COASTAL VULNERABILITY ASSESSMENT AND IDENTIFICATION OF ADAPTATION MEASURES TO CLIMATE CHANGE BETWEEN CAPE MATIFOU AND CAPE DJINET ALGERIA

Miloud SALLAYE*, Khoudir MEZOUAR, Abdelalim DAHMANI, Youssra Salem CHERIF

École Nationale Supérieure des Sciences de la Mer et de l'Aménagement du Littoral (ENSSMAL),
Campus universitaire, Bois des cars, DELY Ibrahim, 16320 Alger, Algérie
e-mail: sallaye.miloud@gmail.com

DOI: 10.5281/zenodo.7493268

Abstract. The sea level rise due to atmospheric warming, is one the phenomena the most treated by the scientific researchers IPCC. One of the regions most affected by this phenomenon on Algerian coast is the region of Zemmouri, located northwest of Algiers, on over 55 km of coastline between Cape Matifou in the West and Cape Djinet in the East. Objective of this paper is to evaluate the CVIPhys (physical coastal vulnerability) and the CVIeco (socio-economic vulnerability). We helped mapping the zones most vulnerable to climate change by using a geographic information system (GIS). Firstly, the CVIPhys was calculated by using six physical variables, these include geomorphology, coastal slope, mean tidal range, wave height, coastal erosion rate and sea level rise. Secondly, CVIeco was determined by using six variables, including population, cultural heritage, roads, railroads, land use and conservation designation. The results obtained from CVIPhys show that 52% (24.58 km) of the eastern coastline has a high to very high vulnerability. According to the values obtained from CVIeco, the most vulnerable areas represent 36% (30 km) along the coast. These results can be used by decision makers and planners in the integrated management of coastal areas.

Key words: coastal risks, coastal vulnerability, climate change, coastal erosion, zemmouri

1. INTRODUCTION

Coastal areas are present always of high interest in the world (Ku *et al.*, 2021; Sudha Rani *et al.*, 2015)our objective was to assess coastal vulnerability to inundation due to global mean sea level rise in response to climate change to help prepare for future scenarios and typhoon-induced surges. To accomplish this, the coastal vulnerability index (CVI. Today, coastal ecosystems are exposed to continuous pressure from anthropogenic and natural factors. (Amuzu *et al.*, 2018). Many indicators show the pressure on these ecosystems, such as : the increase in global atmospheric temperature of about 0.6°C (Bernstein *et al.*, 2008), changing precipitation patterns; increasing intensity of storms; and sea level rise of 10 to 20 cm (Team *et al.*, 2014). This latter, considered the major concern of the coastal zone, is principally due to thermal expansion (due to ocean warming), ice melting, and a decrease of liquid water storage on land. According to (Bernstein *et al.*, 2008), at the end of the 20th century, the marine and ocean areas of the planet are expected to increase by 59 cm by 2100.

For this purpose, The coastal areas, which are highly urbanized, are very vulnerable to several climatic hazards such as: flooding, marine flooding, coastal erosion, salt water intrusion and landslides (Hadef and Labii, 2017). In this context, the assessment of the vulnerability of coastal areas is essential for an integrated management of coastal areas (Yin *et al.*, 2012).

The Algerian coastline extend for 1626 km along the Mediterranean, does not escape the effects of climate change, including the sea level rise. However, it is marked by a high degree of urbanization (Rabehi *et al.*, 2020), so that this region has experienced many dysfunctions such as excessive land use, coastal erosion and industrial pollution. (Hichour and Essamoud, 2011).

Many methodologies have been developed to analyze and assess coastal vulnerability to sea level rise; one of the most adapted methods is the Coastal Vulnerability Index (CVI) which is most often used to assess the vulnerability of coastal areas to sea level rise (Gornitz *et al.*, 1994).

On the Algerian coastline, the assessment of coastal vulnerability using the CVI is rare. Due to insufficient data base, Some scientific research has been realized and published about the vulnerability of Algerian coasts (Djouder & Boutiba, 2017; Otmani *et al.*, 2020; Rabehi *et al.*, 2018)which stretches over 15 km, is currently experiencing very intense socioeconomic and urban development that is causing severe disturbances to the coastal environment. The main issue of this study concerns itself with understanding the evolutionary trends of this system and assessing its state of vulnerability towards erosion phenomena. This work focuses on the historical study of the variation in the shoreline position by combining photogrammetry data and in situ DGPS measurements (Differential Global Positioning System.

The coastal stretch of Zemmouri, situated between cape matifou and cape djinet is very vulnerable, this coastal stretch is a densely populated zone. Climate change, particularly Sea level rise, presents an ongoing threat to this coastal area resulting in marine flooding, coastal erosion, and salt water intrusion, which have modified the environmental, physical and socio-economic conditions of this coast. (Hossain *et al.*, 2022).

The present study aims at giving an analysis of the vulnerability along the coast of Zemmouri. In order to map the coastal areas affected by the erosion and the marine flooding, and to determine the degree of vulnerability of the cities of the bay of Zemmouri.

2. STUDY LOCALISATION

Is the part of the North Center Algerian littoral, close to the Mediterranean Sea It is located between Cape Djinet to the East and Cape Matifou to the West, and whose total length is 55 km. it includes 10 cities, is located between parallel 36°37´37˝ N and 36°46´32˝ N and meridians 5°.00´55˝ E and 5°25´13˝ E (Fig. 1).

