



Assessment of the coastal environmental status in Western Algeria: Mostaganem case study

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Abstract

Mostaganem Coastal environments in Western Algeria constitute a dynamic environment influenced by both natural and anthropogenic continental inputs and controlled by the hydrodynamic network, climatic factors, and anthropic pressures. The geological structure individualizes rocky massifs, separated by valleys, with rivers flowing into the sea. The high cliffs that generally line Mostaganem coast are naturally exposed to hydric, marine, and wind erosion. The hydrographic network leading to the sea includes the Cheliff river (with a length of 800 kilometers). This network provides the marine environment with terrigenous inputs. Rivers are collectors of all pollutants from human, agricultural and industrial activities. Some coastal zones are, by their geography and geomorphology, a receptor where are trapped water bodies loaded with exogenous mineral and /or organic matter resulted from the anthropic activities. The coastal areas most affected by water pollution, which are neighboring industrial ports. These areas are the receptacle for various sources of pollution, including heavy metals, hydrocarbons, and organic compounds... etc. The residence time of these water bodies is related to the sea current's intensity which controls the distribution and dilution of dissolved substances that can unbalance the ecosystem. The aim of this paper is the characterization of the Mostaganem coast status in Western Algeria and the assessment of the land-sea interface -based on “Driver-Pressures-State-Impact-Responses, DPSIR” approach.

Keywords: coastal environment health, climate change, land-sea interface, Western Algeria, DPSIR.

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1. Introduction

The Algerian coastline stretches for 1622 kilometers. They represent a fragile and constantly threatened ecosystem that is deteriorating due to the concentration of people, economic activities, and infrastructure. Mostaganem coast is in Western Algeria, is an important socioeconomic province. It represents around 7.7 % (124 kilometers) of the Algerian national coastline [1]. The functioning of the coastal marine ecosystem depends on the influence and interaction of two different environments, the marine environment, and the continent [2]. Along the Algerian coast, the circulation of the Atlantic water (Algerian current) leaves an indelible mark on the coastal waters [3]. It induces a characteristic coastal dynamic that ensures the renewal of bay waters and contributes to the undeniable determination of trophic fertility levels [4]. The influence of the sub-aerial environment depends on the quantity and the quality of these contributions. These are themselves concerning the natural and anthropogenic conditions of the catchment areas of the coastal fringe [5, 6].

2. Climate change

2.1. Changes in Temperatures and rainfall

The climate in this region is Mediterranean, hot summer and mild winter, with a pronounced dry season from mid-June to mid-September, while October to December is the wettest. Rainfall distribution between the wet months of 2010 (rainfall of 295 mm, an average temperature of 18.7 °C) showed a significant difference from average climate conditions at western Algeria [7]. Taibi *et al.* (2015) [8] found a significant relationship between the monthly rainfall in northwestern Algeria including the Cheliff basin and the MO index which represents the regional atmospheric circulation and characterizes the Mediterranean basin (Figure 1).

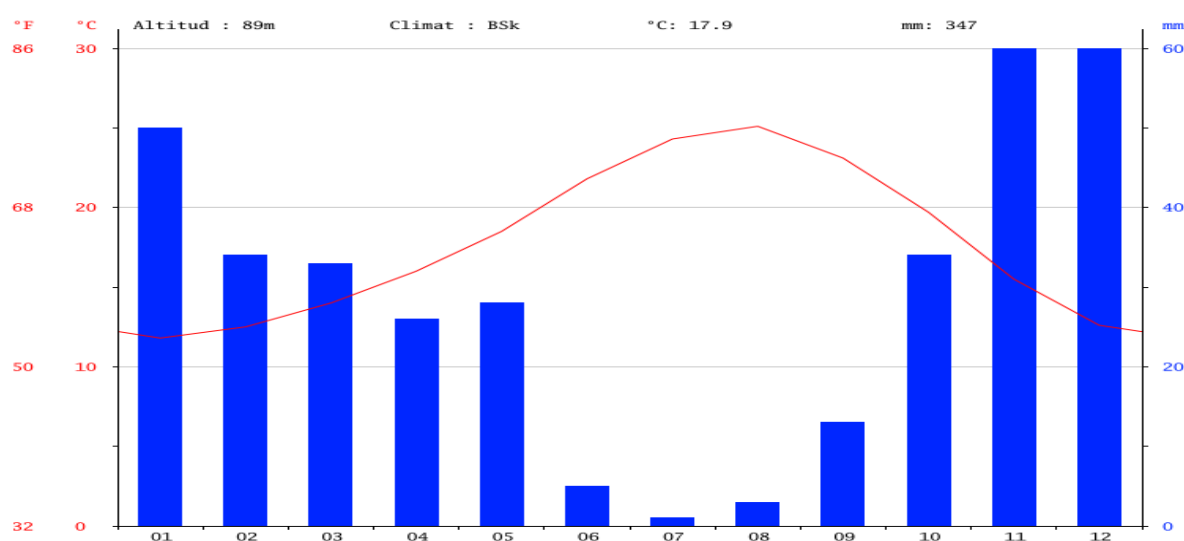


Figure 1. Bioclimatic diagram of Mostaganem (Source: <https://fr.climate-data.org>)

2.2. Hydric Sedimentation

Runoff coefficients have increased significantly over the last decade from upstream to downstream of the Cheliff Basin, despite a marked decrease in precipitation [9]. The evolution in the same direction of the impact of human activities on flow, erosion, and environmental degradation due to discharges annual from urban wastewater and industrial, which can impact directly the surface water quality of sub-basins, dams, and estuaries water quality. Erosion is very important in the Cheliff watershed [9, 10]. The erosion rates specific reach 4000 t / km² / year on the chain of coastal Dahra. According to the MATE (2002) [11], Floods of the city of Mostaganem caused by Ain Safra River in November 1900 with discharges of 25 m³/s, November 1927 with discharges of 35 m³/s. While in Cheliff River in October 2000 and 2001, December 2010 and 2017, were recorded the most catastrophic windstorm and flood event in recent years, causing human deaths and damage in Mostaganem. (Figure 2).



