5500 years BP). These deposits are sands or grey marl rich in coastal fauna with limestone bets of an average thickness of 100 m. The brown marl deposits are also visible in the northern part of Dakar. As a result, the limestone and limestone soils are currently the framework and substratum of Dakar (Adjoussi, 2001). Geologically, from the Mesozoic to the Quaternary age, the overall advancement of western Senegal is portrayed by significant faulting framed two horsts (in Dakar's surrounding region). In Dakar city, the southern horst shapes the Dakar plateau 50 m high above the ocean level. It comprises essentially tertiary volcanic, for example, basaltic, doleritic, and tuffaceous rocks, and sedimentary rocks. The Ndiass horst arrives at a tallness of 105 m and is framed by Quaternary volcanic deposits. The morphology of the two horsts is emphasized by the occurrence of recent volcanic cones made out of both volcanic debris and basaltic magmas. The horsts create intended, cliffy shorelines that safeguard a less corrupted structure. On such shorelines, the wave's immediate effect is reduced, which slows erosion. Between the two horsts is an enormous graben overwhelmed by Quaternary residue, which shows the lowest topographic point since altitudes rarely rise 5 m above sea level. Long after the tertiary volcanism, severe disintegration of the horsts happened during the early Quaternary. Mechanical change of the igneous rocks happened by common enduring of the dolerite facies and separation of the stone along joints, causing the formation of erratic blocks. Chemical modifications started with the decay of individual grains. This phenomenon is notable in tropical areas (Sane and Yamagishi, 2004). The geology of the study area is meanly characterized by fine unconsolidated sediments, volcanic, and sedimentary rocks. Information concerning the geology of Dakar region were added to the workspace by making the layers Geology.Shp. Each shoreline part is attributed to a geologic feature by joining the information of the two layers (Split_shore_geom and Geology.Shp) through the Spatial Join Tools (Figure 9).

Existing Protective Infrastructures

The protective infrastructures against coastal erosion are installed along the coast of the Dakar region. Plantations that fix the dunes, riprap, defensive walls, and breakwater and

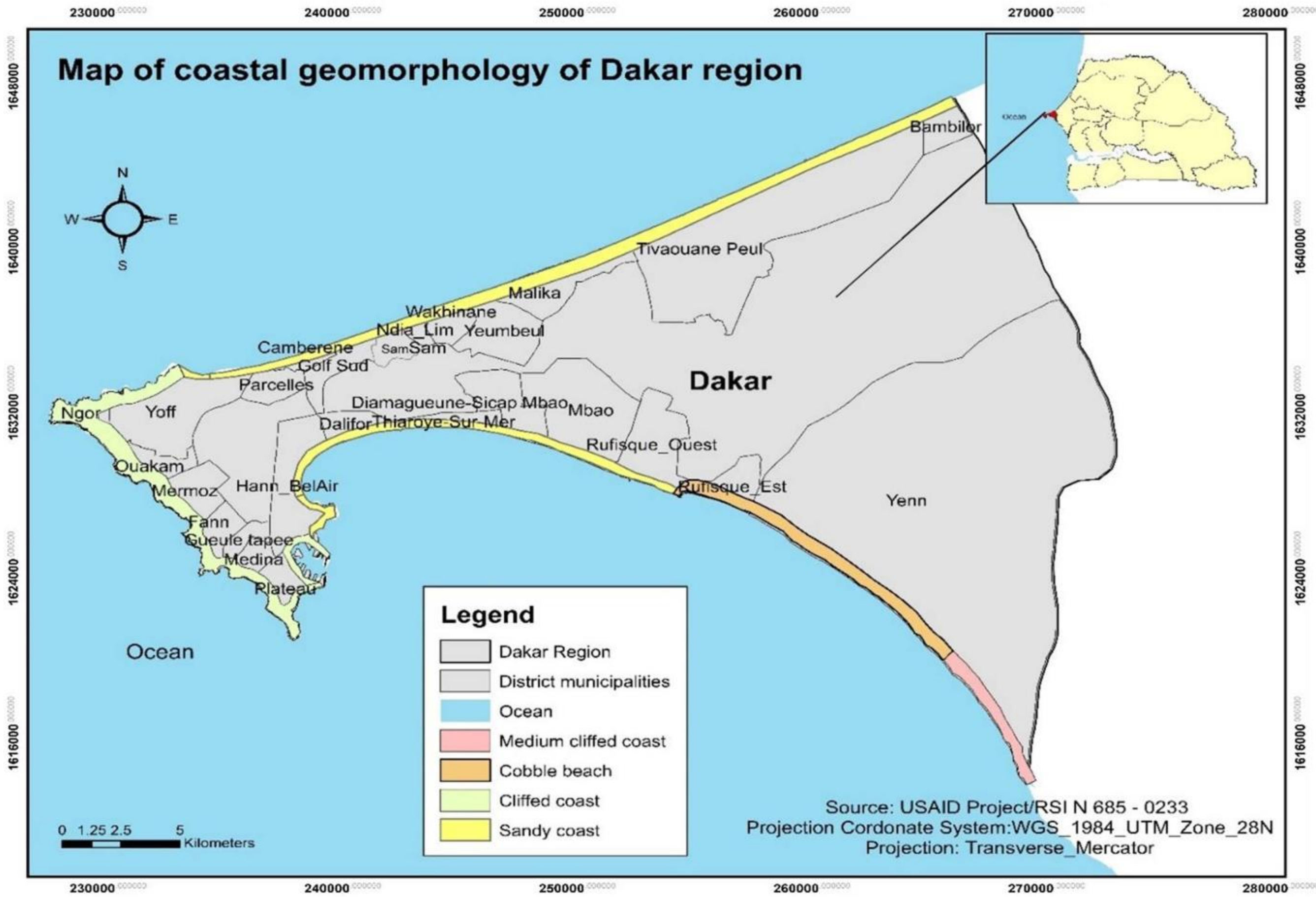


Figure 8. Different coastal geomorphological structures in the district municipalities of the Dakar region.

gravel are noted in some coastal segments in the Dakar region. The existing or no existing protective infrastructures is a helpful variable to determine the level of vulnerability and adaptative capacity of local communities to cope with coastal erosion. For the incorporation of the existing protective infrastructures in the CVI assessment, each shoreline part was assigned to "existing protective infrastructure" or to "not existing protective infrastructure." For that, the coastal areas that have a protective infrastructure or not were inventoried. The vector layers (polygon) for protective infrastructures were created. After that, the information was joined to the layer.

