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ORIGINAL PAPER

Vulnerability assessment of coastal areas to sea level rise from the physical and socioeconomic parameters: case of the Gulf Coast of Bejaia, Algeria

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Abstract The study area (the Gulf of Bejaia) is a coastal zone of about 70 km long in the eastern-central part of the Algerian coast. The coastline characterized by sandy beaches, hotels and tourist facilities, airport, port, villages and towns has known during these last decades several threats like storms, floods and erosion. The present work concerns the mapping of the physical and socioeconomic vulnerability of the Gulf Coast of Bejaia to sea level rise, using Coastal Vulnerability Index (CVI) and geospatial tools. The Physical CVI (CVI_{Phys}) is calculated from seven physical variables: geomorphology, coastal slope, coastal regional elevation, sea level rise rate, shoreline erosion/accretion rates, tidal range and significant wave height. On the other hand, the parameters population, cultural heritage, roads, railways, land use and conservation designation constitute, for their part, the socioeconomic CVI (CVI_{eco}). The values obtained from the calculation of CVI_{Phys} vary between 3.53 and 81.83. These results revealed that 22.42 km of the studied coastline has a low physical vulnerability, 21.68 km a high vulnerability and 15.83 km a very high vulnerability, indicating that the most part of the coastline (53.59%) is vulnerable to sea level rise. According to the obtained values of CVI_{eco}, the most vulnerable areas of high and very high risk represent 31.81 km of the total coastline. They were found along the western (Bejaia and Tichy) and eastern (Aokas, Souk El Tenine and Melbou) coast, while the least vulnerable stretches, covering 38.19 km of the total length of the coast, occupy the rest of the area. This study highlighted areas that will be most affected by future sea level rise (SLR) and storm events. It revealed that several development projects of Bejaia Gulf Coast, including tourist expansion areas, are planned in sites identified as very vulnerable. The results obtained from this assessment could guide local planners and decision-makers in developing coastal management plans in the most vulnerable areas.

Introduction

Coastal areas are subjected to many pressures related to growing and invasive presence of humans. As a result, they have become densely populated and highly productive (Small and Nicholls 2003; McGranahan et al. 2007). They hold natural ecosystems of immeasurable importance and encompass the main social organizations of the majority of countries. According to Chen and Chen (2002), 2/3 of the planet's big cities, with great economic potential, are built in these zones where 60% of the world population live. This excessive occupation has disrupted the natural dynamics and balance of these areas and has generated many problems with their associated risks. On this subject, the coastal strip is a very specific territory in terms of risk (Paskoff 2001; Meur-Férec 2002; Robin 2002; Meur-Férec and Morel 2004). For these areas, evolution and risks have always been inseparable. With effective and expected global warming and its impact on mean sea level rise, these risks will increase during the current century and

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even beyond. Indeed, the mean sea level rise (MSLR) is certainly the most well-known and most publicized consequence of this new episode of global warming (Allen and Komar 2006). During the twentieth century, world marine and ocean surfaces recorded an increase of 1 to 2 mm/year (Douglas et al. 2000; Church and White 2006). For the twenty-first century, the projections are much more alarming and worrying, predicting spectacular and unexpected rising sea levels (Leuliette et al. 2004; Beckley et al. 2007; Rahmstorf 2007; Meehl et al. 2007; Church et al. 2008, 2013; Kopp et al. 2014) with rates up to eight times higher (Ranasinghe and Stive 2009). According to the Intergovernmental Panel on Climate Change (IPCC), in its fourth assessment report of 2007, the global sea level will rise by more than 59 cm by the year 2100. Many other researchers such as Pielke (2008), Pielke et al. (2008) and Schiermeier (2008) believed that many inconsistencies exist in the IPCC estimates. The recent studies such as that carried out by Strohecker (2008), based on a new model showing the evolution of sea level over the last 2000 years, have predicted that sea level could increase by nearly 1.5 m by the end of this century following the melting of glaciers, the disappearance of ice caps and the thermal expansion of oceanic waters. Pfeffer et al. (2008), for their part, went even further in estimating the future sea level rise by anticipating a plausible limit of +2 m by the same year.

In 2013, the IPCC released its fifth assessment report reinforcing its certainty on the major role of man and his activities in global warming and sea level rise. In this latest report, the IPCC has revised its estimates upwards. It anticipates a rise of up to 0.98 m by the end of the twenty-first century compared with the period 1986–2005. As was the case for the fourth report, the estimations of the fifth report are probably clement and optimistic because they did not take into account the results of recent studies, which show an increase in the ice melts of Greenland and West Antarctica (Helm et al. 2014; Joughin et al. 2014; Rignot et al. 2014). In recent years, efforts to estimate the future level of marine waters have followed each other and, mainly, diverged. However, everyone agrees and expects that this rise will result in widespread coastal erosion, sensitive increase in storm surges, salinization of coastal aquifers, frequent and widespread flooding of wetlands and low-lying areas, threats to cultural and historical resources and infrastructure (Church et al. 2001; Meehl et al. 2007; Nicholls et al. 2007; Fitz Gerald et al. 2008).

Faced to all this, coastal areas are highly vulnerable. This vulnerability lies in the propensity and predisposition of these territories to be adversely affected by the effects of this phenomenon (IPCC 2014). The sensitivity of their natural, social and economic components has given rise to growing concern within the international community. Consequently, and from 1990 onwards, it was necessary to develop methodologies for assessing coastal vulnerability to sea level rise. The first of them was the common methodology developed by the former Coastal Zone Management Subgroup of the IPCC (IPCC/CZMS 1992). Using this methodology, assessments have been made at national or international scales (Hoozemans et al. 1993; Hoozemans and Hulsbergen 1995; Baarse 1995; Nicholls and Mimura 1998; Nicholls 2002). The objective of these global studies was to provide decision-makers necessary information to implement adaptation and coastal protection strategies in their respective countries. The problems arising from the use of the common IPCC/CZMS methodology (Klein and Nicholls 1999) and its focussing on socioeconomic impacts of the phenomenon (Hinkel and Klein 2009) have led to the development of new methodologies and indices such as that of Gornitz et al. (1994). This latter, contrary to the IPCC/CZMS methodology, only allows treating coastal physical vulnerability without including socioeconomic variables. Subsequently, other indices were developed combining both physical and socioeconomic factors. With these developed methodologies and indices, implication studies of the sea level rise phenomenon and the associated coastal area vulnerability have known a remarkable improvement, particularly after they have integrated the university research world. Today, most countries have conducted vulnerability assessments of their coasts at national, regional, or local scales, unlike the Algerian coast which has not been, until today, the subject of any similar studies.

The Algerian coast, 1622 km long, constitutes an undeniable asset for economic and social development of the Algerian national territory. Its importance has increased with hydrocarbon decline and the need for a national economic renewal, based on the diversification of resources. However, this coast presents some risks for its exploitation and development, including problems related to erosion and coastal flooding. These impacts may increase with the expected sea level rise (Jiménez and Sánchez-Arcilla 1997). Howsoever its degree of manifestation, the actual and expected Mediterranean Sea level rise represents, in coming years, one of the major challenges for Algeria. Faced with this phenomenon, the Bejaia Gulf Coast, like all the coasts of the country, is vulnerable. This vulnerability lies in its natural sensitivity (low topography of the coast), which is aggravated by excessive and sometimes anarchic human occupation resulting from the "mismanagement" or the "non-management" of this space for years. The changes in coastal environmental processes, in particular the Mediterranean Sea level rise, may exacerbate the already significant and perceptible vulnerability of the area's ecosystems, its lands, its population and its built environment. This is why it is important to assess its vulnerability in order to distinguish the most vulnerable sectors requiring urgent intervention. This study will also allow the local managers of this space to anticipate and adapt practices and existing planning policies to new environmental conditions. It will enable them to be effective in their choice of strategies that must be adopted for the protection of property
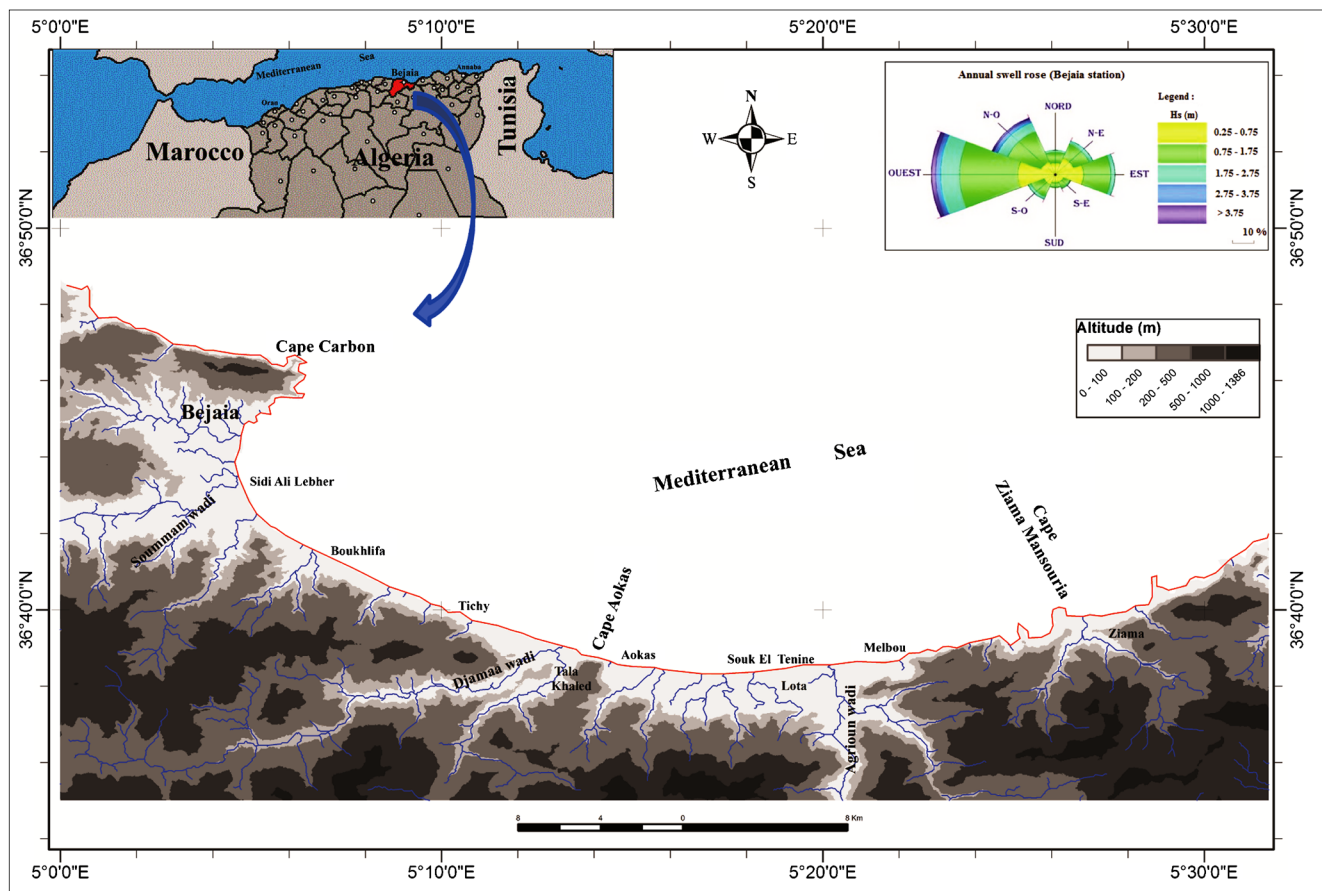
Fig. 1 Localization of the study area (Bejaia Gulf Coast)