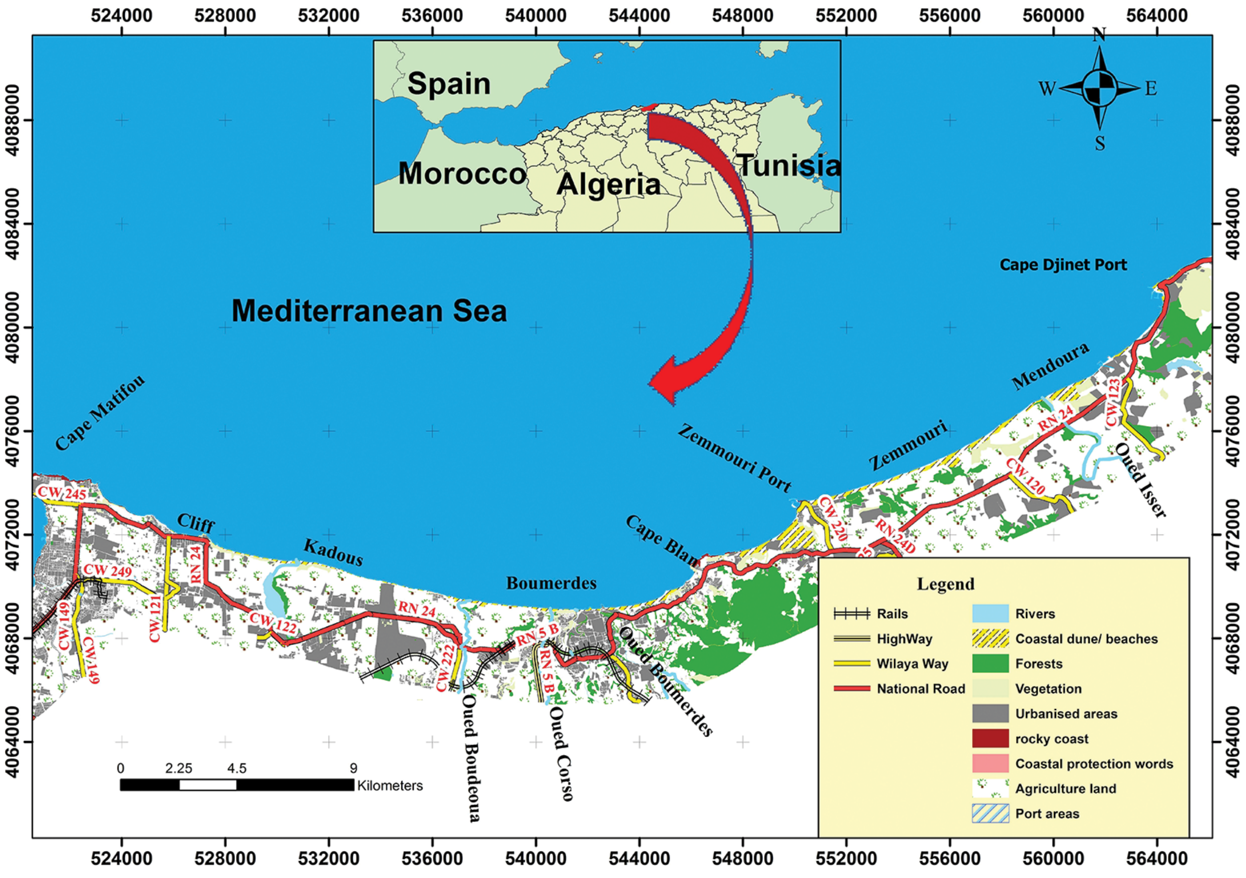

Fig. 1. Localization of the study area (Bay of Zemmouri).

The bay morphologically characterized by beaches, cliffs and rocky coasts directly exposed by coastal erosion (Rabehi *et al.*, 2018), The study area has a Mediterranean climate, being shot in the summer and warm/rainy in the winter. The wave and wind regime characteristics responsible for shoreline evolution have been calculated using data taken from the Infoplaza Marin Weather (2020) database available on the internet www.waveclimate.com. The prevailing winds arrive from the East and Northeast during the summer and, also from West and North-West direction during the winter. The latter shows that the most dominant winds are from the east with speeds varying between 3 and 9 m/s.

This coastal stretch is morphologically characterized by a sandy beach with seabed relatively regular, the slope varies from 1% to 3% with isobaths of -10 m. This area is highly vulnerable to erosion due to the presence of low-lying land area covered by sandy sediments (Fig. 2).

The study area is characterized by a dense hydrographic network, which the most important are the Wadi Isser, Wadi Boumeredes, Wadi Corso and Wadi Boudeoua El Bahri, these wadis take their source in the Atlas blidéen.

The geological structure of the study area is mainly covered by Plio-Quaternary deposits, the latter covers alluvial deposits composed of gravel, silt and clay in the marine terraces and basin area the along the coast (Fig. 3) (Samai *et al.*, 2017).

3. METHODOLOGY

On coastal lines of 55 Km kilometers (between Cape Djinet in the east and Cape Matifou in the west), it was necessary to determine a method of analysis of coastal vulnerability. To this effect, among the methods that can assess this vulnerability, particularly in the face of the phenomena of marine flooding and coastal erosion, it is the CVI (coastal vulnerability index) (Gornitz *et al.*, 1991). (Gornitz *et al.* 1994). This index we used to assess coastal physical vulnerability to climate change has been modified by (Hammar-Klose and Thieler 2001a). These modifications particularly affect the number and type of variables used. For our study area (between Cape Djinet and Cape Matifou), the coastal vulnerability index is based on six (6) physical variables, which are the same variables used by the USGS (US Geological Survey) when producing a national Atlas of coastal vulnerability to climate change (Hammar-Klose and Thieler 2001a). The six variables used in this study are: geomorphology, coastal slope, shoreline erosion/accretion rate, Sea Level Rise , Significant Wave Height, and finally tidal range (Kumar *et al.* 2010) (Amarni *et al.*, 2021). The Coastal Vulnerability Index (CVI) is calculated by the equation of (Gornitz *et al.* 1994). It is the square root of the product of the different variables, scaled by the total number of variables used.

Fig. 2. Morphological map of the study area

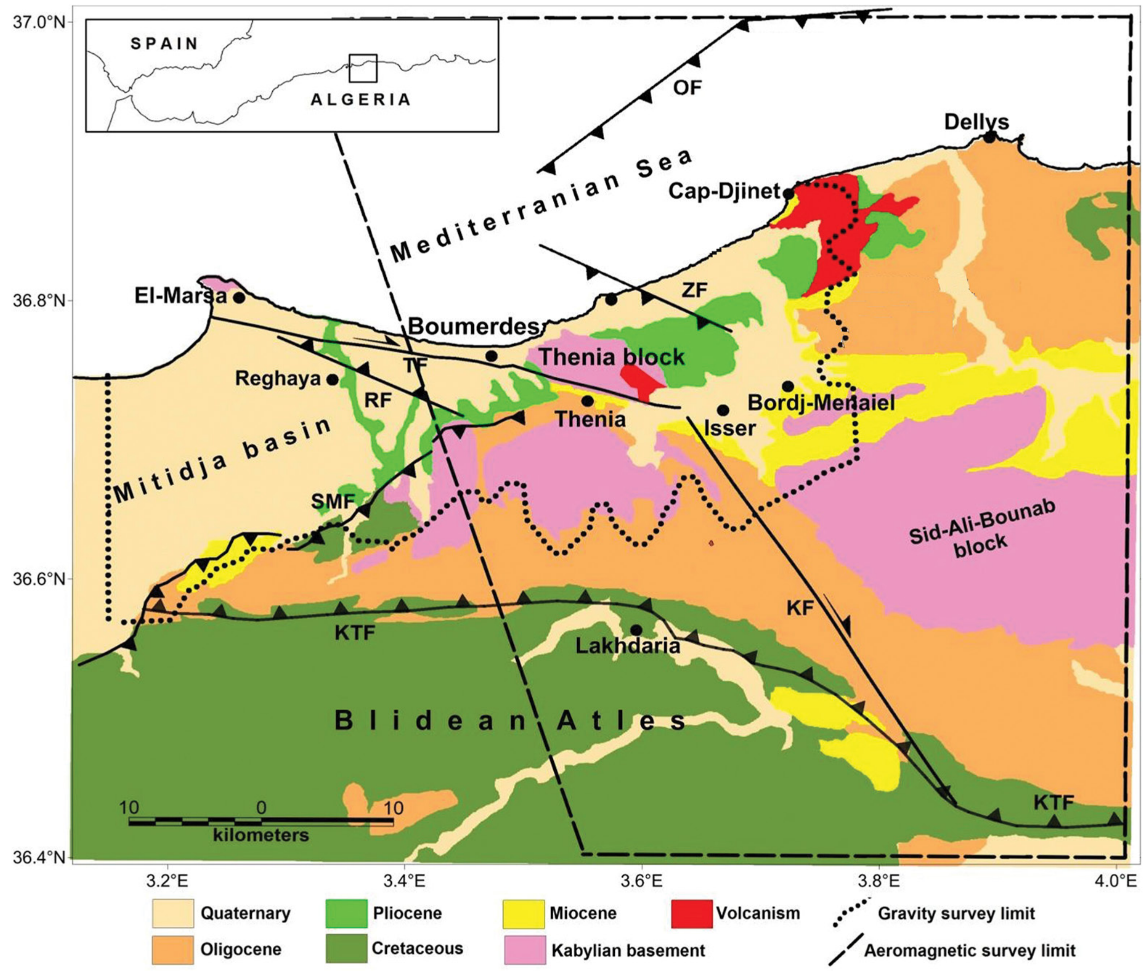

Fig. 3. Geological map of the study area. OF, RF and ZF are the faults related to the 2003 Boumerdes earthquake. TF: Thenia Fault, KF: Kabyle Fault, KTF: Kabylies Thrust Front, SMF: South Mitidja Fault (Samai *et al.*, 2017).

$$CVI = \frac{a \times b \times c \times d \times e \times f}{6} \quad (1)$$

with: a = geomorphology; b = coastal slope; c = Shoreline erosion/accretion rate; d = Sea Level Rise Rate; e = Significant Wave Height; f = tidal range.