Relative Sea Level

Since 1982, the sea level of Dakar has been recorded through tides gauges. These sea-level data records were not regular because of the temporal breaking down of the tide gauges and other inconveniences. For example, data about 2004, 2005, and 2006 were not recorded. Therefore, the mean sea level (MSL) trend at Dakar 2, Senegal, is +1.14 mm/year with a 95% confidence interval of ±0.61 mm/year, based on monthly mean sea level data from 1992–1999 to 2018–2012. The plot shows the monthly mean sea level without regular seasonal fluctuations due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. By default, the long-term linear trend is also shown, in red, along with its 95% confidence interval. The plotted values are relative to the most recent MSL datum established by the National Oceanic and Atmospheric Administration's (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS). To account for sea-level change, data should be added to the layer's attribute table. For that, a new file is created by selecting Table Option and Add Field and then creating the new field named "RSL." Each transect is attributed to a value of 1.14 mm.

Shoreline Displacement

The shoreline displacement is an indicator that informs on the vulnerability to coastal erosion and is determined by the End Point Rate, which is computed by dividing the Net Shoreline Movement (NSM) by the time elapsed between the oldest and the youngest shorelines (Equation (1)) through the use of the DSAS tool, which is an extension of ArcGIS software (Himmelstoss *et al.*, 2018). The NSM distance between the most recent shorelines and the oldest shorelines for each transect, and is measured in meters (m) (Pouye *et al*., 2022).

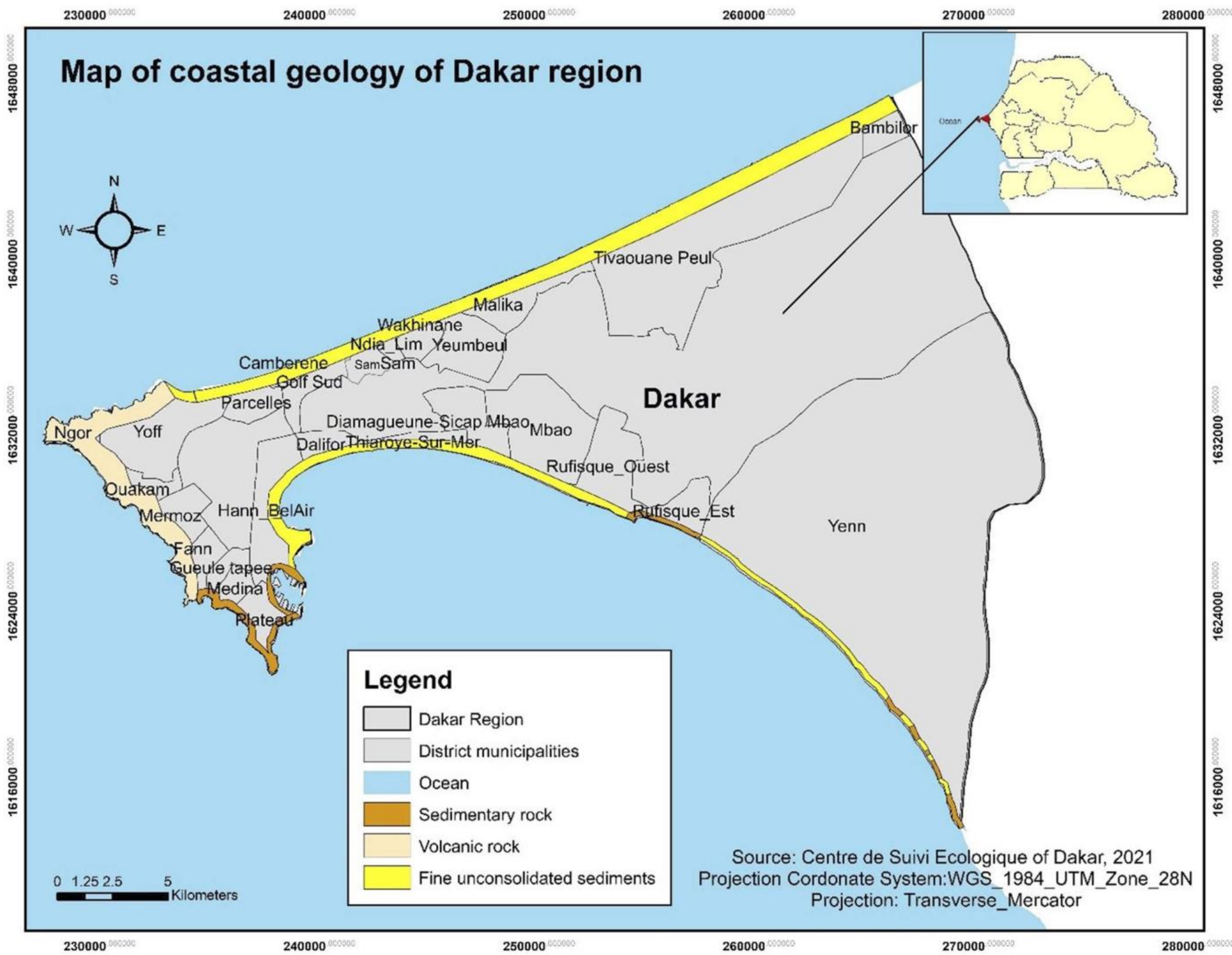


Figure 9. Different coastal geological structures in the district municipalities of the Dakar region.