and persons. Thus, the main objectives of this study are to (1) detect and map coastal areas threatened by erosion and marine submersions and (2) assess the vulnerability of the Bejaia Gulf Coast.

Study area

The Gulf Coast of Bejaia is located in the central-eastern part of the Algerian coast, 300 km east of Algiers. It extends on 70 km of coastline between Cape Carbon to the west and Cape Ziama Mansouria to the east. The study area lies between parallels 36° 37′ 37″ N and 36° 46′ 32″ N and meridians 5° 00′ 55″ E and 5° 25′ 13″ E (Fig. 1).

The main morphological units of the coast are plains and beaches. These ones take shape from the right bank of the Soummam wadi mouth to the west up to the Melbou cliffs to the east and are dominated by a mountainous area with average altitudes exceeding 200 m. The contact between the mountain range and plains is done by short and steep slopes, interspersed by more or less wide valleys whose altitudes vary between 2 and 4 m. In some places, these mountainous reliefs are connected directly to the Mediterranean Sea through the headlands and cliffs dividing the area into small bays.

The mountain range bordering, over a large part, the gulf is mainly formed of Mesozoic and Cenozoic formations, very thick, folded, sometimes schistose and metamorphosed. These terrains were transported in the form of thrust sheets during the alpine orogeny. In this zone, the tectonics is very active and results in numerous earthquakes that frequently shake the region.

The present morphology of the study area is formed by a succession of morphological landscapes resulting from Tertiary tectonic activity, nature of rocks, sea wave's aggressivity and fluvial depositions. Between Cape Carbon and Cape Ziama Mansouria stretches, a sandy strip formed of 33 beaches totalling a length of 34.5 km. The continuity of this sandy strip is interrupted in the central part of the coast by Tichy and Aokas Capes, which divide the coastal strip into two fringes. From the right bank of the Soummam wadi mouth, main provider of this coast in terrigenous materials, and going eastwards, these beaches have tendency to become wider then they become thinner as soon as they reach, successively, the around of cliffs of Tichy and Aokas Capes, to finally disappear in the extreme east in contact of Melbou cliffs. Their widths range between 27.5 and 100 m but still keep, all the same, two common characteristics: their low slopes (less than 2%)

Fig. 2 Urbanization in the coastal area of Bejaia Gulf. **a** Capritour Tourist complex, Tichy. **b** Vaccaro town. **c**, **d** Urban framework of Bejaia City

and altitudes (between 0 and 5 m). In very few places, these beaches are bordered by relics of dunes on the limit of disappearance, because of the already existing tourism facilities and irrational sand and gravel extractions for the construction of the villages, towns and the urban centre of the region.

As for the alluvial plains of the study area, they are represented by the lower valley of the Soummam wadi and the coastal plains. The lower valley of the Soummam wadi is formed of alluvial terraces which are composed, essentially, of silts, sands and several clay layers flooded during the period of high-water levels. The coastal plains are located below the Babors mountain range and stretch in longitudinal strips over 30 km. Indeed, from west to east stretch the plain of Tichy, that of the mouth of Djemaa wadi and the plain of Souk El Tenine. The latter hide many aquifers that supply a large part of the gulf coast.

The human occupation of the studied zone goes beyond the urban units listed above. It also results in a multitude of tourist complexes and industrial structures that overrun its whole coastal strip (Figs. 2 and 3). Indeed, the current tourism development of this coast is significant and reflected in the presence of 05 tourist expansion areas (ZET). These tourist facilities cover a 3225-km^2 area including tourist complexes, sports fields, recreation equipment, camping sites and spaces for human and economic activities. With regard to the industrial sector, the wilaya of Bejaia with a fabric of more than 220 active units has become, during the last decades, a hub of food-processing industry. Its industrial zone located in the western part of the Gulf Coast is classified third industrial hub of eastern Algeria. This zone covers 228 ha of land and contains many public and private enterprises, including small- and medium-sized enterprises and industries (PME/PMI), which allow employing some 14,063 people. The low cost of investments, coupled with a culture and citizen greed that privileges the sea proximity, has often allowed anarchic and illegal development of urbanization to the detriment of lands with high agricultural value.

Bejaia is the fifth most populated wilaya in Algeria. In 2009, its population reached 924,272 inhabitants, with a density of 287 inhabitants per km^2. The population living in the urban areas is around 809,580 inhabitants accounting for 87.6% of the total population (Alloui 2011). For their part, the coastal plains account for nearly 5.82% of the wilaya total population, with a density of 244 inhabitants per km^2.

The Gulf Coast of Bejaia is a fragile coastal environment which has known, during the last decades, important morphological changes due to both physical and anthropogenic factors. Currently, the regressive evolution of the shoreline combined with this human occupation has generated huge pressures on the coast, reducing its natural and socioeconomic capacity to adapt to future changes and thereby increasing its vulnerability to future rise of the Mediterranean Sea level.
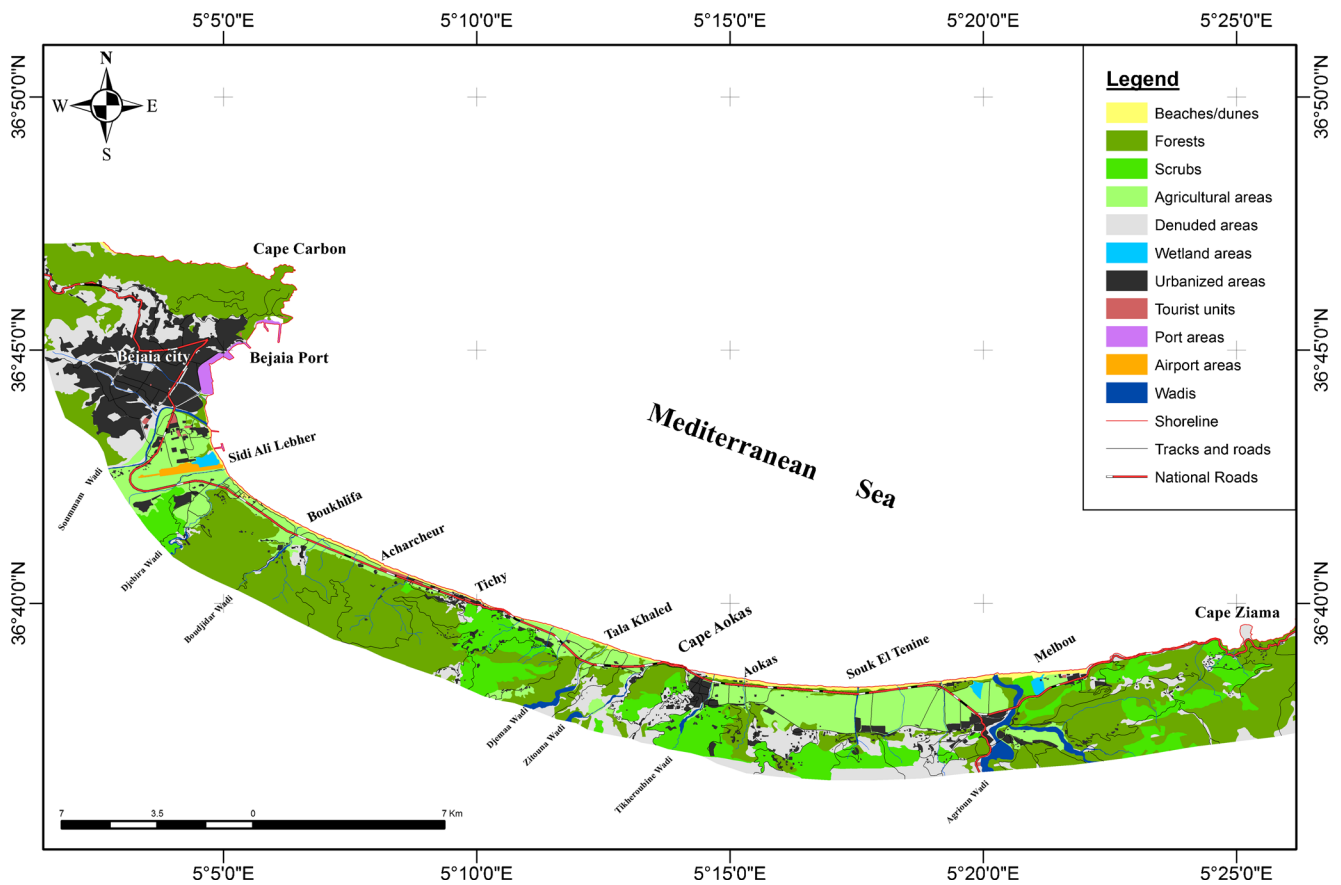
Fig. 3 Land use map of the Bejaia Gulf coastline