Figure 2. Flood of Cheliff river in December 2017.

2.3 Land-Coastal dynamic

According to Badji *et al.* (2015) [12], on land, the Mostaganem area (Figure 3) is considered part of the Tellian area. The outcrops consist of Miocene and Quaternary sediments, composed of marl, limestone, sandstone, and gypsum, well known in the Chellif basin in the south of Mostaganem.

In the sea, the Mostaganem area (Figure 3) is considered part of the Gulf of Arzew. The current is maximum on the surface and decreases in depth. The current of the Gulf of Arzew is oriented mainly towards the east. According to Grimes *et al.* (2003) [1], calculated speeds are 30 to 40 km from the coast and 50 m depth, reaching 20 to 30 cm/sec at 300 m depth.

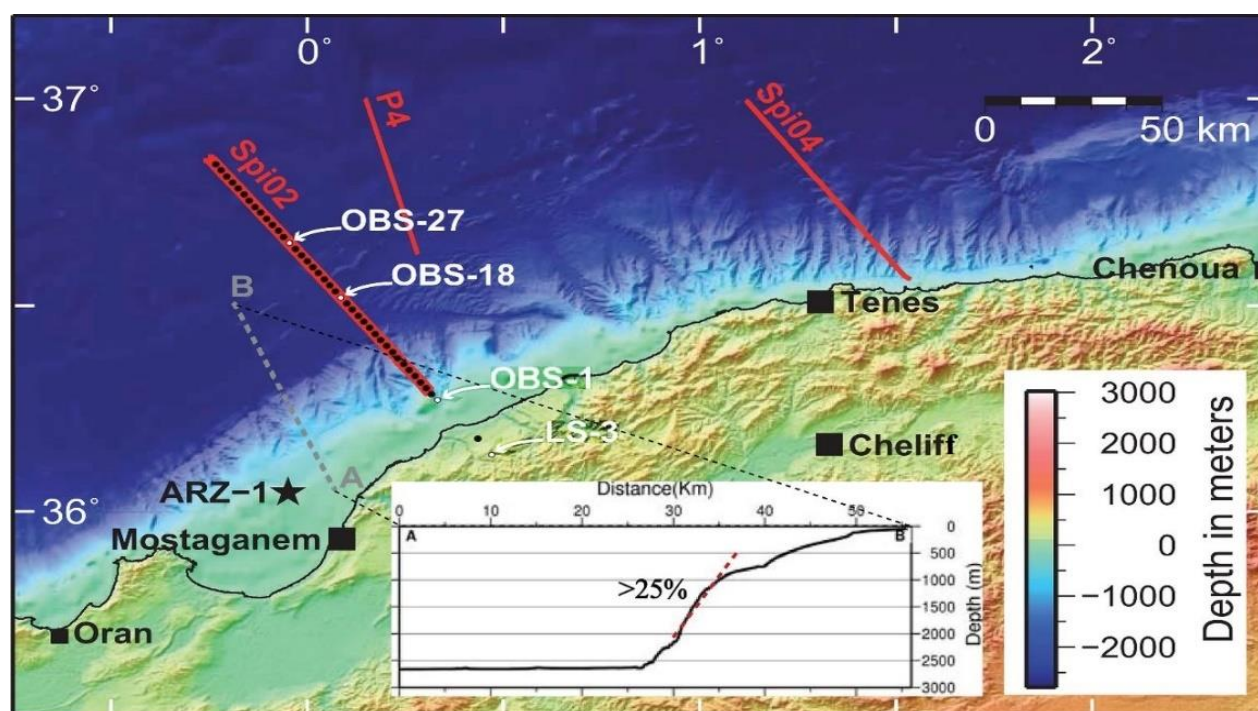


Figure 3. Land-coastal dynamic [11].

This current generates an opposite circulation, its speed is very low, it can increase when the winds blow from the North. They are of the Atlantic origin and under the influence of the flow coming from the strait of Gibraltar which dominates the sea of the region of Mostaganem. This current (Algerian current) flows along the Algerian coast with a width of 50 km. becomes apparent with the creation of cyclonic and anticyclonic eddies associating upwellings. These turbulent structures cause an important mix of the Atlantic and Mediterranean waters.

2.4. Geomorphology

The combination of various factors (tectonics, lithology, hydrodynamics) created the main forms and current formations. The 124 kilometers of Mostaganem coast are largely made up of rocky reliefs, of - more or less- elevation concerning the sea level. Rocky shores are more common in the west than in the east [1]. They are observed, especially in the western part of the Mostaganem coast (Stidia). However, to the benefit of the sea cliffs to the east of the coast, fuelled more particularly by the contributions of the Cheliff basin [13]. The Mostaganem continental margin is variable in both size and shape. In the west, the continental shelf is relatively large, with gentle slopes.

To the east, there is a slight increase in the slope. The lands forming the shoreline are very unstable because of their sensitivity to water and wind erosion (soft rocks) that result from an imbalance in the dynamic interactions between climate, soil, vegetation, and human [13], as well as natural factors (degraded forests and relatively low vegetation cover).

Generally, pure vases occupy most of the Gulf of Arzew and thus constitute an immense mudflat that extends from the shallows towards the open sea [1]. This mudflat is the consequence of the contributions of fine elements of the Cheliff basin [13]. Locally, the coastal strip is sandy and stony formations with sandstone and limestone elements. The coastal forms of the wilaya of Mostaganem are expressed by the existence of large and beautiful open beaches, especially around the main areas of estuaries of Cheliff and Mactaa rivers. The geomorphological aspect is reflected by the high presence of cliffs, subject to marine erosion, thus participating in the feeding of the adjacent beaches (Figure 4). Marine processes, the most influential of which is hydrodynamic, which accelerates erosion in areas of high marine energy concentration and promotes accumulation in less turbulent sites [14].