Tidal Range

Tides are linked with both permanent and episodic inundation events. An extensive tidal range determines the spatial extent of the coast. Areas with large tidal waves have broad, near-zero relief intertidal zones and are susceptible to permanent inundation following sea-level rise. Besides, they are exposed to episodic flooding associated with storm surges, particularly if these coincide with high tide. The annual daily averages of tide recorded in Dakar show that the trend line of tide increased from 1992 to 2020 with a mean daily tide of 10.55 cm (ANACIM, 2020). To consider tide, data should be added to the layer's attribute table. For that, a new file is created by selecting Table Option and Add Field and then creating the new field named "Tide." Each transect is attributed to the value of 10.55 cm.

Swell Range

Generated by wind and currents, swell is one of the most important forces that influence and determine the dynamic behavior of beaches. In the Dakar region from 1991 to 2018, the height of the swell does not exceed 2 m. The highest height swell was about 1.74 m, recorded in 1995. Guerin (2003) states that the swells of the Cape Verde peninsula are short (less than 7.5 seconds). The swell data were acquired from the Agence National de l'Aviation Civile et de la Meteorologie (ANACIM). Furthermore, the mean high swell from 1991 to 2018 is about 1.65 m. The swell data were added to the layer's attribute table. For that, a new file is created by selecting Table Option and Add Field and then creating the new field named "Swell Range" and each transect is attributed to a value of 1.65 m.

Mean Wave Height

Toffoli and Bitner-Gregersen (2017) define waves as oscillations or disturbances of water surface that can be observed in any water basin; for example, rivers, seas, lakes, and oceans. The initial equilibrium state, its disturbance, and compensation by a restoring force are the conditions for a wave to exist. Local wind, seismic oscillations of the Earth during earthquakes, atmospheric pressure gradients, and gravitational attraction between the Earth, Moon, and Sun. Data about the average wave height is from Guerin (2003). It plays an important role in coastal erosion. Its action on the beach depends on the nature of the wave and the coastal sediment where it breaks (Reeve, Chadwick, and Lleming, 2018). In a study, Strahler (2013) stipulated that the breaking of waves against a shoreline yields a variety of distinctive features. If the coast is made up of weak or soft materials (various kinds of regolith, such as alluvium), the force of the forward-moving water alone easily cuts into the coastline. Here, erosion is rapid, and the shoreline may recede rapidly. Under these conditions, a steep bank, or marine scarp, will form and steadily erode as storm waves attack it, whereas, where resistant rocks meet the waves, sea cliffs often occur. A notch is carved essentially by physical weathering at the base of a sea cliff. Constant splashing by waves followed by evaporation causes salt crystals to grow in tiny crevices and fissures of the rock, breaking it apart, grain by grain. Hydraulic pressure of waves, and abrasion by rock fragments thrust against the cliff, also chisel the notch. Undercut by the notch, blocks fall from the cliff face into the surf zone. As the cliff erodes, the shoreline gradually retreats shoreward. Sea cliff erosion results in various erosional landforms, including sea caves, arches, and stacks (Strahler, 2013). To account for Mean Wave Hight (MWH), data should be added to the layer's attribute table. For that, a new file is created by selecting Table Option and Add Field and then creating the new field named "MWH" and each transect is attributed to a value of 1.75 m.

Distance between Settlements and the Sea

The distance between the settlement and the sea is a useful variable in assessing vulnerability. It is one of the indicators which informs about the level of exposure of local communities to coastal erosion. The distance between the settlement and sea for each transect was determined using Google Earth, GPS visualizer, and ArcGIS. The urban population growth in Dakar is the consequence of the rapid occupation of the coast, reflecting the importance of the settlement's proximity to the sea. The coastal occupation dynamic shows two types of evolution: The advance of the dwellings toward the sea and, on the other hand, the advance of the sea towards the houses. In addition, there has been a reduction or disappearance of vegetation cover in the Dakar region in favour of the settlement. For instance, the retreat of the filao on the northern coast, particularly in the department of Guédiawaye, is less exposed compared to the southern coast, which is more vulnerable based on the distance between the houses and the sea, which does not exceed 100 meters (Pouye, 2016). The corresponding "distance between settlement and sea" was attributed to each transect in the attribute table by joining the information of the layer and "distance between settlement and sea" based on their spatial information through the Spatial Join Tools.

Ranking Values for CVI Calculation

The ranking values for CVI are made based on the different variables. The scale is from 1 to 5, indicating each variable's vulnerability level (Table 2; Figure 10). The ranking values were done first by creating a new field for each variable in the layer and then the ranking value.

Table 2. *Coastal Vulnerability Index (CVI) variables (personal work inspired by Thieler and Hammar-Klose [1999] in Kotinas et al. [2016]).*

	CVI				
Variable	Very Low, 1	Low, 2	Moderate, 3	High, 4	Very High, 5
Coastal slope (%)	> 32	16–32	8–16	4–8	0–4
Geomorphology	Rocky, cliffed coasts, artificial constructions	Medium cliffs, indented coasts	Low cliffs, alluvial plains, beach rocks, dunes (mixed material)	Cobble beaches, estuary, lagoon	Barrier beaches, sand beaches, salt marsh, mudflats, deltas, mangrove, coral reefs
Geology	Plutonic volcanic high-medium grade metamorphic	Low grade metamorphic sandstones and conglomerates	Most sedimentary rocks	Coarse, poorly sorted unconsolidated sediments	Fine unconsolidated sediments volcanic ash
Existing protective infrastructures	The forest which fixes the sand dunes	Riprap	Protective walls andbreakwater	Gravel	No protective infrastructure
Relative level sea change (mm/year)	< 1.8	1.8–2.5	2.5–3.0	3.0–3.2	> 3.2
Shoreline displacement (m/yr.)	> 2.0	1.0–2.0	-1.0–+1.0	-1.1–2.0	<-2.0
Mean tide range (m)	> 6.0	4.1–6.0	2.0–4.0	1.0–1.9	<1.0
Mean swell range (m)	< 2.0	2.5–3.0	3.0–3.5	3.5–4.0	> 4
Mean wave height (m)	< 0.55	0.55–0.85	0.85–1.05	1.05–1.25	> 1.25
Distance between settlements and sea (m)	1149–2053	589–1149	267–589	96–267	0.72–96