Data and methods

For the whole Bejaia Gulf Coast, between Cape Carbon and Cape Ziama Mansouria, the physical and socioeconomic vulnerability was assessed by using indices. In this regard, among the methods for assessing this vulnerability to erosion and marine flooding phenomena arising from eustatic sea level rise, the Coastal Vulnerability Index (CVI) is the most often used, particularly for its simplicity (Gornitz et al. 1991). These indices allow the physical and socioeconomic variables that compose them to be respectively linked in a quantitative manner to express the coastal vulnerability to both phenomena mentioned above. In general, the proceeded methodology for this is carried out in three steps: as a first step, the key variables influencing the coastal zone vulnerability in question should be identified (Gornitz et al. 1991). In the second one, comes the quantification of the selected variables and, in the third, their integration into a composite index and the cartographic translation of the obtained results. Thus, a good vulnerability assessment is based, prima facie, on a good choice of variables to be taken into account in the process. These variables are selected according to several principles. Among these, representativeness is the most important in that it guarantees a simple and easy application of the index (Del

Rio and Garcia 2009). In addition to that, in the choice made, one can also be confronted with the issues related to the applicability of these variables in the studied area and the availability of the respective data. Once selected, there are different ways to combine these variables into a composite index. For the needs of some studies, some variables of the same index were considered more important than others. In each of these cases, the importance attached to each of them was based on judgement established as for their influence on vulnerability (Hahn et al. 2009). However, in this study, an equal weight was given to all the variables. This choice is justified by the diverse number of value judgments that lie behind combined weights (Cendrero and Fischer 1997). This weighting principle has been applied in numerous studies carried out around the world. Among these studies, we quote those conducted by the United States Geological Survey (USGS) (Gornitz et al. 1991; Thieler and Hammar-Klose 1999, 2000a, b) and many others later (Pendleton et al. 2005; Boruff et al. 2005; Hegde and Reju 2007; Dwarakish et al. 2008, 2009; Ozyurt and Ergin 2009, 2010; McLaughlin and Cooper 2010; Kumar et al. 2010; Gaki-Papanastassiou et al. 2010; Sheik Mujabar and Chandrasekar 2011; Di Paola et al. 2011; Kumar and Kunte 2012; Karymbalis et al. 2012; Clavano 2012; Joevivek et al. 2013; Addo 2013; Gorokhovich et al. 2014).

Physical vulnerability calculation

The methodology employed here, to assess the physical vulnerability of the Bejaia Gulf Coast to sea level rise, is based on the use of seven physical variables, whose six were used by Thieler and Hammar-Klose (1999), which have amended the initial index developed by Gornitz et al. (1994). These six variables are geomorphology, coastal slope, sea level rise rate, shoreline erosion/accretion rates, tidal range and significant wave height. The seventh parameter is the coastal regional elevation. This last parameter was first used by Gornitz et al. (1991, 1994) to calculate their CVI. Thereafter, it was used by several authors especially Diez et al. (2007), Kumar et al. (2010), Di Paola et al. (2011), Mahendra et al. (2011), Kumar and Kunte (2012), Addo (2013) and Kunte et al. (2014).

In previous studies, the used variables were ranked according to different scales. In this study, for each coastal stretch of the area, each of the seven physical variables has been ranked from 1 (very low risk rating) to 5 (very high risk rating) according to the values provided by Thieler and Hammar-Klose (1999) and Gornitz et al. (1991, 1994) and presented in Table 1. This ranking system is based on the contribution of each of these variables to the coast's physical changes. Consequently, a variable assigned a risk value equal to 1 indicates that it weakly contributes to coastal physical changes, and the one assigned a risk value equal to 5 contributes very highly (Table 1).

Geomorphology variable

The geomorphology variable expresses the relative erodibility of the various coastal morphological units. The erodibility of these landforms is related to the resistance degree of the materials that compose them to erosive processes increased by sea level rise (Thieler and Hammar-Klose 1999). Indeed, the types of forms found in a coast determine and influence, considerably, its reaction to new marine environmental conditions. This differential response explains the very low degree of risk associated with cliffs and rocky coasts when assessing the vulnerability to erosion. It also justifies the very high risk rating assigned to friable forms (sandy beaches, muddy deposits, mangroves, etc.), which are considered as very vulnerable to erosion (Table 1). For the purposes of this study, data concerning the geomorphology variable were obtained from detailed field geomorphological mapping, at a scale of 1:25,000, carried out during the period of study. Also, the lithology of geological formations, which outcrop along the study area, was identified in the field using geological maps, at the scale of 1:50,000, of the Office of Geological and Mining Research (ORGM).

Coastal slope variable

The coastal slope allows identifying the vulnerability degree of the coast to marine flooding. It is a quantitative variable which is also used to determine and situate the potential rate of shoreline retreat. Indeed, it is well demonstrated that the coastal strips of low slopes are more susceptible to erosion and recede thereby faster than those characterized by steep slopes (Gaki-Papanastassiou et al. 2010). Furthermore, their sensitivity is not restricted to erosive processes as they are also the most prone to flooding especially during storm events and tsunamis (Kumar et al. 2010). From the physical vulnerability point of view, coastal strips with gentle slopes (<3%) show a very high degree of vulnerability to flooding. They will also have to retreat faster than cliffs and rocky coasts, whose risk will be very low, because of the steep slopes (>12%) that characterize them (Table 1). In this study, the Bejaia Gulf Coast slope was calculated and determined using the Digital Terrain Model (DTM) at the scale of 1/5000th.

Coastal regional elevation variable

In the present study, the regional elevation means the average elevation of a coastal zone above mean sea level. Generally, in the vulnerability study to sea level rise, the importance of this variable is highlighted when identifying and estimating the extent of coastal lands threatened by the rising marine waters (Kumar et al. 2010; Kumar and Kunte 2012). This parameter also enables to identify the coastal stretches most vulnerable to marine flooding, particularly during storm events (Diez et al. 2007). From vulnerability point of view, the higher the coast, the less it is at risk to be negatively impacted by sea level rise (Table 1). In some studies, the "coastal slope" was preferred to this parameter on the pretext that the slope refers to a space and the elevation to a point. However, it is useful to indicate that two coastal stretches, which have the same low slope, will not have the same reaction to sea level rise if one has a high average elevation and the other a low. This is the reason why the two variables should be included together to well characterize the vulnerability. In this study, the mean coastal regional elevation, in turn, was also calculated using the DTM at the scale of 1:5000.

In order to calculate these two variables (coastal slope, mean coastal regional elevation), the coastal strip taken into consideration has a width of 500 m, going from the shoreline toward inland, in the western part of the Gulf (between Cape Carbon and Cape Aokas) and 1.5 km in its eastern part (between Cape Aokas and Cape Ziama Mansouria). It should also be noted that this limit marks a significant and radical change in the topography of the area. It corresponds to the southern end of the coastal plains (low topography) which give way to the Babors mountain range (high and hilly relief).

Table 1 Risk rating assigned for the seven variables used in calculating the physical CVI (after Thieler and Hammar-Klose 1999; Gornitz et al. 1991, 1994)

Variables	Risk ranking				
	Very low 1	Low 2	Moderate 3	High 4	Very high 5
Geomorphology	Rocky, cliffed coasts	Medium cliffs, indented coasts	Low cliffs, alluvial plains	Cobble beaches, lagoons	Barrier beaches, mangroves, mudflats, deltas
Coastal slope (%)	>12	12–9	9–6	6–3	<3
Coastal regional elevation (m)	>30	>20 and ≤30	>10 and ≤20	>5 and ≤10	≥0 and ≤5
Sea level rise rate (mm/year)	<1.8	1.8–2.5	2.5–3.0	3.0–3.4	>3.4
Shoreline erosion/accretion rates (m/year)[a]	> (+2.0)	(+1.0)–(+2.0)	(−1.0)–(+1.0)	(−2.0)–(−1.0)	< (−2.0)
Tidal range (m)	>6.0	4.0–6.0	2.0–4.0	1.0–2.0	<1.0
Significant wave height (m)	<0.55	0.55–0.8	0.85–1.05	1.05–1.25	>1.25

[a] Positive values (+) indicate accretion while negative values (−) indicate erosion

Sea level rise rate variable

The results of several studies conducted around the world revealed that the mean sea level has globally risen about 2 mm/year during the last ten centuries (Gornitz 1995; Fleming et al. 1998). Indeed, sea level rise is one of the main impacts of climate change. For the twenty-first century, all studies carried out to date predict that mean sea levels will rise on a global scale. Obviously, this phenomenon and its future potential acceleration will have serious repercussions on all components of the coastal zones, including the human economic activities (e.g., McLean et al. 2001; Nicholls et al. 2007; Walton 2007). It will result in the amplification of erosive tendency of shores and more recurrent floods in low-lying coastal areas. Thus, the rate of sea level rise is an important parameter to consider in any coastal vulnerability study. From the vulnerability point of view, the higher the rate, the more vulnerable the coast to induced changes (Table 1). In this study, data concerning the sea level rise were obtained from measurements made by altimeters satellites Topex/Poseidon and Jason 1, between 1993 and 2006, in the western Mediterranean. These satellite measurements are very useful since no historical tide gauge measurements are available for the Bejaia Gulf. In addition to that, these satellites enable to measure directly the current variations of the global mean sea level compared with the centre of the Earth, with a high accuracy (+1 mm/year).