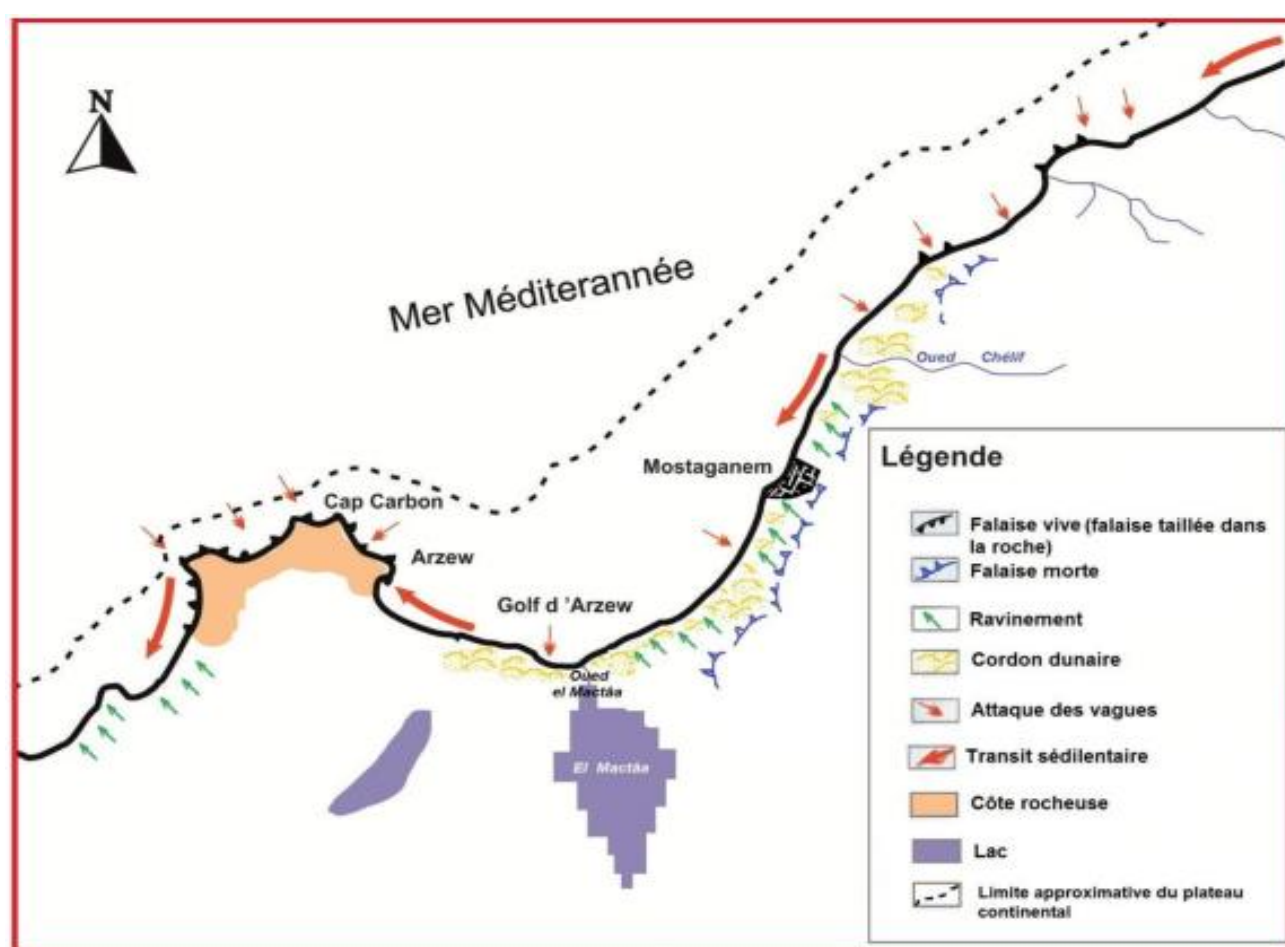


Figure 4. Morphological sketch of the Gulf of Arzew (Aggoun, 2013).

3. Anthropic pressures

3.1. Population

In 1998 and 2008 Mostaganem is ranked among the top cities with more than 100,000 inhabitants. Number of the coastal rural municipalities is 10 (Abdelmalek Ramdane, Achaacha, Fornaka, Hadjadj,

Khadra, Mazagran, Ouled Boughalem, Sidi Lakhdar, Stidia). The 11 coastal urban agglomerations of the wilaya of Mostaganem are distributed as follows: 7 agglomerations of 5 000 to 10 000 inhabitants, 3 agglomerations of 10 000 to 200 000 inhabitants, and 1 agglomeration of 100 000 to 300 000 inhabitants [15]. This concentration of the population and the activities on the coastal fringe thus leads to strong tensions in the use of the water resource (Figure 5, Table 1). Besides, the population discards thousands of tons of solid urban waste, evacuated to 9 wild dumps located on the coastal strip.