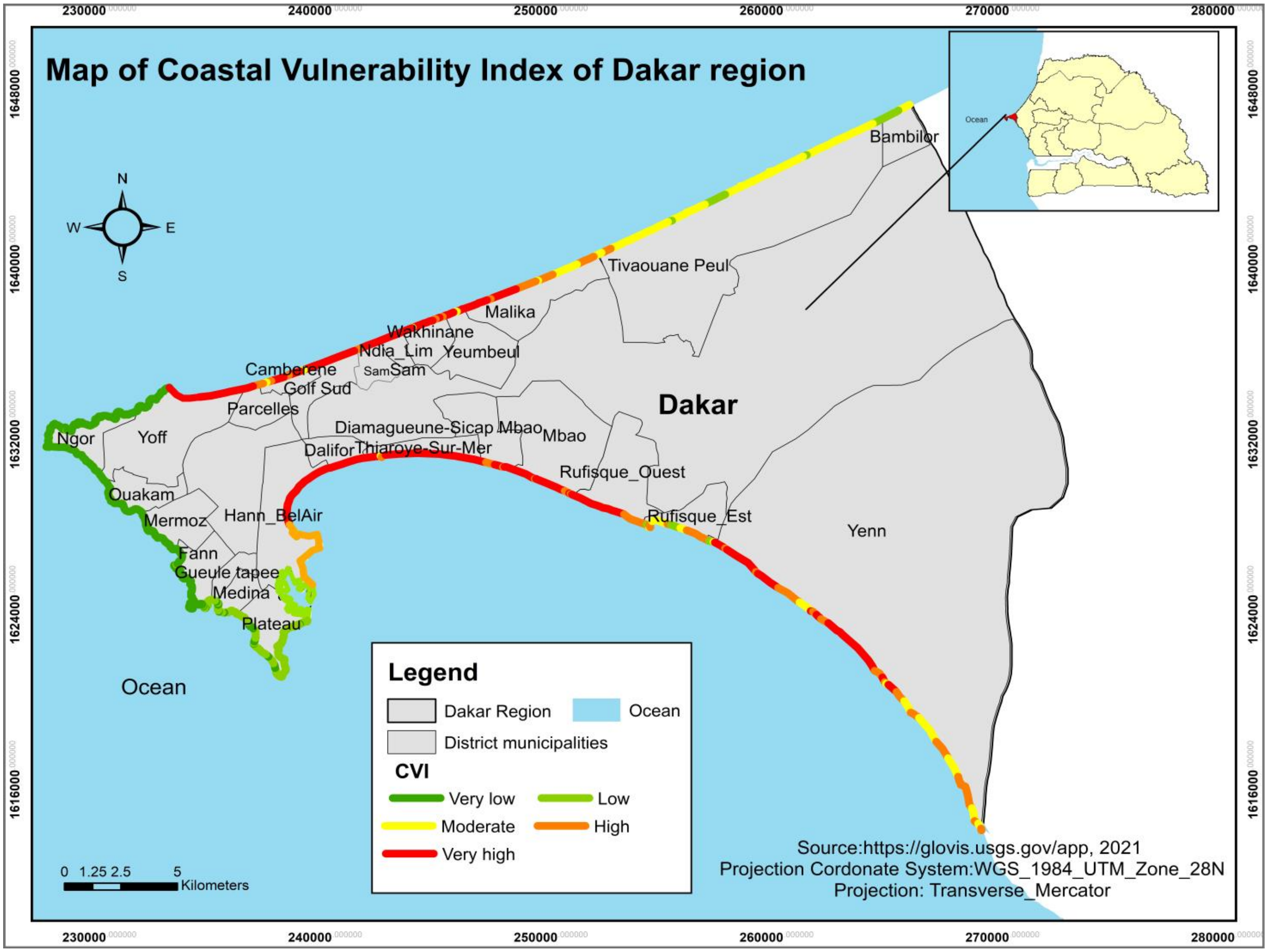


Figure 10. Physical coastal vulnerability map of the Dakar region showing the level of vulnerability in each district municipality.

The fields were created by selecting Table Option and Add Field. In Name, CVI_ plus the name or abbreviation of the variables is set and Type set as "integer." These names should be CVI_Slope, CVI_Geom, CVI_Geol, CVI_EPI, CVI_SLR, CVI_EPR, CVI_Tide, CVI_Swell, CVI_MWH, and CVI_Dist.

To rank the values of a variable for example Slope, the following procedure was used: Selection Menu > Select by Attributes> in Layer option, the file Split_shore_FINAL has to be set > Double click on Slope > Set the expression Slope > 32 (for the Index 1, Very low) > Ok > Right click on CVI_Slope > Calculator > Assign the value 1 > Ok. As a result, all coastal areas with a slope over 32 will be highlighted in blue. The sameprocedure was done for Indexes 2, 3, 4, and 5.

METHODS

Starting from the idea that, in the event of a shock the decrease in the economic value of the littoral in 2030 and 2040 is a clear sign of the vulnerability of the coast and its need for coastal protective infrastructures (because coastal areas which do not record erosion do not need protection). This study considers the shock caused by the decrease in littoral price generated by physical and socio-economic parameters. Multi-linear regression in R software is used.