Shoreline erosion/accretion rate variable

From time immemorial, the natural processes have tirelessly shaped the coastal areas worldwide. Among these evolution processes, shoreline erosion is the most important phenomenon affecting these zones. In this regard, recent studies clearly showed that shorelines recede more than they advance with

70% of sandy and gravelly beaches in a regressive dynamics and only 10% in accretion. The remaining percentage (20%) characterizes the stable shores (Paskoff 1998). For the populations living in the coastal areas, coastal erosion is not a phenomenon to be taken lightly because it often threatens the lands of these areas, their beaches, their ecosystems and their habitats. Even worse, it threatens the existing buildings and infrastructures, particularly those relating to tourism, affecting these communities which depend enormously on this sector for survival (Dominguez et al. 2005). From the vulnerability point of view, the coastal stretches in retreat will not have the sedimentary stock required to make up for the recorded losses due to erosion and flooding. As a result, they are considered as more vulnerable to the phenomenon than stretches in accretion (Table 1). The latter are considered as less vulnerable because they move toward the sea thus resulting in the addition of land areas. This positive evolution of the coast also increases the distance between the population and sea, thereby reducing their risk of exposure to coastal hazards.

In this study, coastline erosion/accretion rates were calculated over a 28-year period in the western part of the gulf (Cape Carbon-Cape Aokas) by using photographs from the 1973 and 1989 aerial missions and the SPOT image of 2001. On the other hand, in the eastern part of the bay (Cape Aokas-Cape Ziama Mansouria), shoreline evolution rates were calculated over a period of 53 years by using aerial photographs of three missions (1960, 1973 and 1998), a SPOT 5 image of 2007 and a topographic map at the scale of 1:25,000 dating from 2013. The image processing (scanning, orthorectification and mosaic) was carried out using ERDAS IMAGINE 9.2 software to obtain orthophotos. These ones were exported in a Geographical Information System (GIS) environment in order to digitize shorelines and to create a geo-database from these shorelines vectors. This geo-database was

then analysed using Digital Shoreline Analysis System (DSAS) in order to calculate shoreline change rates. These rates are computed over 40 km of coastline, between the mouth of the Soummam wadi to the west and Melbou cliffs to the east, and risk ratings are assigned according to the obtained results.

Tidal range variable

Tides are regular oscillations in water levels of seas and oceans on a daily cycle. This regular daily oscillation may range from few decimetres to more than 15 m in few world regions. They result from the gravitational attraction of celestial bodies such as the moon or the sun and are therefore periodic and highly predictable (Kumar et al. 2010). Tidal range is defined as the vertical difference between the highest high tide and the lowest low tide (Doukakis 2005; Diez et al. 2007; Kumar et al. 2010). These tidal fluctuations are very important in coastal areas. They cause permanent and episodic inundations, especially by affecting coastal physical processes such as the enlargement toward the coast of wave action zone. The degree of influence of this physical variable, taken into account when assessing vulnerability, differs according to studies. In those carried out by Gornitz et al. (1994), Doukakis (2005), Diez et al. (2007), Kumar et al. (2010), Duriyapong and Nakhapakorn (2011), Di Paola et al. (2011), Yin et al. (2012) and Addo (2013), a coast with a high tidal range is considered as highly vulnerable to sea level rise. The high degree of vulnerability assigned to these areas is explained by the fact that a large tidal range is associated with strong currents that can transport sediments away from the coast (Gornitz et al. 1994; Kumar et al. 2010). For other authors, the most vulnerable coastal areas are those with low tidal range (Pendleton et al. 2005; Dwarakish et al. 2008, 2009; Ozyurt and Ergin 2010; Gaki-Papanastassiou et al. 2010; Sheik Mujabar and Chandrasekar 2011; Karymbalis et al. 2012; Joevivek et al. 2013; Gorokhovich et al. 2014). They argue that coastal zones characterized by high tidal range have a high resilience to sea level rise (Chauhan et al. 2004). On the other hand, coasts at low tides can become at high tides during storm events. As a result, they are more vulnerable to erosion and marine flooding (Dwarakish et al. 2009; Gaki-Papanastassiou et al. 2010). In this study, coastal zones characterized by low tidal range are considered as highly vulnerable and those with high tidal range as low vulnerable (Table 1). The average tidal range was obtained from tide gauge measurements in the Bejaia port and the available data.

Significant wave height variable

In all studies relating to coastal zones, the study of swell is particularly important for its direct or indirect impacts on shoreline mobility. In these studies, it is admitted that the ability of waves to mobilize and transport coastal sediments is closely linked to their heights (USGS 2001). In those relating to vulnerability, wave height is used as a proxy for wave energy (USGS 2005). Significant wave height is defined as the average height, measured from trough to crest, of the one-third highest waves (Kumar et al. 2010). It was used as a variable in numerous vulnerability studies carried out around the world because of its impact on coastal erosion and flooding, which result in losses of coastal lands (Gaki-Papanastassiou et al. 2010). From a vulnerability point of view, the higher the waves, the higher their energy and the greater the risks involved (Table 1). For the purposes of this study, the mean annual values of significant wave height have been obtained from the Wind and Wave Atlas of the Mediterranean Sea (MEDATLAS), which encompasses offshore measurements carried out during the period between 1999 and 2004. These values are used as an indicator of the transferred wave energy toward the Bejaia Gulf Coast.

For each segment of Bejaia Gulf coastline, the risk values assigned to the seven physical variables, taken into account in the present study, are then combined to produce the Physical Coastal Vulnerability Index (CVI_{Phys}). This index is calculated as the square root of the product of the ranked variables divided by their total number (Eq. 1):

$$CVI = \sqrt{\frac{a \times b \times c \times d \times e \times f \times g}{7}} \qquad (1)$$

Where

a   risk rating assigned to geomorphology
b   risk rating assigned to coastal slope
c   risk rating assigned to coastal regional elevation
d   risk rating assigned to sea level rise rate;
e   risk rating assigned to shoreline erosion/accretion rates
f   risk rating assigned to tidal range
g   risk rating assigned to significant wave height

The CVI values obtained for the different sections of coastline were categorized into four classes. Each of these categories indicates the coast's degree of physical vulnerability to sea level rise: low vulnerability ($0 < CVI_{Phys} \leq 20$), moderate vulnerability ($20 < CVI_{Phys} \leq 40$), high vulnerability ($40 < CVI_{Phys} \leq 60$) and very high vulnerability ($CVI_{Phys} > 60$).

Socioeconomic vulnerability calculation

The coastal zone is a space highly coveted by various human activities: industrial, tourism, commercial, agricultural and military. It is also an area that is effortlessly degradable by thoughtless and uncontrolled development. Climate change and sea level rise are among the phenomena endangering the coastal zones and their various components for several years.

These two phenomena and their expected effects give rise to a growing concern at various levels of society. In coastal areas, these concerns are about the impact of these phenomena on human infrastructure and activities rather than on the sustainability of the environment itself (Cooper and McKenna 2008b). Generally, it is the social and economic value of a coast at risk that has often justified actions to protect it (Gornitz et al. 1993). Despite this, recent coastal vulnerability studies to sea level rise have focused more on the physical aspect of vulnerability. However, the authors of these studies admitted that the inclusion of socioeconomic variables in the analysis of vulnerability would significantly improve the identification of the most vulnerable coastal areas (Gornitz et al. 1991, 1994; McLaughlin et al. 2002; Dominguez et al. 2005; Diez et al. 2007; Clavano 2012; Lichter and Felsenstein 2012).

To assess the socioeconomic vulnerability of the Bejaia Gulf Coast, six variables were used. These variables are population (settlement), cultural heritage, roads, railways, land use and conservation designation. The latter were used in numerous vulnerability studies particularly those conducted by McLaughlin et al. (2002) and McLaughlin and Cooper (2010). The choice of these variables, on which the application of this method is based, is not fictitious because they are considered by both the scientific community and policy-makers to be essential components of global coastal regions. This is the reason for using them in this study.

Once selected, each of the six socioeconomic variables was ranked on a scale from 1 to 5 according to its degree of vulnerability to coastal erosion and/or marine flooding. Value "1" corresponds to a very low risk and "5" to the highest (Table 2).

For each section of Bejaia Gulf Coast, each of the six variables mentioned above is associated with a risk induced and conveyed by the Mediterranean Sea level rise. From the socioeconomic vulnerability point of view, all these variables characterize the monetary value of the coastal area. In the case of damage from extreme natural events, some of these coastal components can be reconstructed and repaired (e.g. roads, railways, urban structures), whereas others are inestimable and thus irreplaceable (e.g. cultural, historical, archaeological and ecological sites; human lives). Accordingly, the most vulnerable coastal stretches are those which contain at the same time an important urban fabric, a developed road network, historical and cultural monuments and sites recognized for their ecological and archaeological heritage. The least vulnerable correspond, in turn, to areas free from any human intervention.

In the current study, the settlement/population variable was included because it is considered as being a key factor of the coasts' socioeconomic development. Indeed, a densely populated area has an important economic value (Hughes and Brundrit 1992). This variable that characterizes the human habitat and its distribution in the study area has been ranked according to the criteria listed in Table 2 and taking into account the importance of the urban fabric and the inherent functionalities to each ensemble. From the vulnerability point of view, an inhabited coast is more exposed to risks related to erosion and marine flooding than an uninhabited one. The difference lies in the endangered human lives and likely to succumb to the effects of both phenomena. Furthermore, in the same inhabited coast, an urban centre is more populated than a village and its impact on the area functioning and development is also more important, what makes it more vulnerable (Table 2). Data concerning this variable were obtained from the Development and Urbanism Management Plans (PDAU) and the land use plans (POS) of the study area.