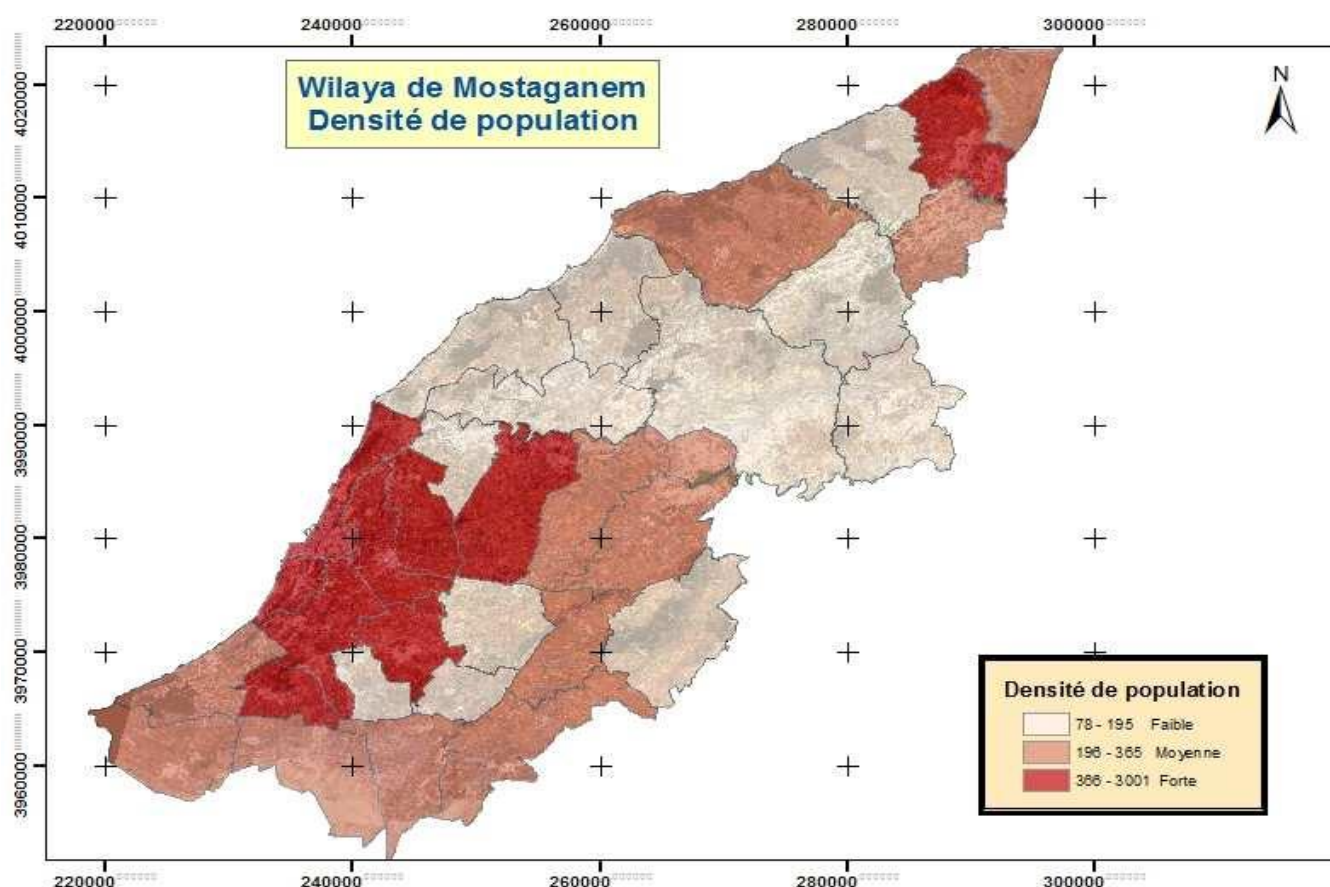


Figure 5. Population density of the wilaya of Mostaganem (Source: Environmental Directorate of Mostaganem)

3.2 Urbanization

Coastal linear urbanization threatening the 300 m zone: 254 ha of the urbanized area encroaches on the 300 m bands. Also, 18 km of coastline of the coastal zone are already urbanized in Mostaganem (Figure 6). *The longitudinal extension of the urbanized perimeter beyond 3 km:* Agglomerations in the coastal domain exceeded 15 km (Figure 6).

Uncontrolled expansion of the coastal town of Mostaganem to the detriment of agricultural land and natural areas: The agglomeration of Mostaganem saw its surface triple between 1962 and 2004 to reach 2000 ha. Its urbanization is characterized by an overflow on the new coastal sites of El H'chem, Sayada, and Salamandre, also involving agglomerations in Mazagran, Kharouba, and Hassi Mameche.

Extraction of sand: destined for urbanization, generated intense erosion notably in Sidi Lakhdar (300.000 T/year).

Table 1. The DPSIR framework is exemplified by authors using population growth as a driver. Values are for Northwestern Algeria (Source: Environmental Directorate of Mostaganem).

Driver	Pressure	State	Impact	Response
Population growth	Increased water extraction (upstream)	Deterioration of water quality	Community changes	Water conservation management
	Increased wastewater release (downstream)	Changes in water level	Pollution	Implementation of wastewater treatment
	Higher loading of pollutants	Variation in river discharge	Sediment accumulation	
		Enhanced turbidity	Reduced infiltration	
Increase of 1000 inhabitants	Water extraction (170 liters per inhabitant)	Groundwater level falls by 170 liters per inhabitant	Change in landed value of local commercial fishing	Water savings (extraction falls from 170 to 120 liters per inhabitant)
	Change in BOD (60 g BOD / inhabitant* day)	Coastal water receives 170 liters*60 kg BOD/ inhabitant* day)	Change in recreational value to bathing beaches	- Wastewater treatment leads to 70% uptake of BOD - BOD release decrease (150*60*0,3 g BOD/day)
	Change in N (17 g N / inhabitant* day)	Coastal water receives 170 liters*17 kg N/ inhabitant* day)	Phytoplankton community change	- Wastewater treatment leads to 80% uptake of N - N release decrease (150*17*0,3 g N/day)
	Change in P (4 g P / inhabitant* day)	Coastal water receives 170 liters*4 kg P/ inhabitant* day)	Phytoplankton community change	- Wastewater treatment leads to 80% uptake of P - P release decrease (150*4*0,3 g P/day)
	Change in SS (70 g SS / inhabitant* day)	Coastal water receives 170 liters*70 kg SS/inhabitant* day)	Phytoplankton community change	- Wastewater treatment leads to 80% uptake of SS - SS release decrease (150*70*0,3 g SS/day)