Variables Used

Dependent variables or variables of interest and independent variables or control variables are used as follows:

- Dependent variable: The dependent variable is each district municipality's respective share of economic littoral value. It is the variable that expresses the economic value of the coast regarding physical and socio-economic parameters.
- Variables of interest: The variable of interest is the Littoral Price.
- Control variables: Beach Width, Lost Areas, Coastal Length, Dynamic Rate, Littoral Areas, Built Areas, Proximity to Town, CVI, Building Price, Number of Buildings, Number of

Table 3. *The variance inflation factor of independents variables in 2030 and 2040.*

Variable	Square Root of VIF	
	2030	2040
Littoral Width	2.67	2.73
Lost Areas	2.06	2.41
Coastal Length	2.46	2.81
Littoral Areas	2.44	2.74
Dynamic Rate	1.63	1.85
Building Areas	2.69	2.87
Hotels	1.24	1.26
Industries	1.19	1.37
Fishing Points	1.39	1.39
Road Length	2.45	3.31
Number of Buildings	2.78	2.75
Proximity to Town	2.37	2.39
CVI	1.58	1.61

VIF = Variance Inflation Factor; CVI = Coastal Vulnerability Index

Hotels, Number of Industries, Number of Fishing Points, and Road Length are the variables of control. The linear model used is expressed as follows:

$$y = \alpha + \beta choc + \lambda X + \varepsilon \qquad (4)$$

where y = The share of economic littoral value for each district municipality; choc = decrease of littoral price X = a set of control variables (Littoral Width, Lost Areas, Coastal Length, Dynamic Rate, Littoral Areas, Built Areas, Proximity to Town, CVI, Number of Buildings, Number of Hotels, Number of Industries, Number Fishing Points and Road Length); choc = the decrease or increase of the variable interest (littoral price); ε = the error term; α, β, and λ = the model parameters.

Multicollinearity Test

In a study, Oke, Akinkunmi, and Etebefia (2022) stated that "multicollinearity is a statistical phenomenon in which a solid or perfect relationship exists between the predictor variables. The presence of multicollinearity can cause severe problems with the estimation and interpretation." Therefore, the much higher correlation between the explanatory variables means more risk in the statistical inference about the significance of the regression coefficients. Various tests and diagnostic measures of multicollinearity have been proposed in the econometric literature. Some measures are available for diagnosing multicollinearity, such as the variance inflation factor (VIF), condition number (CN), condition index (CI), and variance decomposition (Belsley, Kuh, and Welsch, 1980); Chi-square test statistic (Farrar and Glauber, 1967; Haitovsky, 1969); and an F-test by regressing each of the independent variables on the remaining independent variables. The VIF, a well-known measure of multicollinearity, is defined as:

$$VIF_i = \left(1 - R_i^2\right)^{-1} \qquad (5)$$

where R_i^2: is the coefficient of determination of the regression of the ith column of X on the remaining columns of X. Based on the VIF diagnostic measure, multicollinearity is severe whenever the VIF is more than 10. There is no logical reasoning behind the value 10. Therefore, there is no logical reasoning behind the value 10 (Mohammadi, 2020). In this study, multicollinearity was done to point out the dependence among independent variables. The results from the multicollinearity test show no collinearity among independent variables because the square roots of the VIF are lower than 5 (Table 3).

Specification of the Model

Akaike information criterion (AIC), Bayesian Information Criterion (BIC), and R^2 are used to select the model used in this study (Table 4). In a study, Romero (2007) stated that it is usual practice in econometrics to use R^2 in model selection. This goodness of fit measurement, along with others like the unadjusted R^2, the AIC, and the BIC, are almost always available to researchers using econometric software. Therefore, the AIC is a prominent approach for selecting models. It is widely used for parameter space singularities and borders to infringe upon regularity conditions (Mitchell, Allman, and Rhodes, 2022). At the same time, the Bayesian information criterion is a helpful metric for comparing multilevel models. The BIC has several benefits over conventional hypothesis-testing techniques (Lorah and Womack, 2019). According to Yulistiani and Suliadi (2019), the good criteria for model selection can use the BIC. For model selection in linear mixed models, one may use AIC or BIC. Distinct random effect specifications result in different covariance structures of observation because linear mixed models might provide the specific dependency structure among responses (Lee, 2015).

RESULTS

Multilinear regression, which is an econometric forecasting model, was used. The model performed well, with 11 out of 13 variables significant at 10%, and the R^2 is estimated at 0.986 for the year 2030. Almost the same case is noted for 2040, with 9 out of 13 variables significant at 10% and an R^2 of 0.9123. The

Table 4. *Specification of the model using Akaike Information Criterion (AIC), R^2, and Bayesian Information Criterion (BIC) test for 2030 and 2040.*

	Test					
	AIC		R^2		BIC	
Model	2030	2040	2030	2040	2030	2040
M_0	1476	1464	0.93	0.93	1497	1486
M_1	1334	1405	0.98	0.95	1354	1426

M_0 = model without diagnostic; M_1 = model neither outlier nor influencer
The lower the AIC, the better the model. The higher the R^2, the better the model. The lower the BIC, the better the model. Based on these later statements, model M_1 was chosen.