The cultural heritage variable refers to historical monuments and archaeological sites identified in the area. These vestiges of history have little economic interest, but because of their representativeness for the local population, they are considered important socially and culturally. In socioeconomic vulnerability assessment, the ranking of this variable is quite simple. The coastal strips, where no ancient monument or archaeological site is identified, are assigned with a minimum value of risk. On the other hand, those where the different stages and tragedies of the past are represented are assigned with a maximum value of risk (Table 2). Data concerning the cultural heritage were derived from the analysis of the area's tourist map completed with field observations.

The roads and railways are the vital arteries of any coastal zone. These lines of communication allow the movement of the population and the transport of goods, thus contributing to the social and economic development of these areas. That is why they are considered important in the assessment of vulnerability. From this point of view, coastal parts with developed circulation networks are more vulnerable to sea level rise (Table 2) because in case of damages caused to these structures by erosion or marine flooding this will lead to significant economic and commercial losses. Furthermore, repairing damaged networks would require financial costs that will be in addition to the already exorbitant costs necessary for their construction and maintenance.

The nature of the coast current use and its future vocation determine greatly its economic, environmental and aesthetic importance. It also influences its vulnerability and participates in decision-making as for its protection. In assessing vulnerability, the ranking of this variable is a subjective estimate of the land use value (McLaughlin et al. 2002). From this vulnerability point of view, the urbanized or industrial areas are considered more vulnerable than natural ones (bare rocks, marsh, bog, etc.) (Table 2). For the purposes of this study, roads, railways and land use variables were characterized from the local development and land use plans (PDAU, POS) that have been studied and analysed. Thus, the current use and the projects planned in the Bejaia Gulf Coast for the short, medium and long terms have been taken into consideration.

Table 2   Risk rating assigned for the six variables used to calculate the socioeconomic CVI (after McLaughlin et al. 2002; McLaughlin and Cooper 2010)

Variables	Risk rating				
	1	2	3	4	5
Settlement	No settlement	Village	Small town	Large town	City (urban centre)
Cultural heritage	Absent	–	–	–	Present
Roads	Absent	–	A-class	–	- Motorway - Dual carriageway
Railways	Absent	–	–	–	Present
Land use	- Water bodies - Marsh/bog and moor - Sparsely vegetated areas - Bare rocks	Natural grasslands Coastal areas	Forest	Agriculture	Urban and industrial Infrastructure
Conservation designation	Absent	–	International	–	National

The last parameter relating to conservation designation refers to coastal parts which are important by their environmental and ecological characteristics. These areas, that have in some cases multiple designations, are often delimited and protected by the national and/or international legislation. They are also subject to conservation and sustainable development efforts. In the ranking method of this variable, coastal areas with national designation status are considered more vulnerable than those with international designations (Tables 2 and 3). This is principally due to their weaker management systems and resources (McLaughlin and Cooper 2010). In this study, we used the available local data (Environment Directorate of the wilaya of Bejaia).

Once ranked, the used six variables were combined to construct the Socioeconomic Coastal Vulnerability Index (CVI$_{eco}$). This index is the sum of the risk values corresponding to these variables divided by 30, then multiplied by 100 (Eq. 2):

$$CVI_{eco} = \frac{a + b + c + d + e + f}{30} \times 100 \qquad (2)$$

Where

a   risk rating assigned to settlement/population variable
b   risk rating assigned to cultural heritage variable
c   risk rating assigned to roads variable
d   risk rating assigned to railways variable
e   risk rating assigned to land use variable
f   risk rating assigned to conservation designation variable

For the different stretches of the Bejaia Gulf Coast, the CVI$_{eco}$ was computed using Eq. 2. The values thus generated were then categorized into four classes corresponding to low vulnerability ($20 \leq CVI_{eco} \leq 30$), moderate vulnerability ($31 \leq CVI_{eco} \leq 50$), high vulnerability ($51 \leq CVI_{eco} \leq 70$) and very high vulnerability ($71 \leq CVI_{eco} \leq 100$).

Results

Physical vulnerability

Along the entire Bejaia Gulf Coast, between Cape Carbon and Cape Ziama Mansouria, each part of this coast will respond unfavourably to the risk induced by the Mediterranean Sea level rise. This reaction to the new environmental conditions allows detecting, highlighting and characterizing the vulnerability degree of each of them to the global scale phenomenon. It is defined by the physical coastal vulnerability index "CVI$_{Phys}$" (Hammar-Klose and Thieler 2001). Although certain and inevitable, this response is also different for each coastal stretch of the gulf. The high vulnerability indices will concern the low-lying areas, composed of friable materials and subjected to a high energy of waves and important shoreline erosion (Gornitz et al. 1994).

Geomorphology variable

This variable indicates the relative natural degradation level of coastal landforms. Along the studied coast, except the artificialized section (the Port of Bejaia), two morphological landforms succeed each other in the landscape: one friable and the other rocky. The present study revealed that about 37 km (52.85%) of coastline containing the sandy beaches of the area have a very high risk rating. On the other hand, about 23 km of coastline covering the rocky coast of Carbon, Bouak, Tichy, Aokas and Ziama Mansouria Capes as well as the cliffs of the Black Cape and Melbou have a very low risk rating (Fig. 4).

Coastal slope variable

The coastal slope variable is the principal indicator of flood risk and directly influences the CVI calculation. The value mapping of this variable (Fig. 5) shows that about 19 km of coastline has a very high risk rating, recording coastal slopes

Table 3 Risk rating assigned for the conservation designation variable (after McLaughlin et al. 2002; McLaughlin and Cooper 2010)

	International	National
Conservation designation	Ramsar site	Areas of scientific interest
	Protecting a special area	Areas of outstanding natural beauty
	Conservation of a special area	National reserves of the nature
	World heritage site	Environmentally sensitive areas
Risk rating	3	5

of less than 3% along the coastal stretches of western and central Souk El Tenine, Boukhlifa and Sidi Ali Lebher. About 16 km of coastline has a high risk rating, recording coastal slopes between 3 and 6% along the coastal stretches of Tichy, eastern Aokas, eastern Souk El Tenine and western Melbou. About 3 km of coastline has low to moderate risk ratings, recording coastal slopes between 6 and 12% along the western part of Aokas and the stretch of about 1 km at the entrance of Melbou cliffs. About 22 km of coastline has a very low risk rating, recording coastal slopes of more than 12% along the rocky stretches of Carbon, Bouak, Tichy, Aokas and Ziama Mansouria Capes and along the cliffs of the Black Cape and Melbou.

Shoreline erosion/accretion rate variable

The present study revealed that about 7 km of coastline has a low risk rating, recording accretion rates oscillating between +0.75 and +1.89 m/year along the western and central coastal stretches of Souk El Tenine. About 14 km of coastline has a moderate risk rating, recording alternation between erosion and accretion, with rates varying between −0.75 and +1.89 m/year, along the coastal stretches of Tichy, eastern Aokas and eastern Souk El Tenine. About 19 km of coastline has high to very high risk ratings, recording evolution rates that oscillate between −0.75 and −2.25 m/year along the coastal stretches of Boukhlifa, Sidi Ali Lebher, Melbou and western Aokas (Fig. 6).

Coastal regional elevation variable

This study revealed that about 37 km of coastline has a very high risk rating, recording coastal regional elevations that oscillate between 0 and 5 m along the coastal stretches of Melbou, Souk El Tenine, Aokas, Tichy, Boukhlifa and Sidi Ali Lebher. On the other hand, about 23 km of coastline has a very low risk rating with coastal regional elevations of more than 30 m along the rocky coastal stretches of Carbon, Bouak, Tichy, Aokas and Ziama Mansouria Capes and those of the Black Cape and Melbou.

Sea level rise rate variable

The measurements of Topex/Poseidon and Jason 1 satellites revealed that the Gulf Coast of Bejaia has recorded a rate of sea level rise of 2.5 mm/year during the period 1993–2006 (Fig. 7). Thus, the entire coastline has a moderate risk rating according to the database of this study shown in Table 1.

Significant wave height variable

Wave energy, transmitted by wind-generated waves toward the coastal area, is proportional to the square of the wave height. Associated with wave-generated currents, they are responsible for the movement of sediments and coastal erosion. In the study area, wave climate is dominated by the strong marine roughness, with wave heights exceeding 2.75 m observed during the first and fourth trimesters. From October to March, the wave heights oscillate between 1.75 and 2.75 m. Between April and September, the offshore wave heights vary from 0.75 to 1.75 m. In the Gulf of Bejaia, the mean significant wave height is 1.75 m. Accordingly, the entire coastline is in the very high vulnerability class.

Tidal range variable

In the Mediterranean Sea, especially along the Algerian coast, the tide is very low because the basic rhythm is due to the low amplitude astronomical tide. Although low in Algeria, it plays an important role in determining sensitive coastal areas to submersion risks. The measurements carried out by the Naval Forces Hydrographical Service (SHFN) along the Algerian coastline indicate that the tidal range is ±0.34 m Algerian General Levelling (NGA). Thus, the tide value for the study area is plus or minus 34 cm, with a maximum level of +0.5 m NGA and the lowest sea is −0.34 m NGA. Accordingly, the Bejaia Gulf Coast, like the whole Algerian coastline, is under the influence of a microtidal environment and has a very high risk rating to sea level rise.

Physical coastal vulnerability index

The seven physical variables were combined and the CVI_{Phys} calculated for the entire studied coastline by anticipation to the Mediterranean Sea level rise. The values obtained from the index computation vary between 3.53 and 81.83 (Table 4), with an average value of 42.68.