These variables include both quantitative and qualitative information. Table 1 represents the different parameters used and their classification to calculate the coastal vulnerability index. Each coastal slice was classified on a scale from 1 to 5 (where (1) represents very low vulnerability (2) low (3) moderate (4) high and (5) very high).

According to the CVI values, four classes were created by using the quartile line method (0-25%. 25-50%, 50-75%, and 75-100%) and by visual control of the data. The results are classified into four categories (low, moderate, high, and very high vulnerability).

The variable of geomorphology was obtained using an older geological map (geological maps at 1/50000 è of Algiers, Thénia, Cherraga and Koléa), and we have completed the description by a morphological field survey in 2017.

Sea level rise is one of the problems associated with global warming, Many studies conducted in this sense in the world have noted that the sea level has increased of about 3.29 (±0.3) mm (Fig. 4). According to (Meyssignac, 2012) (Cazenave *et al.*, 2016), This phenomenon is the major problem of the coastal zone (Djouder and Boutiba 2017), it causes a very important retreat of the shoreline, an increase in the intensity and frequency of marine flooding. For our case study, the data from Sea level rise were obtained using satellite measurements by altimetric measurements such as Topex / Poseidon and Jason 1, Jason 2, Jason 3 jointly developed by NASA and launched in 1992. These measures are very useful in the Algerian Gulf in the absence of mareographs which can give us point measurements of sea level variation.

Shoreline change rates (erosion/accretion) was calculated using a digital shoreline analysis system for a 37-year period (1980 to 2017). These values were determined by using aerial photographs from the two aerial missions (1980 and 2003) and a high resolution satellite image from the year 2017.

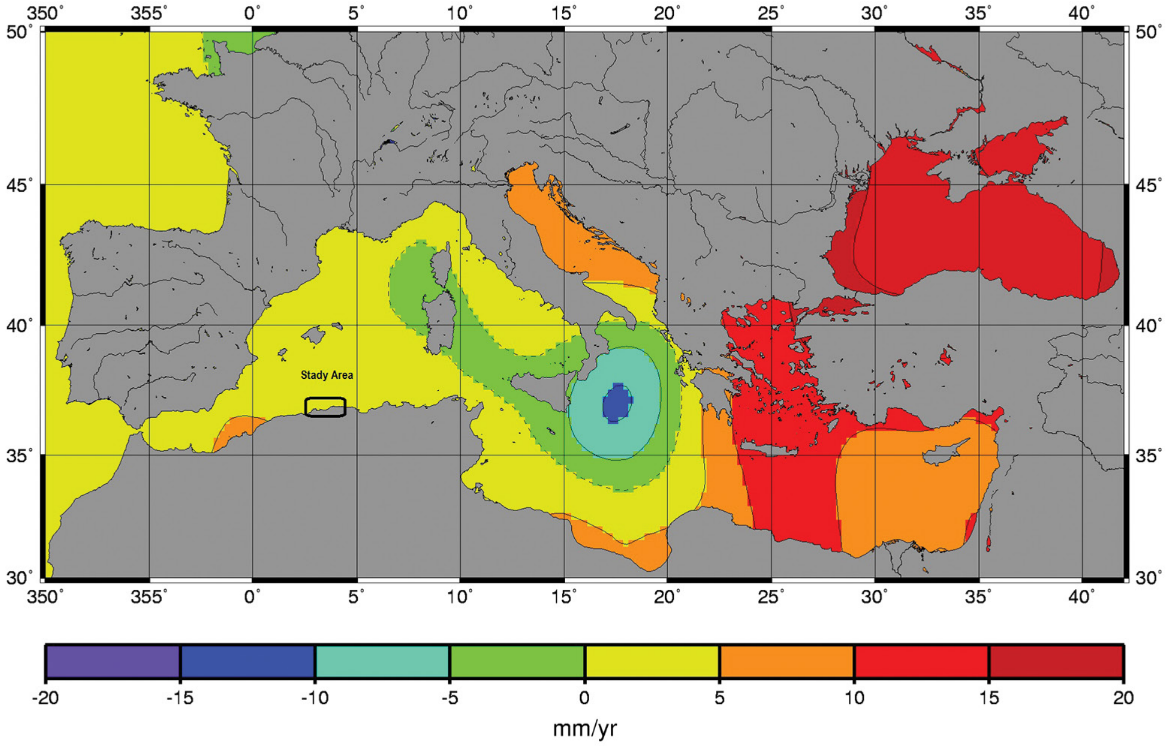

Fig. 4. Average sea level in the Mediterranean basin. Spatial altimetry data (CMEMS Ocean Monitoring Indicator) (von Schuckmann *et al.*, 2018). https://climate.copernicus.eu.

Table 1. The seven physical variables used for determining the coastal vulnerability index (CVIphy) by ((Gornitz *et al.*, 1991; Gornitz *et al.*, 1994; Hammar-Klose and Thieler, 2001).

	Classes of the coastal physical vulnerability index (CVIphy)				
	Very low	Low	Moderate	High	Very high
Variables	1	2	3	4	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

The aerial photographs were digitized and georeferenced and orthorectified by the National Institute of Cartography and Remote Sensing (INCT), and using ERDAS IMAGINE 9.2, we exported these images into Arc Gis in order to digitize the shorelines and create a database using the extension 'Digital Shoreline Analysis System' (DSAS), this database was used to calculate the rate of shoreline change.

In the absence of onshore wave data, mean annual values of the significant wave height were extracted from the oceanographic observing site data (www.climatewave.com) during the period 1992-2016. The simulation of the mean wave height was performed using the Mike 21 numerical model developed by DHI (DHI, 2014), which simulates the refraction of the swell from the offshore to the coast, to finally give the values of the wave heights near the coast.

The values of coastal slope of the bay of Zemmouri were determined with the help of a Digital Terrain Model (DEM) with a vertical resolution of 2 m.

Mean Tide Range is a very important parameter for the evaluation of the vulnerability of the coasts to the rise of the sea level, it provokes risks of flooding episodic and permanent (Mahapatra *et al.* 2015). The mean tidal range in the Algerian coasts is very low (Alberola *et al.* 1995), it is measured by the Hydrographic Service of the Naval Forces (S.H.F.N), it is under the influence of a microtidal environment (Djouder and Boutiba 2017).

Following a similar procedure, the social vulnerability index (SVI) is measured. From the socio-economic plan, coastal areas frequently show other specificities: a) A high population density, which can exert pressure on the coastal environment; b) A high rate of tourism in the summer seasons; c) An urbanization along the coastline (Denner *et al.*, 2015). (Lins-de-Barros, 2017), To this effect, the integration of the socio-economic component in the analysis of coastal vulnerability to sea level rise is an essential addition for the identification of the most vulnerable areas (Domínguez *et al.*, 2005; McLaughlin *et al.*, 2002). There are many methods of assessment of socio-economic vulnerability; for our study we have opted for the method of (McLaughlin and Cooper, 2010) . The number of variables included in this index is six, they are classified from 1 to 5 according to the degree of vulnerability (Tabel 2).

Six variables are used to calculate the social vulnerability index: population, cultural heritage, roads, railroads, and land use and conservation designation.

After completing the classification of these variables according to the method of (McLaughlin and Cooper 2010), the Socioeconomic Vulnerability Index is calculated (SEVI). This is the sum of the different variables, divided by 30 and then multiplied by 100.

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

with: a = Population, b = Cultural Heritage, c = Road, d = Railway, e = Land Use, and f = Conservation Designation.

After the determination of the values of the CVIeco, in follows the results are devised in four categories: a low vulnerability (20 ≤ CVIeco ≤ 30), moderate (31 ≤ CVIeco ≤ 50), high (51 ≤ CVIeco ≤ 70), and very high (71 ≤ CVIeco ≤100).