Table 5. *Linear model results for 2030 and 2040.*

Variables	Code	Model 1 (2030)†				Model 1 (2040)‡			
		Estimate	Std. Error	t value	Pr(>|t|)§	Estimate	Std. Error	t value	Pr(>|t|)§
	(Intercept)	-5,822,000,000	4.49E + 09	-1.296	0.21594[e]	-20,840,000,000	7.28E + 09	-2.863	0.01185[c]
Littoral Width	LW	74,080,000	4.48E + 07	1.653	0.120663[e]	-104,900,000	2.45E + 07	-4.278	0.00066[a]
Lost Areas	LA	186,100	3.32E + 04	5.615	0.0000638[a]	137,900	4.07E + 04	3.39	0.00404[b]
Coastal Length	CL	1,790,000	8.66E + 05	2.066	0.0578[d]	3,131,000	1.47E + 06	2.132	0.04995[c]
Littoral Areas	LA_s	-11,400	3.26E + 03	-3.493	0.003587[b]	-3187	3.33E + 03	-0.959	0.3529[e]
Dynamic Rate	DR	1,361,000,000	3.10E + 08	4.397	0.000608[a]	791,400,000	2.61E + 08	3.028	0.00848[b]
Built Areas	BA	281,200	6.42E + 04	4.38	0.000628[a]	280,800	1.33E + 05	2.109	0.05218[d]
Number of Hotels	NH	23,850,000,000	1.50E + 09	15.881	0.000000000239[a]	4,502,000,000	6.96E + 09	0.647	0.52736[e]
Number of Industries	NI	471,400,000	4.21E + 09	0.112	0.912426[e]	-634,500,000	5.94E + 09	-0.107	0.91635[e]
Number Fishing Points	NFP	-11,060,000,000	4.40E + 09	-2.517	0.024655[c]	-4,989,000,000	5.12E + 09	-0.974	0.34542[e]
Road Length	RL	1,091,000	3.73E + 05	2.924	0.011113[c]	1,194,000	6.63E + 05	1.8	0.09197[d]
Number of Buildings	NB	-32,040,000	8.97E + 06	-3.573	0.00306[b]	-48,100,000	1.65E + 07	-2.919	0.01058[c]
Proximity to Town	PR	1,174,000	3.51E + 05	3.347	0.004795[b]	2,635,000	4.87E + 05	5.412	0.000072[a]
Costal Vulnerability Index	CVI	-203,900,000	4.94E + 07	-4.127	0.001026[b]	-93,700,000	6.08E + 07	-1.541	0.14408[e]

†*Model 1 (2030): Residual standard error = 4.468E + 09 on 14 df; multiple R^2 = 0.9927; adjusted R^2 = 0.986; F statistic = 147.3 on 13 and 14 df; p = 1.206E-12*
‡*Model 1 (2040): Residual standard error = 6.756E + 09 on 15 df; multiple R^2 = 0.953; adjusted R^2 = 0.9123; F statistic = 23.39 on 13 and 15 df; p = 1.343E-07*
§*Signification of codes: a = 0; b = 0.001; c = 0.01; d = 0.05; e = 1*

more confident the coefficient's ability to predict, the higher the *t*-value. Low *t*-values signify that the coefficient's predictive capacity could be more reliable (AllBusiness.com, 2023). Therefore, 9 out of 13 have positive t values for 2030, whereas 7 out of 13 have positive t values in 2040. The relationship between littoral price and variables is significant since the p-value is less than 0.05. It is estimated at 1.206e-12 for 2030 and 1.343e-07 for 2040. That means that the independent variables (Beach Width, Lost Areas, Coastal Length, Dynamic Rate, Littoral Areas, Built Areas, Proximity to Town, CVI, Number of Buildings, Number of Hotels, Number of Industries, Number Fishing Points, and Road Length) affect the dependent variable (economic littoral value).

The results show that if the beach width, coastal length, dynamic rate, proximity to a town, and road length change by one meter, it is expected that the littoral value gets, respectively, 74,080,000, 1,790,000, 1,361,000,000, 1,174,000, and 1,091,000 FCFA in 2030. If the lost, littoral, and building areas change by one square meter, the littoral value is expected, respectively, 186,100, -11,400, and 281,200 FCFA. If the coast vulnerability index, number of buildings, hotels, industries, and fishing points change by one unit, the littoral value will get respectively -203,900,000, -32,040,000, 23,850,000,000, 471,400,000, and -11,060,000,000 FCFA.

In 2040, if the beach width, coastal length, dynamic rate, proximity to a town, and road length change by one meter, it is expected that the littoral value gets respectively -104,900,000, 3,131,000, 791,400,000, 2,635,000, and 1,194,000 FCFA. If the lost, littoral, and building areas change by one square meter, the littoral value is expected, respectively, 137,900, -3187, and 280,800 FCFA. If the coast vulnerability index, number of buildings, hotels, industries, and fishing points change by one unit, the littoral value will get respectively -93,700,000, -48,100,000, 4,502,000,000, and -634,500,000 FCFA (Table 5).

Economic Lost Estimation Based on Littoral Price

In all district municipalities, economic loss is estimated based on littoral price and lost areas in 2030 and 2040. The district municipality of Malika recorded the highest loss, with a loss estimated at 16,808,000,000 FCFA in 2030 and 23,191,150,000 FCFA in 2040. Plateau records a loss of about 830,010,0000 FCFA 2030 and 11,259,000,000 FCFA 2040. In Ngor, the economic loss is estimated at 2,869,900,000 FCFA 2030 and 7,421,260,000 FCFA 2040. The overall economic loss based on littoral price and lost areas in all district municipalities along the coast is estimated at 38,507,856,000 FCFA in 2030 and 57,822,698,000 FCFA in 2040 (Figure 11).

DISCUSSION

Covering more than 71% of the Earth's surface, the oceans are the most heavily trafficked areas because of their usefulness for the economy, transport, and biodiversity. More than 600 million people live in coastal areas, representing 10% of the world's population (Gou and Tourian, 2021). Due to its geographic location and low-lying sections, the Dakar region, like the majority of the world's capitals, is vulnerable to the effects of coastal erosion. The Dakar region's coastal morphology is affected by the advanced sea brought on by sea level rise and climate change. The disruption of hydrodynamic agents like waves, tide, wind, *etc*. accentuates this scenario. As a result, there is a reduction in coastal regions, a shift of people inland, and a disturbance of various economic activities like fishing, lodging, and industry. Sand mining, pollution, and unauthorised settlements along the coasts are examples of human activities that exacerbate these problems (Pouye *et al*., 2023).