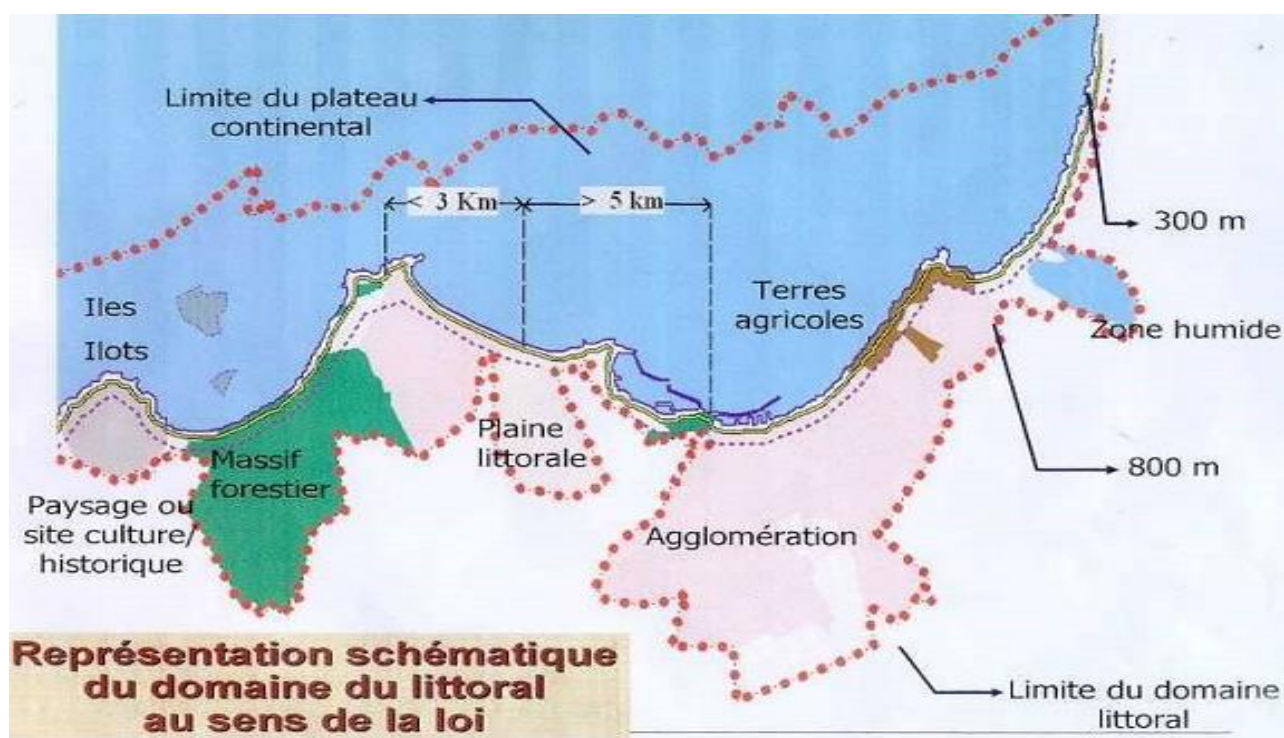


Figure 6. Schematic representation of the coastal zone in the sense of Algerian law (Source: Environmental Directorate of Mostaganem)

3.3 Industry

88 industrial units are located near the coast of the wilaya of Mostaganem. The main industrial branches concern chemicals, building materials, mining products, and agro-food industries (Table 2).

Table 2. Physico-chemical characteristics of liquid industrial discharges at Mostaganem coast [16].

Units	pH	SS	BOD	COD
GIPLAIT	6,72	726	6800	12300
MEGISSERIE	8,70	8698	6320	10400
SOACHLORE	11,08	602	45	180
DAHRA	8,66	764	3200	9410
ENASUCRE	9,83	2042	2800	6600

3.4 Agriculture

Mostaganem has more than 14000 ha of agricultural land (Figure 7), is considered the most fertilizer consuming province in Algeria with an average of 8375 T.

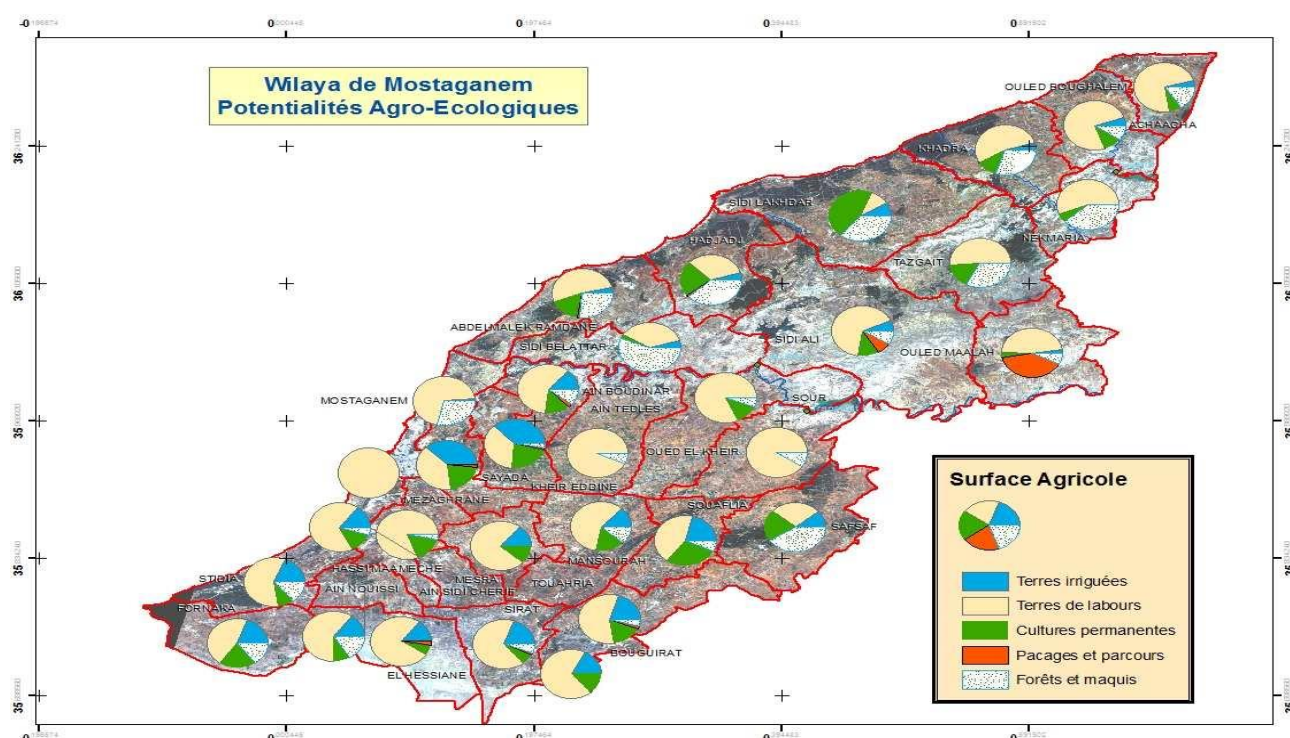


Figure 7. Agro-ecological potentialities of the wilaya of Mostaganem (Source: Environmental Directorate of Mostaganem)

3.5 Fishing

Intensive fishing in 3 nautical miles. During the period from 2001 to the year 2008 (Figure 8), there was intense pelagic fishing (more than 14,000 tons) compared to demersal landings, whereas during the two years 2009 and 2010, there was a decline in fish production (Figure 8).