3.1. Data analysis and processing

During this work, maps of physical and socio-economic coastal vulnerability were elaborated with the help of Geographic Information System GIS (Arc Gis). Mesh cells in the form of identical squares of 20 m on 20 m were drawn along the coast of the bay of Zemmouri (Cape Matifou West to Cape Djinet East). Then for each variable, we classified each cell according to the degree of vulnerability (from 1 to 5) (Sallaye, 2021). Finally, the maps were exported in Tif format.

4. RESULTS AND DISCUSSION

The evaluation of the physical coastal vulnerability shows that the zone between Cape Matifou in the West to Cape Djinet in the East has been exposed to the effects of climate change, especially the sea level rise. The analysis indicated that the vulnerability of the coast of Zemmouri to the erosion and the marine flooding will increase with the sea level rise with regard to the conditions of the current state.

During the last years, many studies were carried out about the coastal vulnerability to sea level rise (Boruff *et al.* 2005). In the present study, the results obtained in the form of maps of vulnerability show that the bay of Zemmouri is very vulnerable to the sea level rise in particular the risk of the coastal erosion and the marine flooding.

Table 2. Classes of variables used to calculate the coastal socio-economic vulnerability index (CVIeco) by (McLaughlin *et al.*, 2002), (McLaughlin and Cooper, 2010).

Variables	Classes of the Socio-economic vulnerability index (CVIeco)				
	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	Natural grasslands	Forest	Agriculture	Urban and industrial
	Sparsely vegetated areas Bare rocks	Coastal areas			Infrastructure
Conservation designation	Absent	–	International	–	National

4.1. Geomorphology

The vulnerability map relating to geomorphology (Fig. 5) shows that about 81.01% of the coast of Zemmouri over a length of 44.07 km is classified as vulnerable and very vulnerable area. These sectors represent principally the beaches and unconsolidated dunes.

The sectors of low vulnerability and very low vulnerability represent 6.24 km that is 11.49%, and are essentially formed of rocky coasts and cliffs type (Gneiss, Andesite)

Finally, the sectors of moderate vulnerability represent 4.69 km, ie 7.5%, are located at the cliffs detailed Boumerdes of light rock type (Fig. 2).

4.2. Sea level rise

According to the map of geographical distribution of the rates of sea level change between 1993-2018, we notice that the sea level rise is not uniform at the regional scale; it varies between -2 and 6 mm per year. However, the Algerian Gulf registered a rate of sea level rise of 2.5 to 3 mm per year, which represents a moderate vulnerability ranking on the coast of Zemmouri.

4.3. Erosion/accretion rate

The present study has shown that about 15 km of the coast has a high to very high vulnerability that is 27.27%, with a maximum erosion rate is 9 m/year. These zones are located in the beach of Decaplage and the beach of Zemmouri East (Fig. 6).

The areas of moderate vulnerability extend along 27 km of coastline that is 49.09% with a rate of retreat varies between 3.42 and +1.85 m / year. These sectors are found in the part of Réghaïa and Boudouaou El Bahri. On the other hand, the sectors of low vulnerability to very low vulnerability extend along 13 km of coastline that is 23.63%, with an erosion rate varies between -1.52 and +0.21 m / year. These areas are located at Cape Matifou and the rocky coast of Boumerdès.

4.4. The significant wave height

According to the results of the simulation of the wave offshore to the coast by the numerical model Mike 21, the height significant, most frequent in the bay of Zemmouri varies between 0.85 and 1.05 m (Fig. 7), representing a classification of moderate vulnerability that affects the area of Boumerdès Center and east of the port of Cape Djinet. The highest values of significant height above 1.05 m affect the cliffs of Ain Taya and Corso. Finally, low values of significant height below 0.85 m are marked in the beach of Sable d'or, the power station and the mouth of Oued Isser.

4.5. The coastal slope

The present study revealed that 37.3 km of the coastline of the study area, that is 66.83%, present a risk of high to very high vulnerability (Fig. 8). They are located principally in the area of Boumerdès Center, the coastal plain of Zemmouri, and at the level of the plain of the lower valley of Oued Isser.

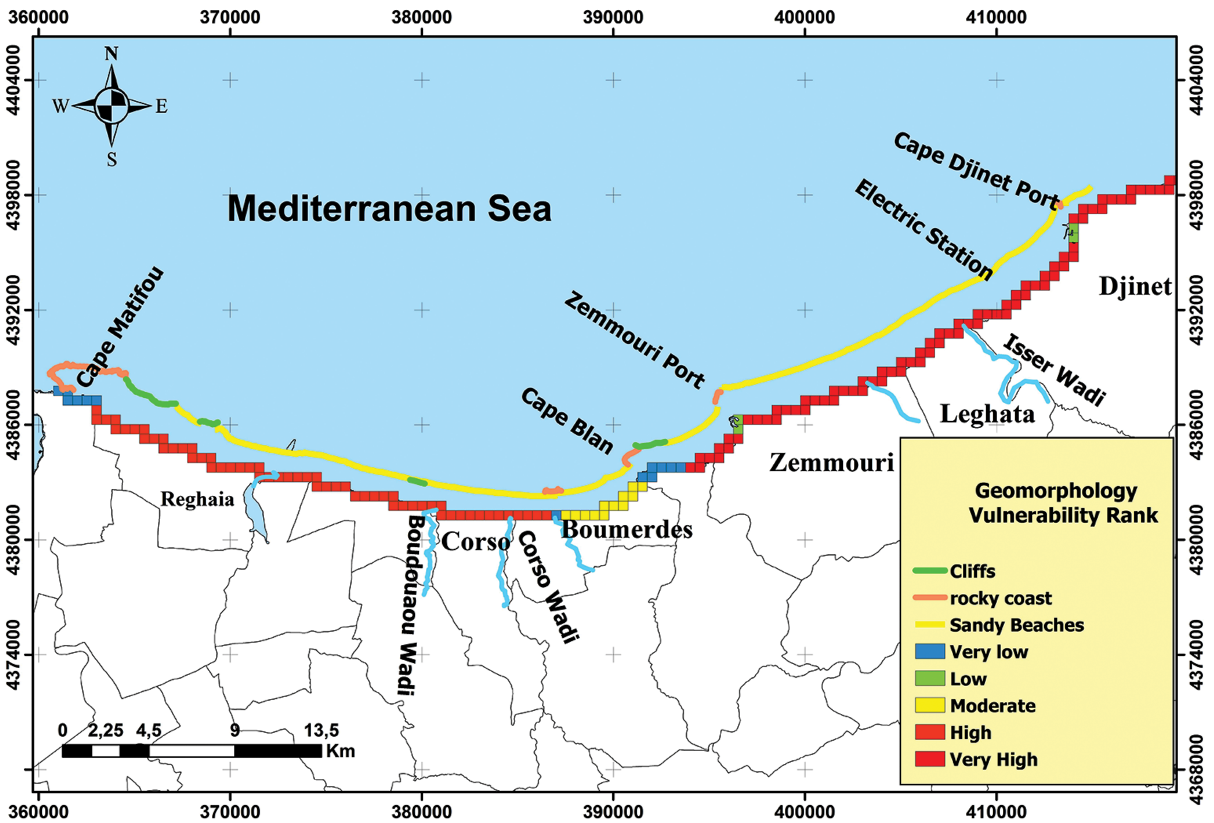

Fig. 5. Vulnerability map of the Zemmouri coast related to the geomorphology variable.