The coasts of the Dakar region have significant economic value for the Senegalese economy. However, climate change and the advancing sea cause the losses of coastal areas by reducing their economic values which vary from one locality to another. These economic values depend on several factors such as the proximity to the town, economic activities (fishing, tourism, and industry), infrastructures (roads, hospitals, stadiums, and university), and other socio-economic parameters (allotment, sanitation, accessibility). Therefore, estimating the economic value of the beach based on physical and

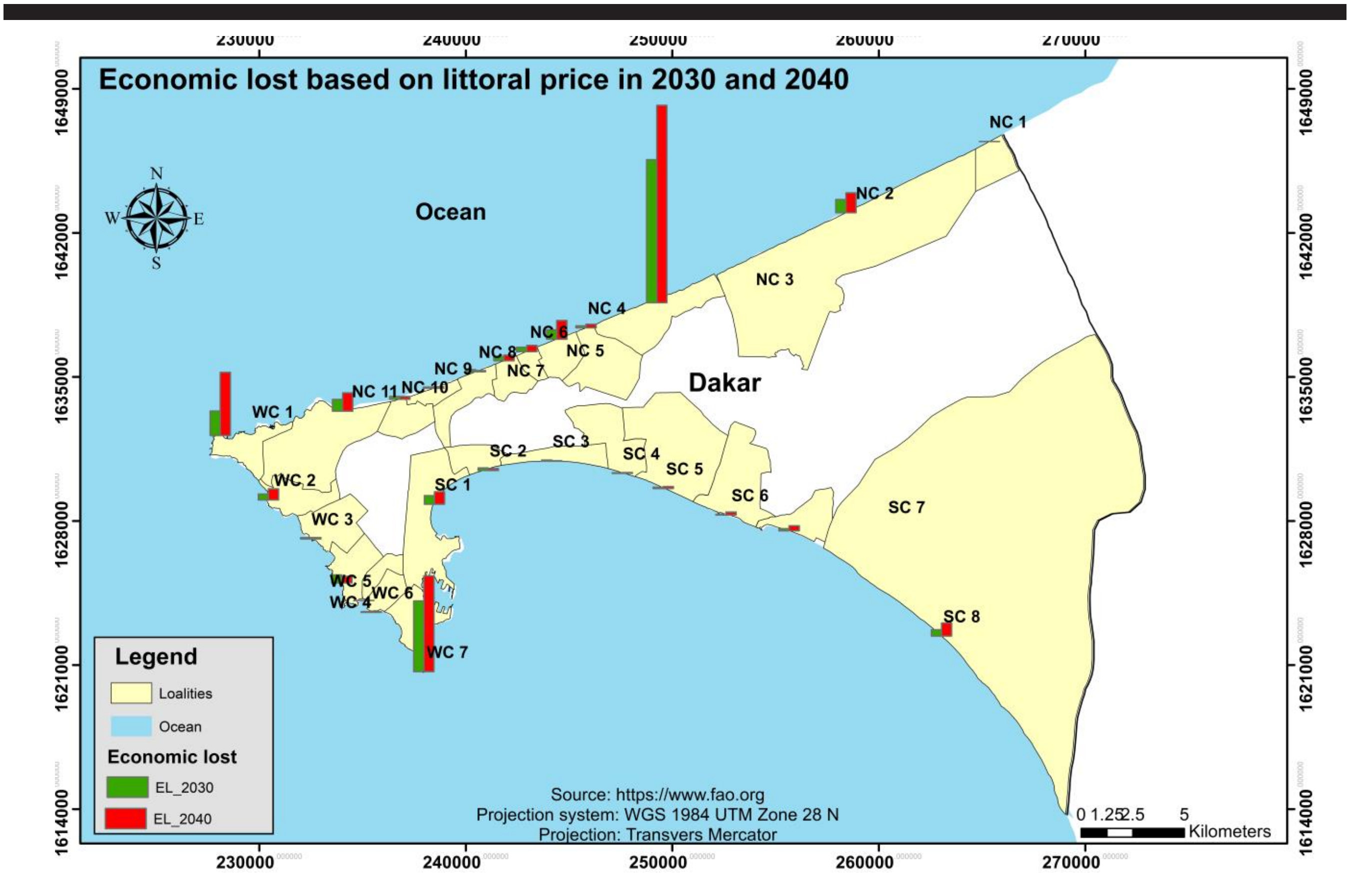


Figure 11. Economic lost estimations in 2030 and 2040 due to coastal erosion in each district municipality.

socio-economic parameters takes much work. Nevertheless, econometric models make it easier than a few decades ago. It helps decision makers understand the economic situation of the coasts in the future to determine whether there is a need for protection to prevent eventual coastal erosion damages. Most of the coasts of Dakar region are highly vulnerable to erosion. For instance, the Dakar region's northern and southern coasts record an average coastal vulnerability index (CVI) of about 94 and 23. In contrast, the western coast, which is less vulnerable, records an average of about 10. This vulnerability is justified by the dynamic rates of the coastline, which are estimated at -0.44 m/year, 0.21 m/year, and -0.11 m/year, respectively, on the northern, western, and southern coasts (Pouye *et al*. 2022). Based on the results of this study, one can note that if the CVI changes by one unit, the littoral value will change by -203,900,000 and -93,700,000 FCFA, respectively, in 2030 and 2040. In addition, the change by one unit of the dynamic rate will cause a change of 1,361,000,000 FCFA in 2030 and 791,400,000 FCFA in littoral value. Since the dynamic coastal lead to erosion or accretion, in addition to the socio-economic activities, it characterizes the width of the beach, which is among the key parameters used by researchers in beach value estimation through the Hedonic pricing model (Alexandrakis, Manasakis, and Kampanis, 2015; Catma, 2020; Gopalakrishnan *et al*., 2011; Landry and Hindsley, 2011).