According to the obtained CVI_{Phys} values, the different vulnerability zones along the Gulf Coast of Bejaia were
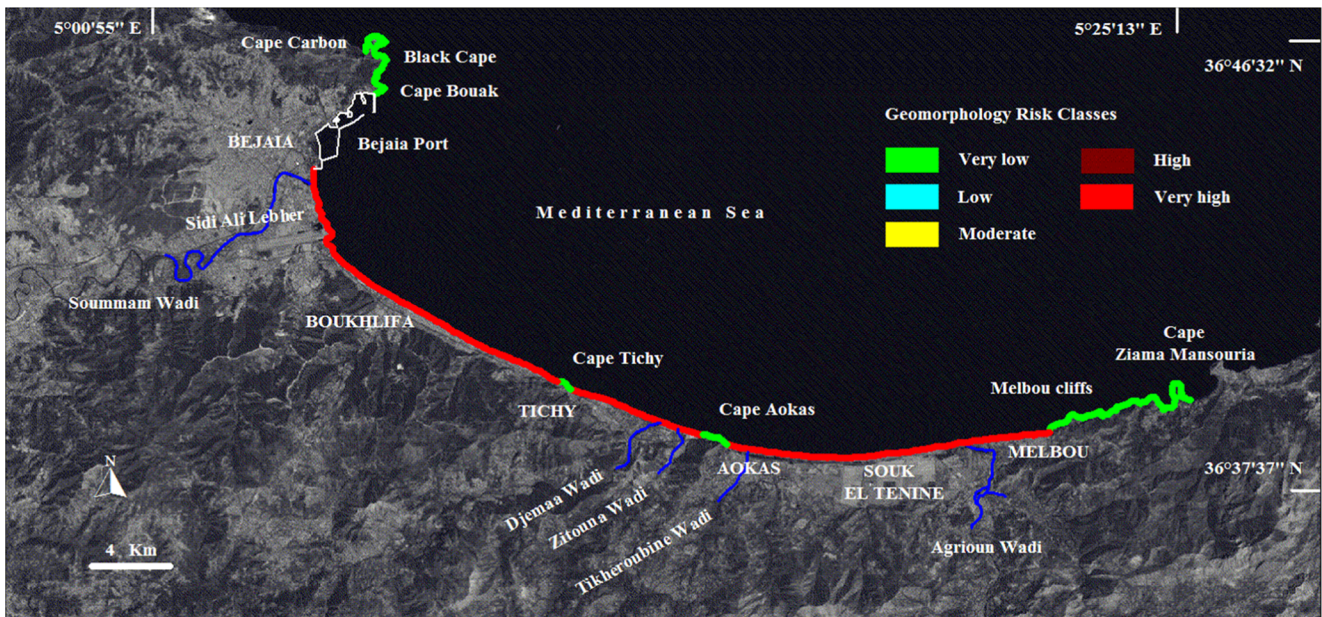
Fig. 4 Vulnerability classes map of the Bejaia Gulf coastline, relating to the geomorphology variable

delineated on the map (Fig. 8). Except the artificialized part (about 10 km) corresponding to the Bejaia Port, this figure highlights three vulnerability classes: low, high and very high. The present study revealed that 22.42 km of Bejaia Gulf coastal strip has a low physical vulnerability to erosion and marine flooding covering the Carbon, Bouak, Tichy, Aokas and Ziama Mansouria Capes, the Black Cape and the rocky stretch of Melbou coast. These coastal stretches have recorded CVI values of 3.53 and 5.67, respectively. On the other hand, 37.51 km of coastline has high to very high physical vulnerability covering Sidi Ali Lebher, Boukhlifa, Tichy, Aokas,

Souk El Tenine and western Melbou. These parts of the study area comprising beaches and plains have recorded CVI values varying between 46.29 and 81.83 (Table 4).

Socioeconomic vulnerability

The CVI_{eco} was computed for the whole Bejaia Gulf coastline. The obtained values range from 33 to 93 (Table 5) with an average value of 63.

These results have allowed us to distinguish three vulnerability classes: moderate, high and very high (Fig. 9). The
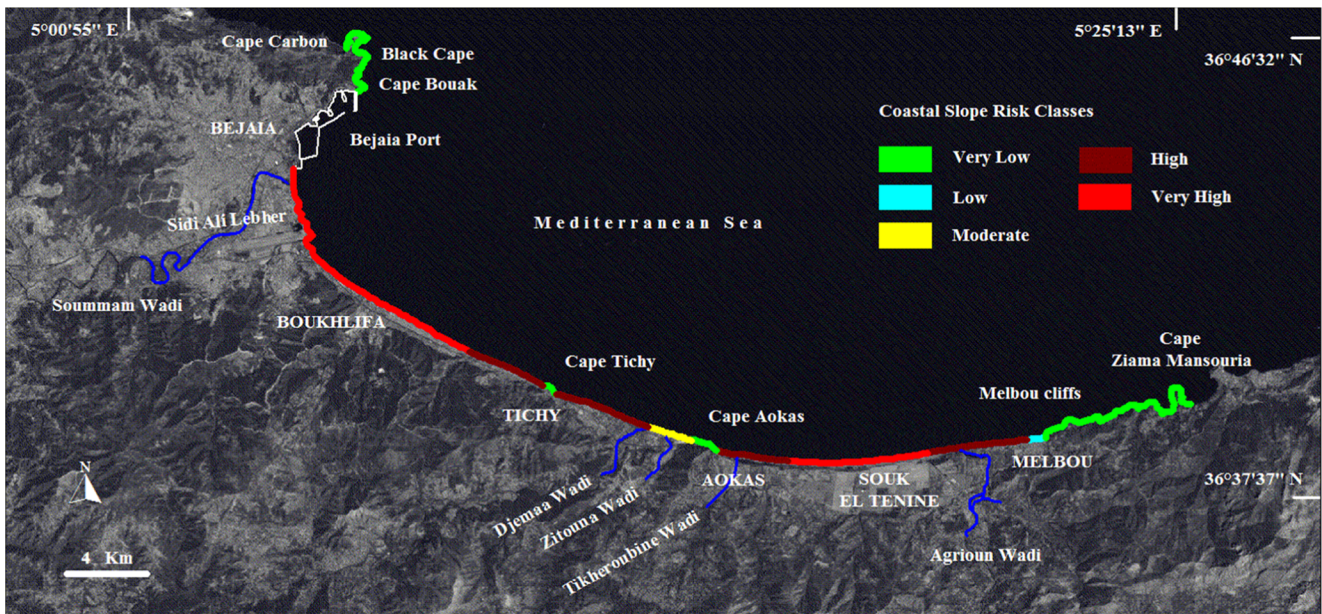
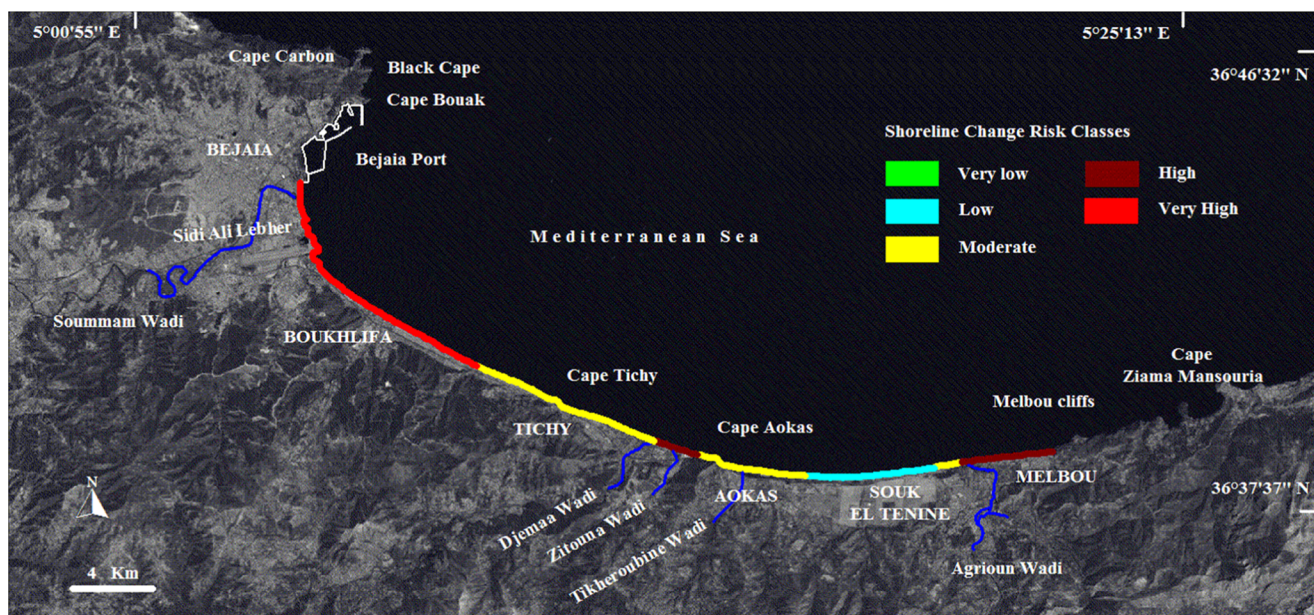**Fig. 5** Vulnerability classes map of the Bejaia Gulf coastline, relating to the coastal slope variable