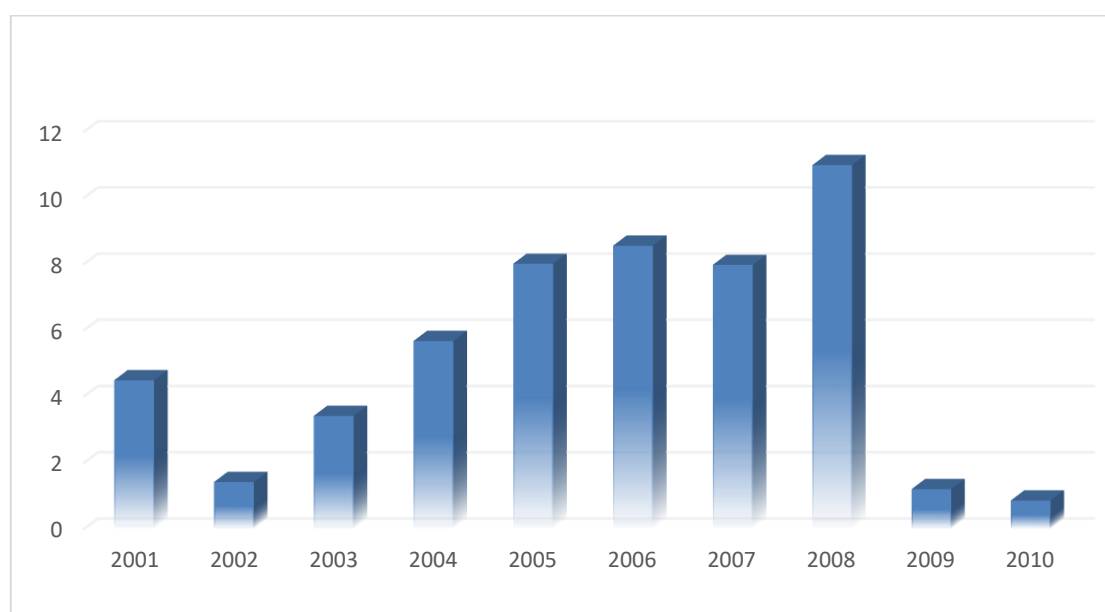


Figure 8. Pelagic landings / Demersal landings [14]

Agglomeration wastewater is discharged directly into basins for both types of ports, commercial, and fishing ports (Figure 9 and Figure 10).



Figure 9. Agglomeration wastewater discharged into the harbor basin of Mostaganem (Photo by Kies, 2018)



Figure 10. Water pollution of the harbor basin of Mostaganem (Photo by Kies, 2018)

3.6 Tourism seaside

Intensification of activities related to seaside tourism ([Figures 11, 12, and 13](#)), requiring the proximity of sandy shores.

The wilaya of Mostaganem disposing of, 50 unsustainable tourist units and more than 8783 beds. A visit to the beaches is estimated at 8.6 million visitors for the Mostaganem wilaya registered in 2011. Among wilayas that have the largest number of Tourist extension area (Zone d'extension Touristique "ZET"), decrees are the wilaya (province) of Mostaganem with 16 ZET, a surface of 4724.8 ha, an occupancy rate of 64.49 %, and a remaining area of 1677,4 ha (Figure 11). Mostaganem has 10 classified sites and monuments, with a classification rate of 20%.

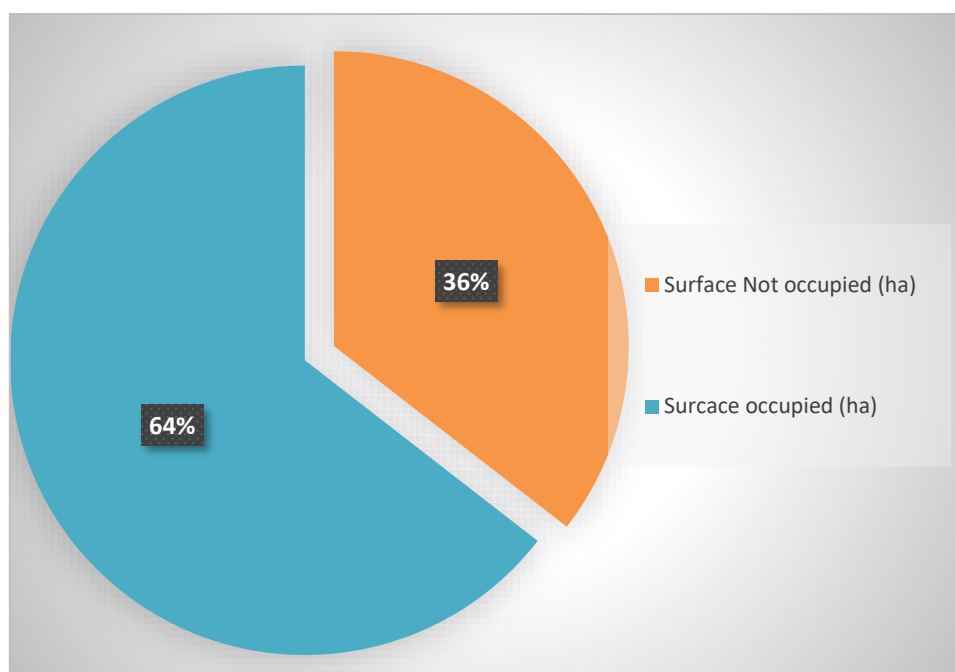


Figure 11. The occupancy rate of tourism seaside (Source: Tourism Directorate of Mostaganem)



Figure 12. Coastal linear urbanization in Sidi El Majdoub threatening the 300 m zone (Photo by Kies, 2018)



Figure 13. Disturbance of coastal water transparency in Sidi Majdoub (Photo by Kies, 2018)

2.7 Hydrographic changes

In terms of hydrography, Mostaganem is bounded by two (02) regions: *i*) the East region, which is crossed by a network of wadis (Kramis river, Roumane river, El Abid river, Seddaoua and Zerrifa rivers), *ii*) the West region which is crossed, (except Cheliff and Mactaa rivers), by a network of wadis and more or less important rivers.