In coastal zones where erosion is noted, the width of the littoral is reduced, causing a loss of areas. Sometimes, this situation leads to the disruption of economic activities along the coast. The economic impacts of beach width change and land loss due to erosion in Dakar are estimated. If the beach width changes by one meter, it is expected that the littoral value will change by 74,080,000 FCFA in 2030 and -104,900,000 FCFA in 2040. In all district municipalities, economic loss is estimated based on littoral price and lost areas in 2030 and 2040. The highest loss is recorded in the district municipality of Malika, with a loss estimated at 16,808,000,000 FCFA in 2030 and 23,191,150,000 FCFA in 2040. Plateau records a loss of about 8,300,100,000 FCFA 2030 and 11,259,000,000 FCFA 2040. In Ngor, the economic loss is estimated at 2,869,900,000 FCFA 2030 and 7,421,260,000 FCFA 2040. The overall economic loss based on littoral price and lost areas in all district municipalities along the coast is estimated at 38,507,856,000 FCFA in 2030 and 57,822,698,000 FCFA in 2040.

Coastal areas in Dakar are the most strategic areas for industry, tourism, transport and fishing activities. However, these activities are confronted with coastal erosion through the reduction of exploitation areas and income. In the Dakar region, socio-economic sectors such as fishing, recreational activities and human settlements along the coast are affected by coastal erosion. Fishing is an activity that depends on the biological production of marine and coastal ecosystems and plays a considerable socio-economic role in Senegal, particularly in the Dakar region. This situation is exacerbated by the rapid retreat of the coastline observed in some coastal areas, resulting in the reduction of secure storage areas for their fishing boats, the destruction of fishing docks and markets. The main fishing points (Yoff, Soumbedioune, Hann, Thiaroye, and Rufisque) are exposed to the impacts of climate change and coastal erosion. In addition, marine pollution from sewage, chemicals, solid waste, *etc*. increases erosion, leading to disruption of marine and coastal biodiversity and exposing local communities to infectious diseases, reduced fish species, reduced income, *etc*. Recreational facilities such as hotels, hostels, restaurants, *etc*. along the coast of the Dakar region are weakened by the retreat of the coastline. From Yoff to Cité Djily Mbaye, there are large huts with hotels and hostels that represent a large part of the working population. The advancing sea destroys the huts, especially during the marshy period (wintering) from November to January, putting many beach workers out of work. It should be noted that in winter, these beach activities are less lucrative because of the cold, and the clientele is less frequent than in summer. This study demonstrates that if the number of hotels, industries, and fishing points changes by one unit, the littoral value will get 23,850,000,000, 471,400,000, and -11,060,000,000 FCFA in 2030. In 2040, if the number of hotels, industries, and fishing points changes by one unit, the littoral value will get respectively -48,100,000, 4,502,000,000, and -634,500,000 FCFA. Usually, economic activities and infrastructures are highly correlated to land value.

In a study, it is stated that the value of land increases as the areas' buildings grow with economic activities (Nakagawa, Saito, and Yamaga, 2007; Saputra *et al*., 2021). In 2030 and 2040, if the number of buildings changes by one unit, the littoral value will become, respectively, -32,040,000 and -48,100,000 FCFA. Far from being neglected, the proximity of the land to the town affects its value. Land value decreases with distance from the Central Business District, according to the urban economic theory built on a monocentric city (Han, Zhang, and Zheng, 2020; O'Sullivan, 2007). If the proximity to the town changes by one meter, it is expected that the littoral value will reach 1,174,000 CFA in 2030 and 2,635,000 FCFA in 2040. The dynamics of the coastline from 1990 to 2040 shows that the region records average retreats of about -0.44 m/year, 0.21 m/year and -0.11 m/year respectively on the northern, western and southern coasts. These dynamic rates are expected to be about -4.4 m/year (for the north coast), 2.1 m/year (for the west coast), and -1.1 m/year by 2030 (south coast). By 2040, they are estimated to be around 28.8 m/year (north coast), 4.2 m/year (west coast), and -2.2 m/year (south coast). These dynamic rates will cause the losses of area which is estimated at 861,273 m^2 in 2030 and 1,256,493 m^2 in 2040 (Pouye *et al*., 2022). In this study, it is estimated that if it changes by one square meter, the littoral value is expected to change by 186,100 FCFA in 2030 and 137,900 FCFA in 2040.

CONCLUSION

In summary, climate change has detrimental effects on the economic value of coastal zones and its adverse effects on the ecosystem. People who live by the coast suffer several harms as a result of one of its effects, coastal erosion. Consequently, these effects affect economically the coastal areas. The results of this study showed that the parameters such as Beach Width, Lost Areas, Coastal Length, Dynamic Rate, Littoral Areas, Built Areas, Proximity to Town, CVI, Number of Buildings, Number of Hotels, Number of Industries, Number of Fishing Points, and Road Length play an essential role on littoral value. The estimation of economic loss based on littoral price and lost areas showed that the district municipalities along the coast of Dakar recorded a loss estimated at 38,507,856,000 FCFA in 2030 and 57,822,698,000 FCFA in 2040. These losses are shared unequally in coastal areas in Dakar. The most exposed in terms of economic loss are Malika, Plateau, and Ngor. Whether the coast of Dakar region is challenged economically by coastal erosion, abnormal settlements, pollution sand mining aggravates the economic loss. It should be essential to note that the application of law no. 76–66 of 2 July 1976, which defines the natural public domain with the shores of the sea, and the artificial public domain with the numerous urban infrastructures built or planned (Quensière *et al*., 2013) and law no. 83–05 of 28 January 1983 of the Environmental Code which specifies that settlements along the coast must "neither be a source of erosion nor degradation of the site" (FAO, 2010). Unfortunately, this law is not respected by most people making economic decisions.

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