Fig. 6 Vulnerability class map of the Bejaia Gulf coastline, relating to the shoreline change rate variable

current study revealed that 38.19 km of Bejaia Gulf coastline has a moderate socioeconomic vulnerability to sea level rise, recording CVI values ranging from 33 to 50, covering the Carbon, Tichy, Aokas and Ziama Mansouria Capes as well as the rocky coast of Melbou. This class of vulnerability also concerns a large part of the coastal plains, notably the coastal stretches of Boukhlifa, eastern Tichy (between Vaccaro town and Djemaa wadi), western Aokas, central and western Souk El Tenine and western Melbou (between Melbou town and Agrioun wadi). This study also revealed that 31.81 km of the total coastline has high to very high socioeconomic vulnerability, recording CVI values varying between 53 and 93 (Table 5), covering most of Bejaia coastal strip and parts of Tichy (on either side of the Cape), Aokas (east of the Cape and east of Djemaa wadi), Souk El Tenine (to the west of Agrioun wadi) and Melbou (at the entrance of the cliffs) (Fig. 9).
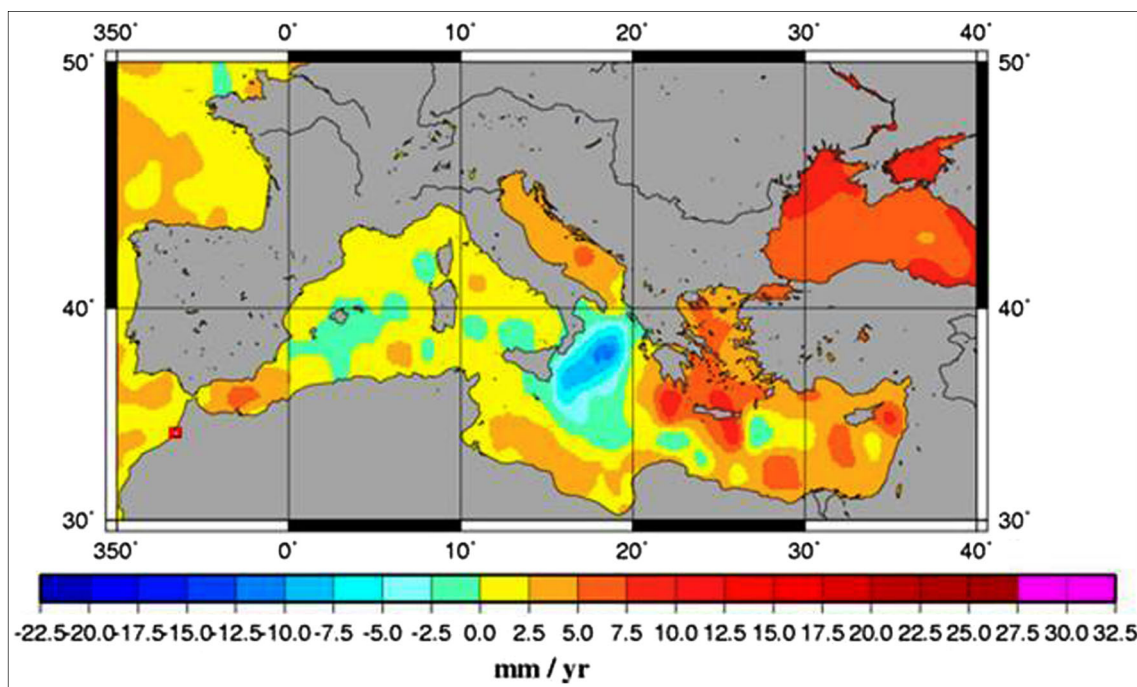

Fig. 7 Geographic distribution map of sea level change speeds (1993–2006) in the Mediterranean Sea, from Topex/Poseidon and Jason 1 (http://www.legos.obs-mip.fr)
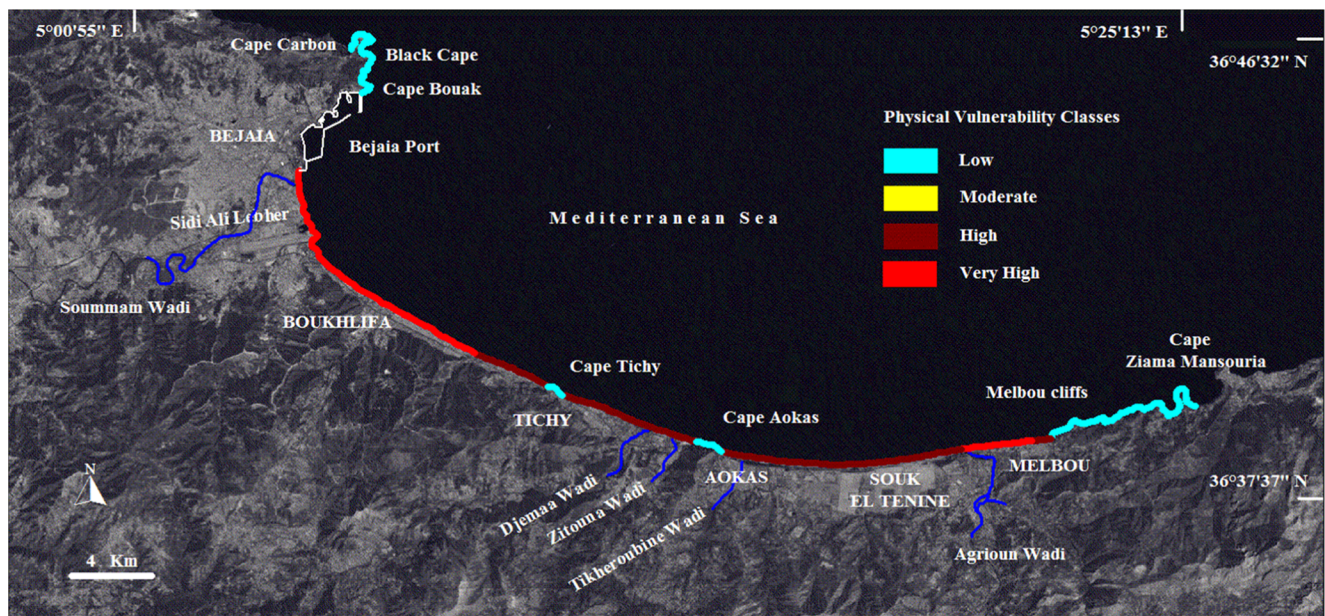
Table 4 CVI_{Phys} values of the Bejaia Gulf Coast, between Cape Carbon and Cape Ziama Mansouria

Commune	Parts of the coast	Length of coastline (m)	CVI_{Phys} values	Risk rating	Vulnerability
Bejaia	Cape Carbon, Cape Bouak, Black Cape	7610	3.53	1	Low
	Sidi Ali Lebher	4324	81.83	4	Very high
Boukhlifa	The entire coast	7610	81.83	4	Very high
Tichy	West	2898	56.69	3	High
	Cape Tichy	727	5.67	1	Low
	East	3714	56.69	3	High
Aokas	West	1762	56.69	3	High
	Cape Aokas	1175	5.67	1	Low
	East	3798	56.69	3	High
Souk El Tenine	West + centre	6789	51.75	3	High
	Extreme east	1671	56.69	3	High
Melbou	West	3902	65.46	4	Very high
	Centre	1048	46.29	3	High
	Melbou cliffs	12,910	3.53	1	Low

Discussion

In recent years, concerns about sea level rise have led to numerous studies of coastal vulnerability (Boruff et al. 2005). Indeed, the majority of countries have anticipated the effects of the phenomenon on their coastal areas, notably by conducting vulnerability studies at different scales. On this subject and as mentioned previously, Algeria is lagging behind compared with these countries. This has considerably affected the way in which the Algerian coast has been exploited for many years. In this proactive study, the vulnerability of both physical and socioeconomic components of the Bejaia Gulf Coast was assessed, in particular by using several variables recognized for their influence on the vulnerability of global coastal zones. For that purpose, this assessment was conducted in two stages. In the first step, the zone physical vulnerability was assessed and allowed us to highlight the degree of its natural predisposition to be negatively affected by the new environmental conditions in the Mediterranean. It revealed a worrying reality and confirmed the poor condition of this coast already subjected to almost widespread erosion. The strong interest aroused by the gulf coast for nearly half a century, which has resulted in a massive human presence, has permitted a rapid urbanization and the development of many
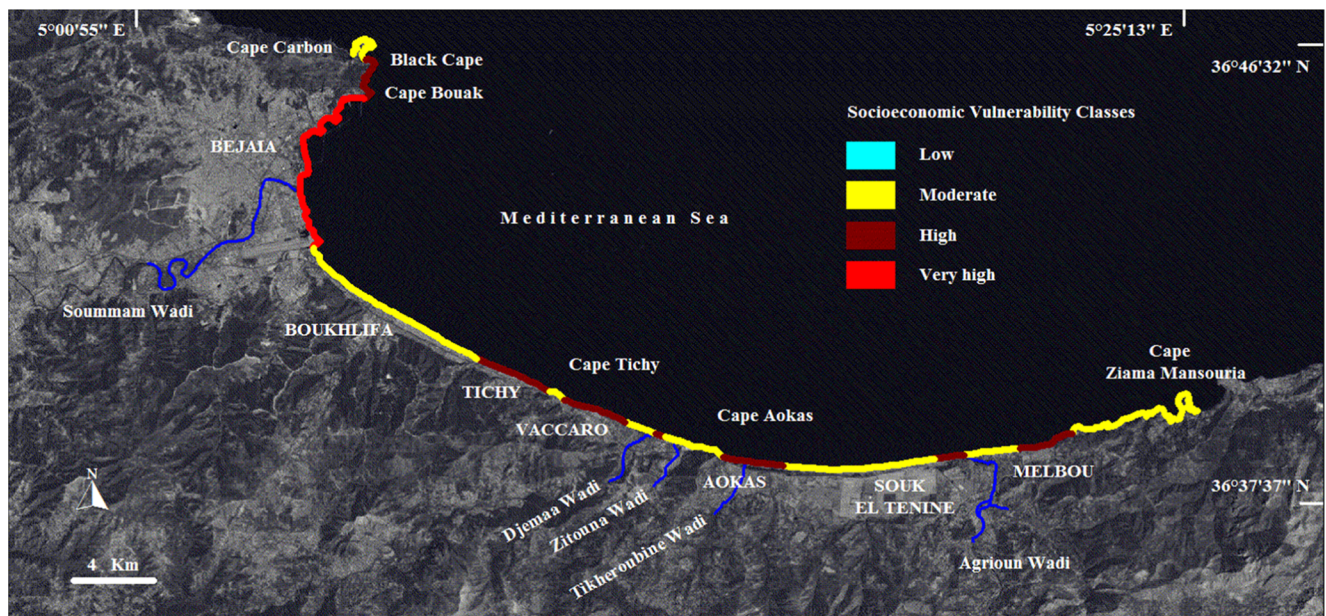