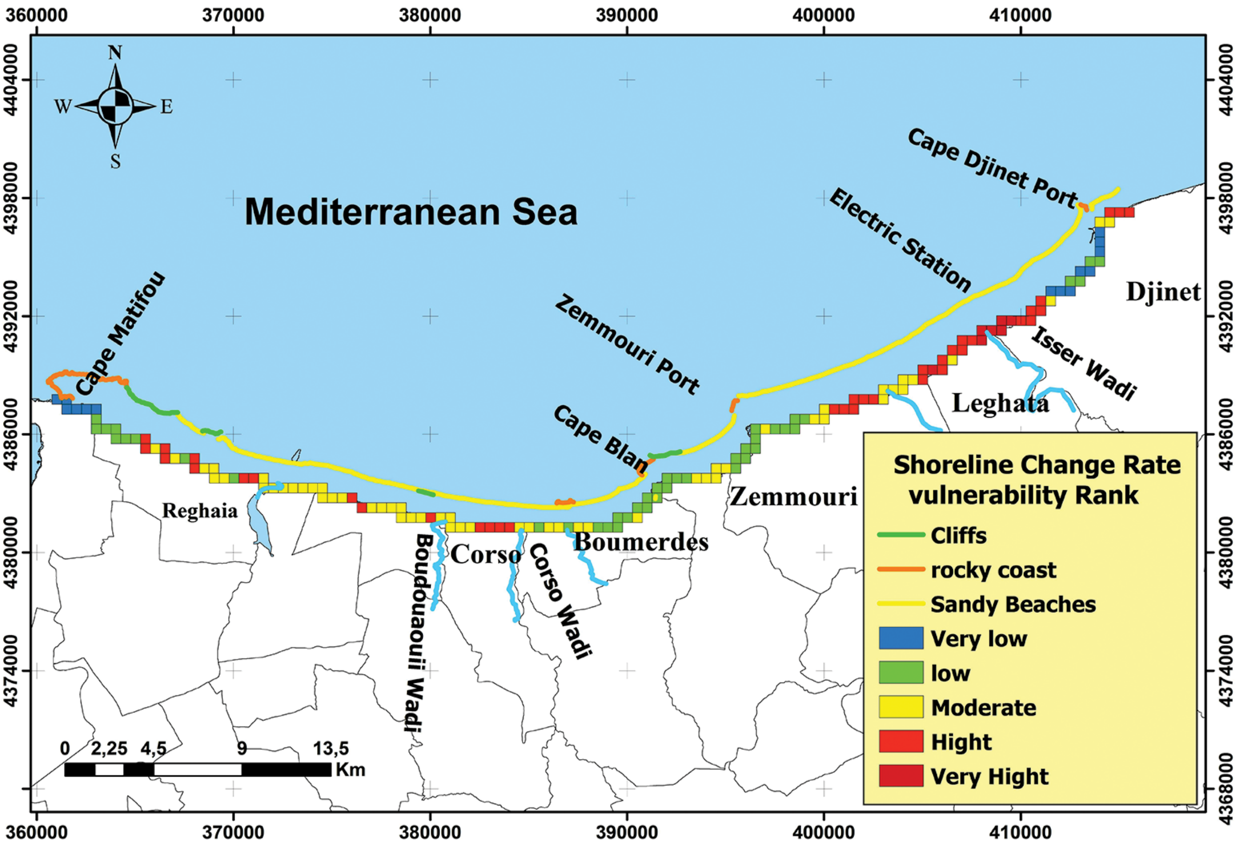

Fig. 6. Vulnerability map of the Zemmouri coast related to the variable Shoreline erosion/accretion rate.

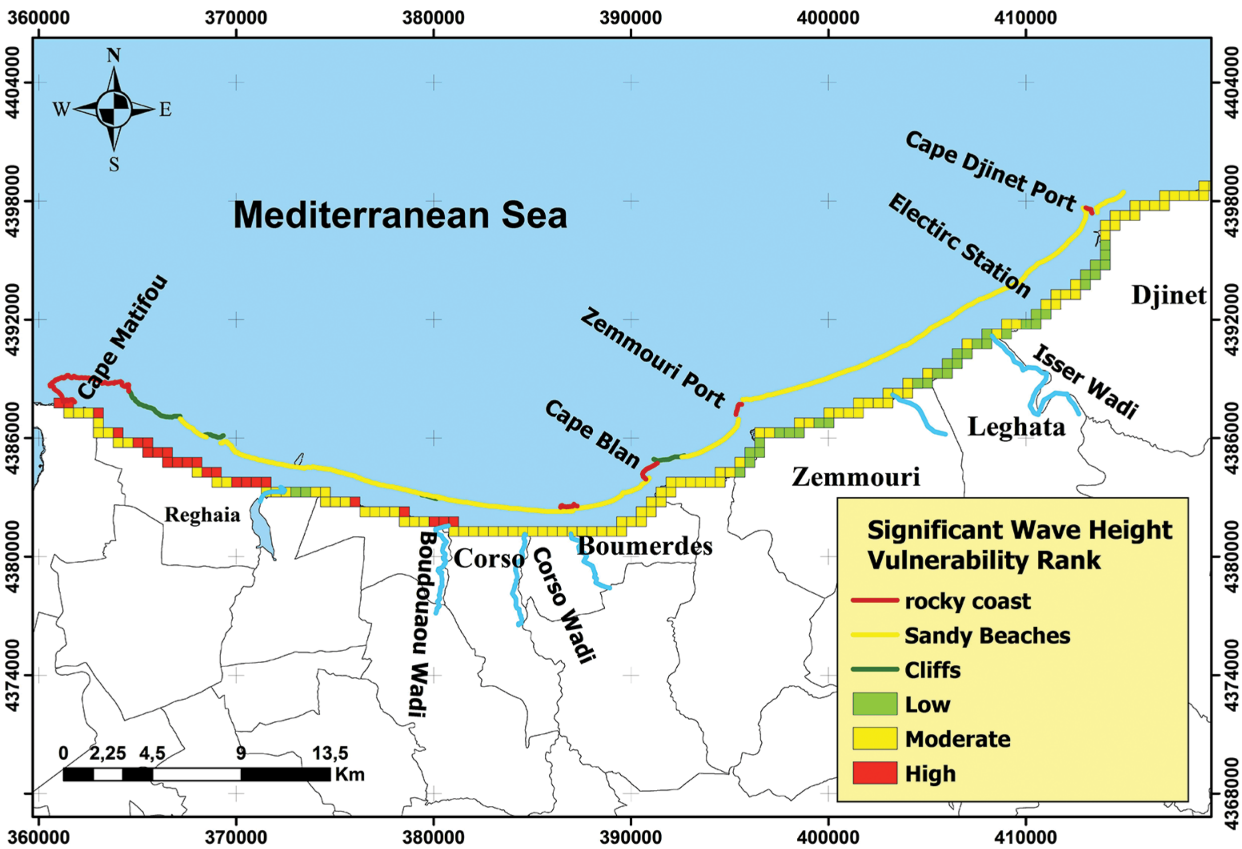

Fig. 7. Vulnerability map of the Zemmouri coast related to the significant wave height variable.