These wadis and streams characterized by irregular flow (with periods of winter floods and summer low water), discharge towards the sea various pollutants from the localities they cross. The concentration of various human activities and property in floodplains of major rivers increases potential flood hazard risk [17, 18].

Hydrographic changes due to dam construction, consumption of different socioeconomic activities, and climate change. Freshwater, estuaries, coastal, and marine pollution with invasive species abundances such as *Caulerpa racemosa* and toxic algae bloom including *Pseudo-nitzschia* [19]. Regression of Seagrass meadows and other endemic species in some areas of the Mostaganem coast. Different pollution indicator species have been highlighted in the coastal areas of Mostaganem, including *Capitella capitata*, *Scolecopsis fuliginosa*, *Audouinia tentaculata*, *Corbula gibba* [20, 21].

4 Water pollution

4.1 Coastal water degradation

In the coastal zone, the main sources of water degradation are the polluted rivers, urbanization,

wastewater discharge directly into the sea water without treatment (Figures 14, 15), and population growth.



Figure 14. Coastal linear urbanization and industrialization in Sonactere in 300 m zone (Source Google maps, modified)



Figure 15. Pollution from land-based sources [in 16].

However, two other issues arise with greater acuity in the coastal zone, reuse of treated wastewater, and the desalination of seawater. Studies on the coastal zone of Mostaganem highlighted the impact of

nutrient and other chemical substances loads on the water quality; abundance and diversity of certain species such as fish [14], macroinvertebrates [20, 21], micro-algae [22, 24], macro-algae [24], certain of which are harmful to the coastal and marine ecosystem [20, 22, 23].

4.2 River water alteration

In addition to the Mactaa with its area of 14389 km², which is classified as a wetland of international importance signed at RAMSAR, Cheliff river is the longest wadi in Algeria with an area of 43 750 km², an average yield of 1 540 hm³/year, and a length of 800 km. It is considered as a source of telluric pollution of the Mostaganem coastline, due to the presence of several industrial and urban units discharging their effluents upstream [25]. The domestic wastewater treatment system is estimated at only 2.8% [10].

Drainage of the basins downstream to the west during floods and eastwards during periods of drought (Table 3). The large total population in the Cheliff catchment area is estimated at more than 3 million inhabitants, the estimated discharge rate of sewage having an impact on water quality is 72 000 m³/d. Cheliff River has its source in the Saharan Atlas, near Aflou in the mountains of Jebel Amour. The Cheliff wadi (Table 3, Figure 16) is fed by several tributaries and groundwater, by the Ghrib dam situated upstream, or by tributaries (Mina wadi).

The results of Table 3, according to the Slope Index (SI) classification, show that the whole basin ranks in a very strong relief class. The area below the Cheliff Basin of Mostaganem (Cheliff Maritime Wadi) is the highest (993 ± 1,635).

The Cheliff river crosses successively nine (09) Algerian wilayas which are Laghouat, Djelfa, Tiaret, Tissemsilt, Medea, Ain Defla (Cheliff river), Chlef (Wadi Fodda and Wadi Sly), Relizane, Oued Rhiou, (Wadi Mina Low), and the downstream in Mostaganem [13, 25]. The monthly and annual flow of the Cheliff river is extremely irregular. The water supply of the Cheliff river increase from September to May and decrease during the summer period.

The estuary is the extreme zone of the lower watercourse of the wadi where it flows into the sea, bringing in considerable quantities of sand, mud, and pebbles. In this zone, the decrease of the velocity of the current and the difference of density between the freshwater and the sea water makes that the sands and the silts in suspension are deposited. The main deposit of the estuary is mud [1, 13]. There are fauna and algae species that can belong to one of the two ecosystems (River or Sea). The estuary is a biotope with high biological productivity. The waters enriched with nutrients, therefore, have a marked eutrophic character [26]. The ecosystem characterizing the estuary zone plays an important role for many species of anadromous and catadromous migratory fish [27].

Table 3. Characteristics of the altitudes and Slope-indices of Cheliff sub-basins (Source: ANRH)