Fig. 8 Vulnerability classes map of the Bejaia Gulf coastline, relating to the physical vulnerability index (CVI_{Phys})

Table 5 CVI$_{eco}$ values of the Bejaia Gulf Coast, between Cape Carbon and Cape Ziama Mansouria

Commune	Parts of the coast	Length of coastline (m)	CVI$_{eco}$ values	Risk rating	Vulnerability
Bejaia	Cape Carbon	3617	40	2	Moderate
	Black Cape and Cape Bouak	3993	60	3	High
	Urban centre of Bejaia	14,386	93	4	Very high
Boukhlifa	The entire coastline	7610	The values oscillate between 41 and 50	2	Moderate
Tichy	Tichy town	2898	56	3	High
	Cape Tichy	771.7	50	2	Moderate
	Vaccaro town	2495.3	53	3	High
	Eastern end	1174	46	2	Moderate
Aokas	Azemmour village	409.9	63	3	High
	Tala Khaled village	1024	The values oscillate between 46 and 50	2	Moderate
	Cape Aokas	1519	33	2	Moderate
	Aokas town	1605	56	3	High
	Sidi Rihane village	1100	63	3	High
	Eastern end	1077.1	43	2	Moderate
Souk El Tenine	West and centre	6778	46	2	Moderate
	Souk El Tenine town	1682	53	3	High
Melbou	West	3076	46	2	Moderate
	Melbou town	2497	53	3	High
	East of Melbou town	739	60	3	High
	Melbou cliffs	11,548	The values oscillate between 33 and 50	2	Moderate

activities that have become indispensable for the economic survival of the entire region. These human facilities have become an integral part of the area, and assessing their vulnerability to sea level rise, especially to erosion and marine flooding, has become a necessity. This second step of the study aims to well characterize the vulnerability of the area

Fig. 9 Vulnerability classes map of the Bejaia Gulf coastline, relating to the socioeconomic vulnerability index (CVI$_{eco}$)

to the impacts of these phenomena and should contribute to decision-making as for its protection.

In the study conducted by Thieler and Hammar-Klose (1999), six physical and geologic risk variables were used. The physical process variables were sea level rise rate, tidal range and significant wave height. Furthermore, the geologic process variables were geomorphology, shoreline erosion/accretion rates and coastal slope. This method has been widely adopted and used in many subsequent studies, carried out in different parts of the world. Its effectiveness in characterizing and highlighting the coastal areas most physically vulnerable to the impacts of sea level rise has been widely accepted. In this study of the physical vulnerability, in addition to the six variables mentioned above, an additional geologic process variable was included in the construction of the CVI. It is the mean regional elevation of the coast. The integration of this variable used by Gornitz et al. (1991, 1994) and others later aims to improve the assessment of the vulnerability in the studied area. Thus, the seven physical and geologic variables were selected on the basis of their wide use in past studies but also according to the local data availability.

The assessment of the physical vulnerability revealed that 32.03% of the Bejaia Gulf coastline has a low vulnerability, 30.97% a high vulnerability and 22.62% a very high vulnerability to sea level rise. The obtained results demonstrated that, except the sea level rise variable, all other variables have exacerbated the vulnerability of the local natural components. They also revealed that the central part of the studied coastline (except Aokas and Tichy Capes) is more vulnerable than its eastern and western ends. This difference in vulnerability is explained by the geological and topographical characteristics of the area. The most vulnerable stretches are low-lying, almost flat and composed of friable materials (beaches and plains). Moreover, they are experiencing sustained erosion for many years. This erosion is due to decreasing of sediment inputs of main wadis (Soummam, Djemaa, Zitouna, Agrioun) as a result of the rapid urbanization along the coast and the construction of dams. It is also due to the illegal extraction of sand and gravel of the beaches for the construction of the region's urban centre, towns and villages. In the rocky part of the studied coastline, the lithology, the steep slope and the high mean regional elevation have played a major role in impacts mitigation relating to erosion and marine flooding. In the coastal stretches of Boukhlifa, Sidi Ali Lebher and Melbou, the signs of vulnerability are already obvious (Fig. 8). The intense and widespread erosion recorded in these areas during these last years is one of the manifestations of the Mediterranean Sea level rise impacts. Thus, these areas are historically vulnerable to erosion and validate the credibility of this study.

In this study, the socioeconomic vulnerability was also assessed because sea level rise, flooding and coastal erosion have direct impacts on the coastal settlements and activities of the Bejaia Gulf. The used index is based on six socioeconomic variables having a large acceptance of scientists and policy-makers. The results of this assessment revealed that 54.56% of coastline has a moderate socioeconomic vulnerability, 24.88% a high vulnerability and 20.56% a very high vulnerability to erosion and marine flooding. Thus, several parts of the studied area are in the high and very high vulnerability classes. The coastal stretches having a high socioeconomic vulnerability contain four large towns (Tichy, Aokas, Souk El Tenine and Melbou) and a small town (Vaccaro). These areas are highly urbanized and contain most of administrative, health, education and housing infrastructures of the respective communes. They also encompass most tourism infrastructures and will host important tourism projects (tourist expansion areas of Aokas and souk El Tenine). This category of vulnerability also concerns coastal sections that contain villages, monuments and sites at high historical and archaeological significance. Among these zones, there is the rocky coast which groups the Black Cape and Cape Bouak. This coast currently contains "les Aiguades" and antique tombs and will host the tourist expansion area of "Gouraya South East". There are also parts of the coastal strip of Aokas which are located in the villages of Azemmour and Sidi Rihane, as well as the coastal strip east of Melbou Town. These areas are not highly urbanized. However, their high level of vulnerability is due to the presence of the Countess Castle and the torture centre dating from the French colonial period, the Roman port as well as the archaeological site where the man of Afalou Bourmel dating from 16,000 years was discovered. They are also vulnerable because of the tourism investments planed in these areas like the tourist expansion areas of Aokas and Zitouna wadi. Thus, the urban and tourist features have strongly influenced the vulnerability of several parts of the studied zone. For the others, it is the historical and archaeological legacy which has weighed on their vulnerability. These coastal areas are important for the local population and testify to crucial episodes in the history of the young Algerian nation.

The coastal stretch having a very high socioeconomic vulnerability to sea level rise corresponds to the urban centre of Bejaia (Fig. 9). The degree of vulnerability reached in this area is explained by the presence of oil and commercial port, an international airport and Cevital industrial complex. This vulnerability is also due to the presence of many production units that make up the industrial zone, an impressive housing stock, many health and education facilities as well as highly developed tourism and road infrastructures. In this part of the gulf, the danger stirred up by this global scale phenomenon does not concern only the built or artificialized framework. It also threatens many historical vestiges and wetlands such as the Lake Tamelaht and the Soummam Valley classified as Ramsar site since 2009.

During the twenty-first century, losses of coastal lands, habitats and ecosystems as well as human and material losses

due to erosion and flooding are dreaded, especially because of the expected acceleration of the Mediterranean Sea level rise. This makes the development of strategies for adapting and protecting property and people a requirement. However, for local planners and decision-makers, it is difficult to identify how, when and where to adapt to the impacts of the phenomenon (Moser et al. 2012). This difficulty is increased by the lack of concrete assessment to identify and locate the most vulnerable sectors requiring urgent intervention. The objective of this vulnerability study is to remedy this lack of data. Indeed, the produced vulnerability maps are simple and intelligible tools intended for the different gulf coast managers. They will help them to optimize the choice of protection and adaptation actions to be undertaken. On that, there are many options available for protecting this coast from future hazards associated with erosion and flooding. These techniques may be reactive or preventive or both combined. They could be periodic beach nourishment, dune reafforestation, wetland restoration and management or the construction of defence structures along the coast and/or at sea. The sand nourishment of beaches is ideal for critical areas with high and very high vulnerability. Through its application, this technique can offer local managers a valuable time for reflection to find sustainable solutions. These ones must be implemented within the overall framework of an Integrated Coastal Zone Management (ICZM) plan, which is the most appropriate tool to tackle current and future vulnerabilities of the Bejaia Gulf Coast. It is also the only guarantee of success of any adaptation strategy.

Conclusion

The present study testifies to the usefulness of remote sensing, GIS and in situ observations as tools of prevention against coastal hazards. For the Bejaia Gulf Coast, this vulnerability study is of major interest in that it highlights the most vulnerable areas to sea level rise and climate changes. However, it will not be effective unless taken into consideration by the various managers of this space. Indeed, the physical vulnerability map produced from the CVI_{Phys} values allows distinguishing the coastal stretches where the losses of lands and natural habitats by erosion and flooding will be the greatest. On the other hand, the socioeconomic vulnerability map, derived from the CVI_{eco} computation results, when combined with the land use map allows characterizing the types of use which are located in coastal stretches having high to very high vulnerability. Thus, these vulnerability maps should help local planners and decision-makers to implement strategies to mitigate the effects of the Mediterranean Sea level rise on the different components of the area.

This study revealed that the Bejaia Gulf Coast is physically and socioeconomically vulnerable to erosion and marine flooding. The obtained results call for an objective reflection concerning the current management of this coast and the whole Algerian coastline. For that purpose, similar studies should be carried out across the national territory in order to characterize the global vulnerability of the Algerian coast, already under the influence of many sources of imbalance. On this subject, we will attempt to contribute to this objective in our future publications, notably by conducting other studies in other coastal zones and by including new variables to improve the characterization of their vulnerability.

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