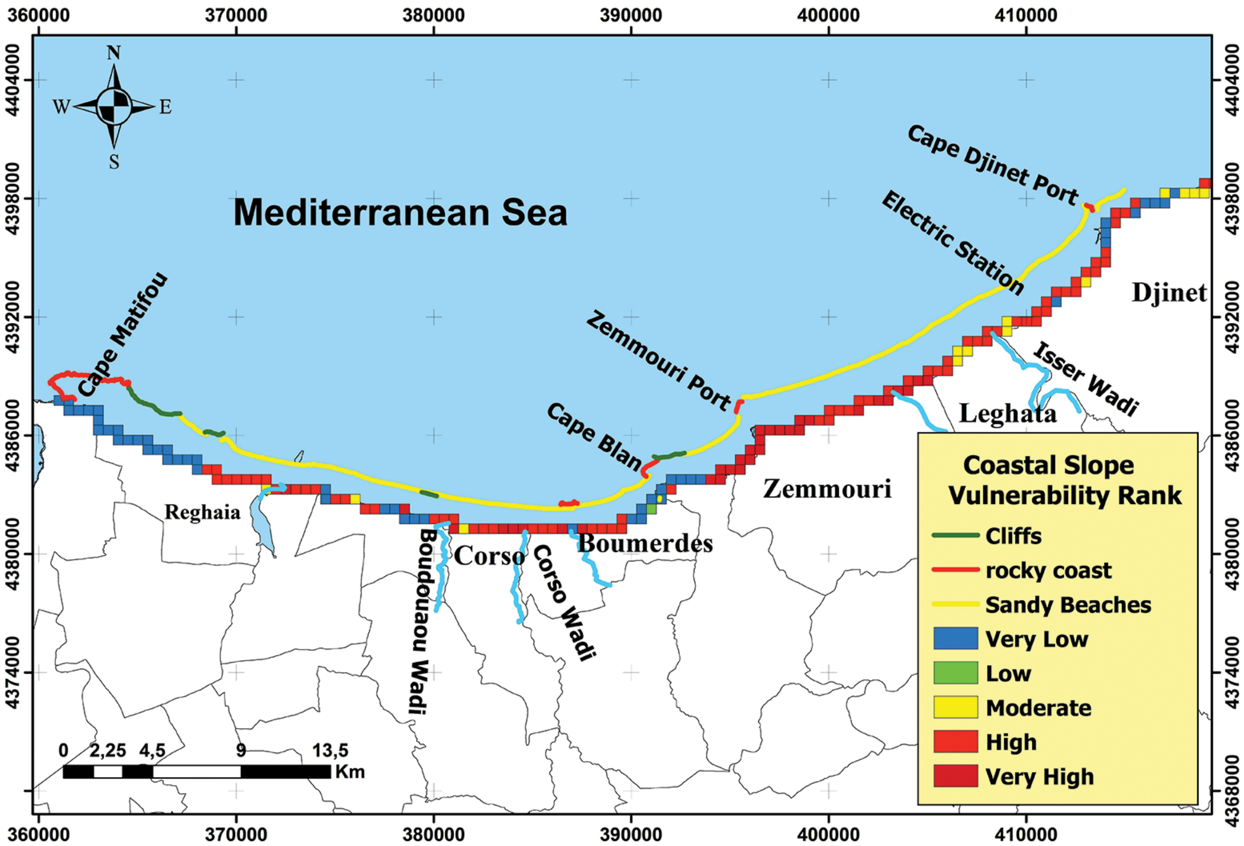

Fig. 8. Vulnerability map of the Zemmouri coast related to the coastal slope variable.

Only 5.63 km of the coastal strip is 10.10% represent a moderate vulnerability with a slope of 06 to 09% and are located at the dunes of Leghata and the hill of Corso. About 12 km of coastline have a low to very low vulnerability that is 23% with a slope greater than 12%, are located in Cape Matifou and the rocky coast of Boumerdès (Cape Blanc).

4.6. Tidal range variable

According to the measurements of the Hydrographic Service of the Naval Forces (S.H.F.N) in the Mediterranean, the tidal range is very low ± 0.34 meters. This value represents a very high vulnerability along the coast of Zemmouri; is influenced by a microtidal environment (Mouhoubi, 2022).

4.7. Physical coastal vulnerability index

The vulnerability of the Zemmouri coast to sea level rise is defined as follows: low, moderate, high and very high vulnerability. The CVI of the study area varies between 2.24 and 22.35 with an average value of 13.26 (Fig. 9).

The results of CVI show that 24.58 km of the coastal area is 52% high vulnerability to very high, covering the beaches of Réghaïa, Boumerdès, Corso and Boudouaou El Bahri and the east of Cape Djinet. About 15 km of the coast is 31%, records a moderate vulnerability, they are located between Ain Taya and Réghaïa, between Boumerdès and Cape Blanc and at the power plant.

On the other hand, the sectors present a low vulnerability to very low vulnerability, extends along 8 km or 16%, they are located in Cape Matifou, Cape Djinet, Cape Blanc, Black Rock.

The results obtained from CVI showed that the eastern sector of the coastline studied (from Cape Blanc to the Electrical Station) is more vulnerable than the central and western sectors. This variation in vulnerability is explained by the geomorphological and topographical characteristics of the area, in the form of beaches and unconsolidated dunes.

The eastern part is more vulnerable, it is in the form of sandy beaches on basaltic bedrock, and dunes with fine sands, characterized by a low slope, almost flat. In addition, it records high erosion since 1980 especially at the mouth of Oued Isser.

This phenomenon is due to the extraction of sand at the beaches of Zemmouri, Mandoura (Fig. 10a), at the dunes of Zemmouri and Figuier, and at the mouth of Oued Isser. On the other hand, the region extending between "the Electricity Station to the port of Cape Djinet East" is moderately vulnerable due to the presence of coastal protection works (groins, breakwaters) (Fig. 10b).

The central part between Cape Blanc and Lake Réghaïa is more or less vulnerable compared to the eastern region; this is explained by the geomorphological form of the area which presents detailed cliffs with beaches at the foot of the cliffs.

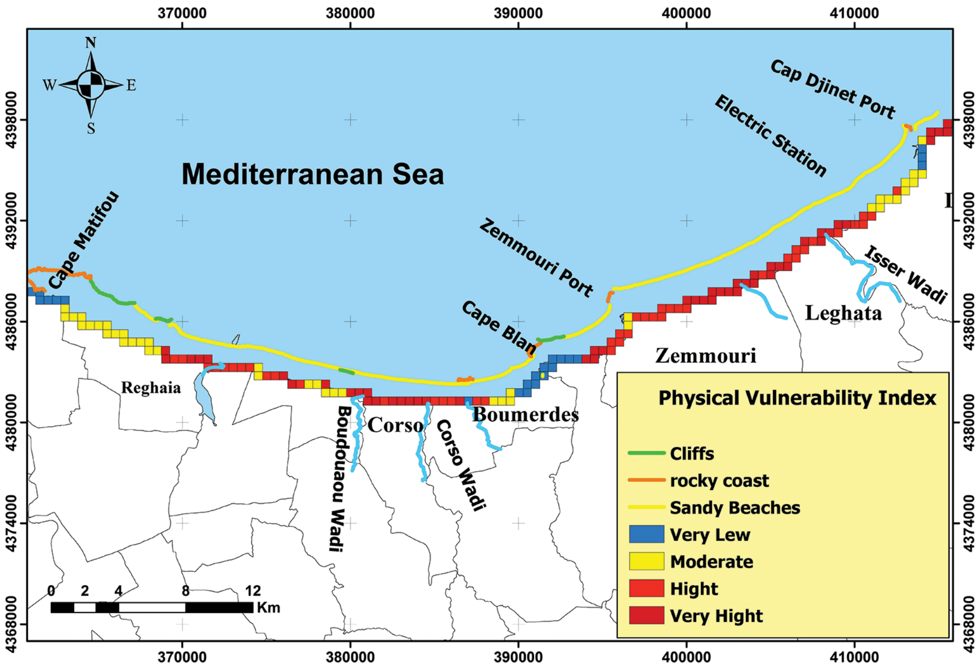

Fig. 9. Vulnerability map of the Zemmouri coast related to Coastal physical vulnerability index (CVIphy).

Fig. 10. Impact of anthropic activities on the coastal zone of Zemmouri: (**a**) illegal sand mining; (**b**)hard protection, breakwater, and groynes; (**c**) uncontrolled urbanization in the coastal zone; (**d**) electric station of Cape Djinet; (**e**) the tourist complex of Zemmouri; (**f**) Perturbation of the dune.