Sub-Basins	Stations	Attitudes characteristics					Slope index characteristics		
		Code	Max (m)	Min (m)	Mean (m)	SD (m)	SI %	SI m/km	Relief According to SI
Ghrib Chellif Wadi	Ghrib upstream	011407	1813	500	705	1402	20	5.14	Very Strong
Cheliff Harbil wadi	Tamzguida	011501	1267	490	842	538	21	37.89	Very strong
Deurdeur Wadi	Marabout Blanc	011601	1813	268	1040	600	21	8.9	Very strong
Cheliff Harraza Wadi	Arib Cheliff	011702	1813	23	1035	1118	18	2.44	Very strong
Cheliff Harraza Wadi	El Ababsa	011715	765	313	476	245	19	22.69	Very strong
Ebda Wadi	Arib Ebda	011801	1417	275	736	802	20	34.13	Very strong
Rouina/Zeddine Wadi	B.O Tahar	011905	1786	205	478	1150	17	28.97	Very strong
Cheliff Tighzal Wadi	El Abadia 1	012001	1813	153	983	1120	10	2.34	Very strong
Ras Ouahrane Wadi	Ouled Fares	012201	960	155	363	710	15	36.04	Very strong
Ras Ouahrane Wadi	Ponteba Défluent	012203	1983	132	1059	1245	10	2.42	Very strong
Sly Wadi	Ouled Ben A. E. K	012311	1661	160	717	1340	19	29.45	Very strong
Cheliff Tarhia Wadi	Djidiouia Cheliff	012806	1983	51	1015	1582	13	2.63	Very strong
Mina Wadi upstream	Sidi Ali Ben Amar	012909	1250	475	719	478	12	11.57	Very strong
Wadi Taht	Kef Mahboula	013001	1250	475	852	775	39.71	19.1	Very strong
Abd Wadi downstream	Takhmart	013301	1300	600	1004	700	26.4	8.6	Very strong
Abd Wadi downstream	Ain Amara	013302	1339	288	711	1051	30.2	15.5	Very strong
Mina Hadda Wadi	Sidi AEK Djillali	013401	1160	225	588	935	46.1	25.03	Very strong
Mina Hadda Wadi	Wadi El Abtal	013402	1339	205	810	1134	25.6	10.04	Very strong
Cheliff Maritime Wadi	Sidi Bel Attar	013602	1983	20	993	1635	12	2.64	Very strong

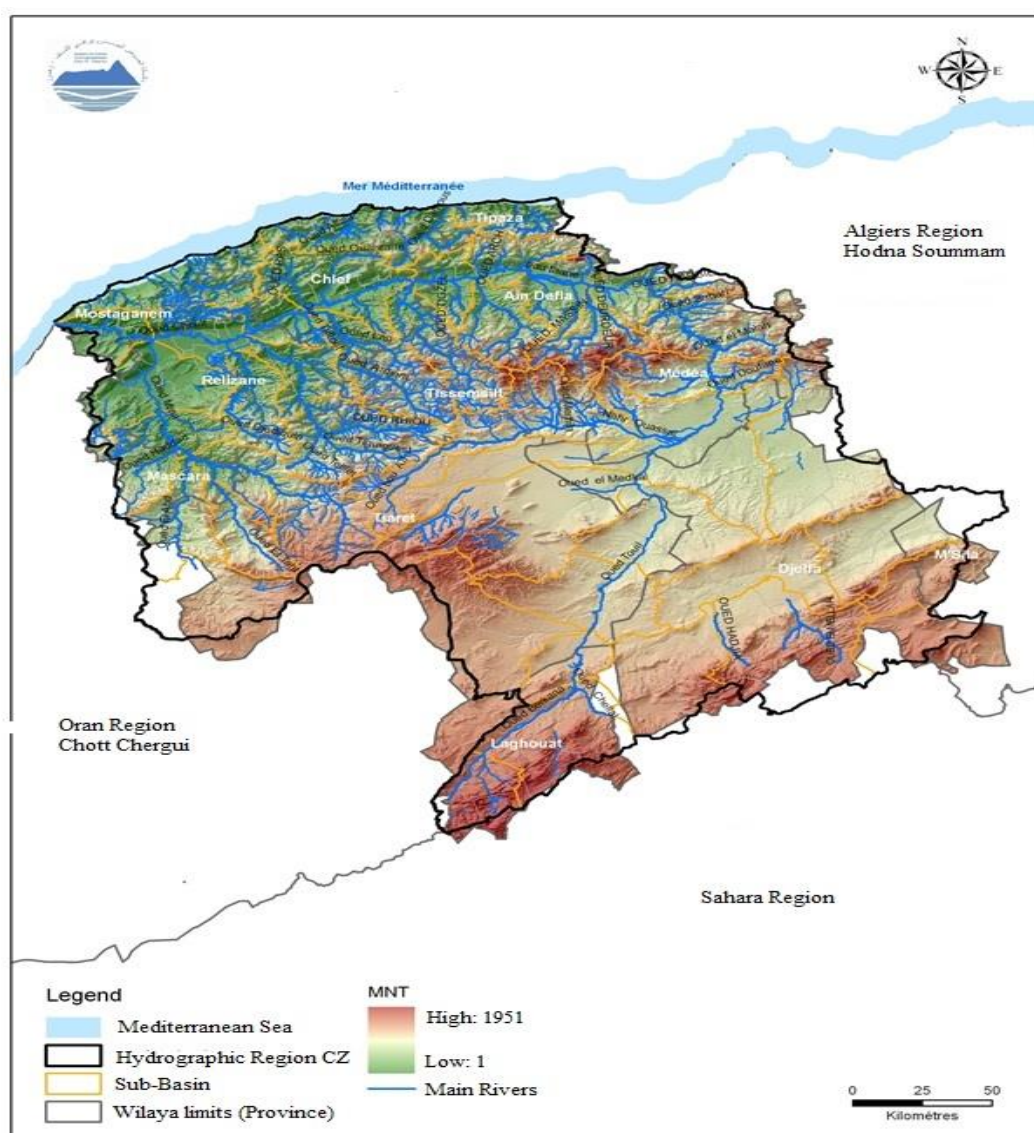


Figure 16. Natural Framework of the Hydrographic Region Cheliff Zahrez "CZ"
(Source: <http://www.abh-cz.com.dz>)

Conclusion

The Mostaganem wilaya, because of its ideal geographical location, a rich but fragile environment due to climate change and the direct discharge of pollutants in coastal zones or the indirect discharge through streams and rivers to the coastal area, makes of it a dynamic area, and a region that is changing rapidly. The development of the wilaya, population, and urban growth, as well as the concentration of most of these tourist, fishing, agricultural, and industrial activities implemented on the coastal strip, have generated alarming environmental problems, some of which are irreversible. The analysis of the various forms of environmental degradation studied in this paper, allowed us to have an idea about the characterization of the Mostaganem coastal zone. This zone has been economically and socially extended but has also caused a series of environmental issues, especially those of pollution includes

nutrient enrichment which caused eutrophication of continental, estuaries, and coastal waters, and lead to degradation of the coastal environment. This situation has also provoked a series of constraints, most of which can only be studied through a deep reflection on the local scale (micro-scale).

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