In this case, the risk of vulnerability is expressed by the effects of hydrodynamic agents, such as the NE direction swell considered the most erosive in this region, which evokes the demobilization of hydro sedimentary processes at the foot of the cliffs (cliffs of Boudouaou El Bahri, cliffs of corso) (Sallaye *et al.* 2018), presence of anthropic activities (anarchic urbanization) on the coastal zone (Fig. 10c) that disturb the morpho-hydrosedimentary processes of the coastal zone. Adding to this the extraction of sand at the mouth of the Oued Corso, and Oued Boudouaou El Bahri.

The western part between the lake of Réghaïa and Cape Matifou presents a more or less low vulnerability; this is explained by the geological formation of the area in the form of detailed cliffs with hard volcanic rocks.

4.8. The socio-economic vulnerability index

The evaluation of the socio-economic vulnerability (ICVsocio-economic) of the coast of Zemmouri permits us to represent graphically the coastal zones the most vulnerable to the sea level rise. For all the coast of Zemmouri, the values obtained of the index ICVSocio-economic vary between 23.33 and 60 with an Average value of 45.91. These results, which differ from one area to another, permit us to identify 03 classes of vulnerability (low, moderate, and high to very high vulnerability) (Fig. 11).

The first class of low vulnerability is extended over 5.4 km of coastline or 09% of the total coastal area (Fig.11), they present at the level of Cape Blanc, Black Rock, port Zemmouri, beach of figuier between Cape Blanc and the plain of Oued Corso and Boudouaou El Bahri.

The second class of moderate vulnerability to sea level rise extends over 34 km of coastline or 19%, covering the plain of Isser Valley, Cape Matifou, the part between Oued Boudouaou and Oued Corso.

The third class of high to very high vulnerability, extends over 30 km along the coast or 36%, affecting the sandy coasts in general like Boumerdes center, power plant of Cape Djinet, port of Cape Djinet and cliff Ain Taya and the edge of the retaining wall of Boudouaou El Bahri and a large part of coastal plain including classified sites (Lake Reghaïa, dunes of Zemmouri), and the coastal band of Leghata.

The results of CVIeco have shown that the majority of the coastal area is characterized by a more or less high vulnerability, this is explained by the presence of a fishing port of Zemmouri and Cape Djinet, the presence of the production unit (Power Plant of Cape Djinet) (Fig. 10d), the establishments of education and health, the national roads and the roads of Wilaya and the tourist complexes at the edge of the sea like the tourist complex of Zemmouri (Fig. 10e). In the last years, these zones underwent a high urbanization after the period of black decade, in addition these zones had a free land, as well as the non-application of the coastal law 02-02-2002 "which prohibits the construction in the band of 300m". These factors explain the degradation of the coastal area, the disturbance of the dunes (Fig. 10.f) and the presence of many structures for protection against the action of the sea in the coastal strip.

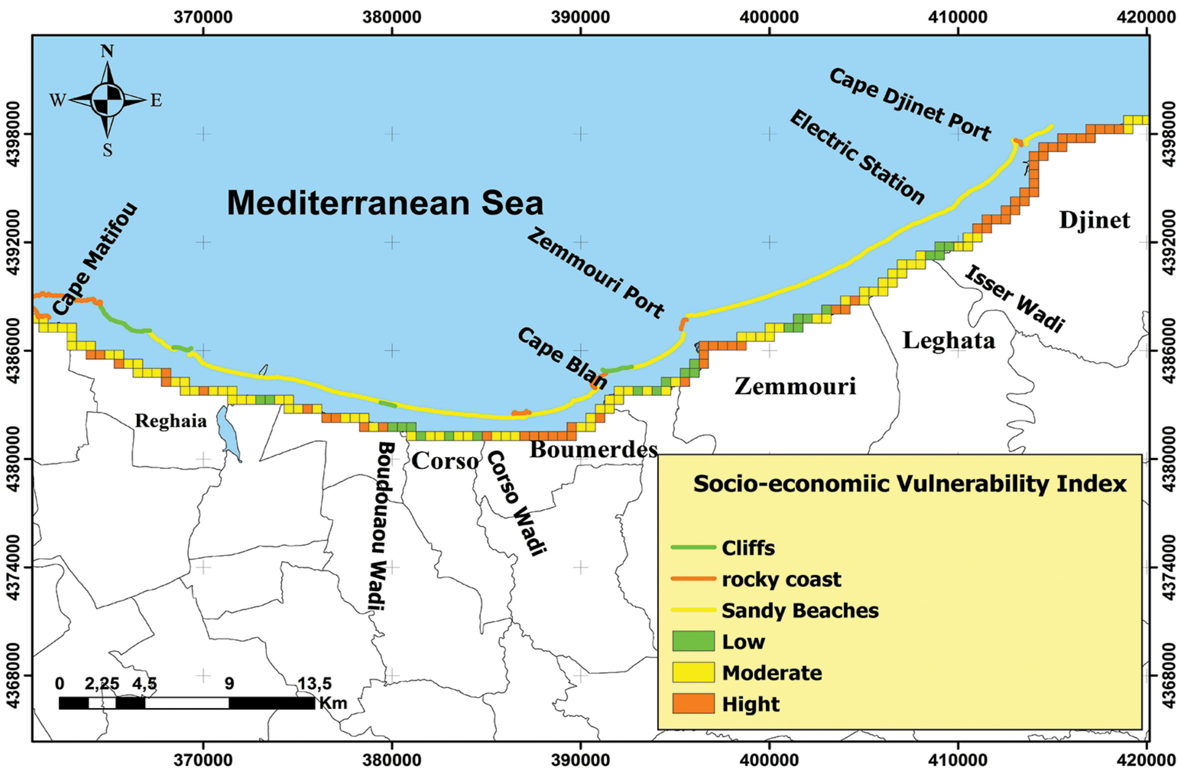

Fig. 11. Vulnerability map of the Zemmouri coast related to Socio-economic vulnerability index.

On the other hand, the other areas are characterized by a low to medium vulnerability; this is explained by the presence of agricultural land, virgin land in the region of Zemmouri East, a rocky coastline in Cape Blanc and Cape Matifou.

5. CONCLUSION

The study of the evaluation of the vulnerability of the bay of Zemmouri allowed to define and identify the most vulnerable zones to the phenomena of coastal erosion and marine flooding. The results of the index of physical coastal vulnerability show that 24.58 km of the coastline of Zemmouri or 52%, has a high to very high vulnerability due to the sea level rise induced by global warming of the atmosphere, covering the beaches of Réghaïa, Boumerdès, Corso and Zemmouri El Bahri and east of Cape Djinet. On the other hand, Cape Matifou and Cape Blanc are characterized by a very low vulnerability.

The evaluation of the vulnerability of the bay of Zemmouri to the risk of sea level rise is essential for the highlighting of the integrated management of the coastal zones (GIZC), for that the combination of two methods of Gournitz and MClaurang is pertinent to identify the zones most vulnerable to the phenomena of coastal erosion and the marine flooding. These approaches can be used as a decision-making tool by proposing measures for adaptation to climate change, particularly to the phenomenon of sea level rise, or by conducting similar studies for the entire national territory or by taking into consideration the problems related to climate change in all planning and development tools (PDAU, POS). The Algerian government should be more interested in adaptation as a priority to respond to the needs of the population, particularly in the natural hazards management, and forest management.

REFERENCES

Amarni, N., Fernane, L., Belkessa, R. (2021). Evaluation de la vulnérabilité côtière du littoral centre ouest algérien (Cherchell), sous l'angle de la géomatique. *GeoEcoMarina*, **27**.

Amuzu, J., Jallow, B.P., Kabo-Bah, A.T., Yaffa, S. (2018). The Climate Change Vulnerability and Risk Management Matrix for the Coastal Zone of The Gambia. *Hydrology*, **5**: 14.

Bernstein, L., Bosch, P., Canziani, O., Chen, Z., Christ, R., Riahi, K. (2008). IPCC, 2007: climate change 2007: synthesis report. Report, IPCC.

Cazenave, M. A., Durand, M. P., Abadie, M. S. (2016). Les conséquences de l'élévation du niveau marin pour le recul du trait de côte. Université Paris I Panthéon Sorbonne - Laboratoire de Géographie Physique - BRGM.

Denner, K., Phillips, M.R., Jenkins, R.E., Thomas, T. (2015). A coastal vulnerability and environmental risk assessment of Loughor Estuary, South Wales. *Ocean & Coastal Management*, **116**: 478-490.

Djouder, F., Boutiba, M. (2017). Vulnerability assessment of coastal areas to sea level rise from the physical and socioeconomic parameters : Case of the Gulf Coast of Bejaia, Algeria. *Arabian Journal of Geosciences*, **10**(*14*): 299. https://doi.org/10.1007/s12517-017-3062-5

DHI (2014). Mike 21 Spectral Wave Module Scientific Documentation, Report, DHI.

Esmail, M., Mahmod, W.E., Fath, H. (2019). Assessment and prediction of shoreline change using multi-temporal satellite images and statistics: Case study of Damietta coast, Egypt. *Applied Ocean Research*, **82**: 274-282.

Domínguez, L., Anfuso, G., Gracia, F. (2005). Vulnerability assessment of a retreating coast in SW Spain. *Environmental Geology*, **47**: 1037-1044.

Gornitz, V., White, T.W., Cushman, R.M. (1991). Vulnerability of the US to future sea level rise, Report, Oak Ridge National Lab., TN (USA)

Gornitz, V.M., Daniels, R.C., White, T.W., Birdwell, K.R. (1994). The development of a coastal risk assessment database: vulnerability to sea-level rise in the US Southeast. *Journal of Coastal Research*: 327-338.

Hadef, R., Labii, B. (2017). Evaluation de la vulnerabilite socio-economique de la zone cotiere de Skikda. *Sciences & Technologie. D, Sciences de la terre*: 119-130.

Hammar-Klose, E.S., Thieler, E.R. (2001). Coastal vulnerability to sea-level rise: a preliminary database for the US Atlantic, Pacific, and Gulf of Mexico coasts. US Geological Survey.

Hegde, A.V., Reju, V.R. (2007). Development of Coastal Vulnerability Index for Mangalore Coast, India. *Journal of Coastal Research*: 1106-1111.

Hereher, M.E. (2016). Vulnerability assessment of the Saudi Arabian Red Sea coast to climate change. *Environmental Earth Sciences*, **75**: 30.

Hichour, S., Essamoud, R. (2011). Distribution des sédiments en milieu côtier de la région de Casablanca – Dar Bou Azza (Maroc). **2**: 185-188.

Hossain, S. A., Mondal, I., Thakur, S., Fadhil Al-Quraishi, A. M. (2022). Coastal vulnerability assessment of India's Purba Medinipur-Balasore coastal stretch : A comparative study using empirical models. *International Journal of Disaster Risk Reduction*, **77**, 103065. https://doi.org/10.1016/j.ijdrr.2022.103065

Lins-de-Barros, F.M. (2017) Integrated coastal vulnerability assessment: A methodology for coastal cities management integrating socioeconomic, physical and environmental dimensions - Case study of Região dos Lagos, Rio de Janeiro, Brazil. *Ocean & Coastal Management*, **149**: 1-11.

McLaughlin, S., McKenna, J., Cooper, J. (2002) Socio-economic data in coastal vulnerability indices: constraints and opportunities. *Journal of Coastal Research*, **36**: 487-497.

McLaughlin, S., Cooper, J.A.G. (2010). A multi-scale coastal vulnerability index: A tool for coastal managers? *Environmental Hazards*, **9**: 233-248.

Meyssignac, B. (2012). La variabilité régionale du niveau de la mer, Université de Toulouse, Université Toulouse III-Paul Sabatier

Mouhoubi, N. el I.S. (2022). Vulnérabilités du littoral aux risques côtiers dans la baie de Zemmouri [Thèse de Doctorat]. École nationale superieure des sciences de la mer et de l'amenagement du littoral.

Niazi, S. (2007). Evaluation des impacts des changements climatiques et de l'élévation du niveau de la mer sur le littoral de Tétouan (Méditerranée occidentale du Maroc): Vulnérabilité et Adaptation, Thèse de doctorat en Changements Climatiques et Zones Côtières : Géosciences de l'Environnement, Mohammed VAGDAL Faculté des sciences, 296.

Otmani, H., Belkessa, R., Bengoufa, S., Boukhediche, W., Djerrai, N., Abbad, K. (2020). Assessment of shoreline dynamics on the Eastern Coast of Algiers (Algeria) : A spatiotemporal analysis using in situ measurements and geospatial tools. *Arabian Journal of Geosciences*, **13**(*3*): 124. https://doi.org/10.1007/s12517-020-5069-6

Ku, H., Kim, T., Song, Y. (2021). Coastal vulnerability assessment of sea-level rise associated with typhoon-induced surges in South Korea. *Ocean & Coastal Management*, **213**, 105884. https://doi.org/10.1016/j.ocecoaman.2021.105884

Rabehi, W., Guerfi, M., Mahi, H. (2018). Cartographie de la vulnérabilité des communes de la baie d'Alger. *Méditerranée. Revue géographique des pays méditerranéens / Journal of Mediterranean geography*. https://doi.org/10.4000/mediterranee.8625

Rabehi, W., Guerfi, M., Habib, M. (2020). La baie d'Alger, un espace côtier prisé, entre pressions d'urbanisation et gouvernance territoriale. *Geo-Eco-Marina*, **25**: 113-130.

Sallaye, M., Mezouar, K., Salem Cherif, Y., Dahmani, A.E.A. (2018). Morphological evolution of center Boumerdes in Zemmouri Bay (Algeria) from 1922 to 2017. *Arabian Journal of Geosciences*, **11**: 602.

Sallaye, M. (2021). Processus mis en jeu dans l'évolution morpho-dynamique de la baie de Zemmouri : Modélisation hydro-sédimentaire et cinématique du trait de côte. [Thèse de Doctorat]. Ecole nationale superieure des sciences de la mer et de l'amenagement du littoral.

Samai, S., Idres, M., Ouyed, M., Bourmatte, A., Boughacha, M. S., Bezzeghoud, M., Borges, J. F. (2017). A structural scheme proposal derived from geophysical data in the epicentral area of the Boumerdes (Algeria) earthquake of May 21, 2003. *Journal of African Earth Sciences*, **133**: 138-147. https://doi.org/10.1016/j.jafrearsci.2017.05.018

Sudha Rani, N. N. V., Satyanarayana, A. N. V., Bhaskaran, P. K. (2015). Coastal vulnerability assessment studies over India : A review. *Natural Hazards*, **77**(*1*): 405-428. https://doi.org/10.1007/s11069-015-1597-x

Team, C.W., Pachauri, R.K., Meyer, L. (2014). IPCC, 2014: climate change 2014: synthesis report. Contribution of Working Groups I, Report

von Schuckmann, K., Le Traon, P.-Y., Smith, N., Pascual, A., Brasseur, P., Fennel, K., Djavidnia, S., Aaboe, S., Fanjul, E.A., Autret, E. (2018). Copernicus marine service ocean state report. *Journal of Operational Oceanography*, **11**: S1-S142.

Yin, J., Yin, Z., Wang, J., Xu, S. (2012). National assessment of coastal vulnerability to sea-level rise for the Chinese coast. *Journal of Coastal Conservation*, **16**: 123-133.