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Contribution to the study of the ecological status of the West Algerian coastal waters within the Water Framework Directive (WFD)

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“*River basin management is focused on its own specific issues, as is the management of the coastal area and marine environment. Some of these issues are common to river and coast and necessitate an integrated approach*”

(Virtual Water Framework, March 16, 2003)

Dedicated to my parents ...

...Reader and for all.

Abstract

Coastal areas are under anthropogenic and climate change pressures. During the last twenty years, the concept of Integrated Coastal Zone Management, as provides the overall policy frames, but tools supporting the planning and management efforts are almost lacking, especially in the estuary areas where the effects of river basins on coastal zones are nearly absent in most implementations.

Coastal environments constitute a dynamic environment influenced by both natural and anthropogenic continental inputs and controlled by hydrodynamic and climatic factors. Some coastal zones are, by their geography and geomorphology, a receptor where are trapped water bodies loaded with exogenous mineral and /or organic matter resulting from the anthropic activity. The residence time of these water bodies is related to the sea currents intensity which controls the distribution and dilution of dissolved substances that can unbalance the ecosystem.

In order to assess the trophic status of coastal Mediterranean marine waters, the Water Framework Directive (WFD) required the monitoring of the Chlorophyll-*a* concentration (Simboura et al., 2005) and the trophic index TRIX proposed by Vollenweider et al. (1998), which takes into account the overall nutrients, chlorophyll-a, and dissolved oxygen in the environment.

Our results highlighted the ranking of the ecological quality status (EQS) of the three sites Sonactere, Cheliff, and Sokhra as bad according to the Chlorophyll concentration and as Poor status according to trophic index (TRIX).

The coastal waters of Mostaganem in western Algeria have proved to be in a situation of severe eutrophication. However, to better understand the state of the ecosystem, it is essential to explore the entire coastal area of Mostaganem over a long period. The Chl-*a* and TRIX index were developed for Mediterranean regions but it should be adapted to local conditions so that it is relevant and more reliable and representative, given the heterogeneous aspect of the Mediterranean coastal zones.

Keywords: Algeria, water quality status, Chlorophyll-*a*, trophic index (TRIX), ecological integrity.

Sommario

Le aree costiere sono sottoposte a pressioni antropogeniche e ai cambiamenti climatici. Negli ultimi venti anni, il concetto di gestione integrata della zona costiera ben presente nelle diverse azioni politiche, manca degli strumenti a supporto degli sforzi di pianificazione e gestione, specialmente nelle aree di estuario dove gli effetti dei bacini fluviali sulle zone costiere sono poco evidenziati nella maggior parte delle implementazioni.

Gli ambienti costieri costituiscono un ambiente dinamico influenzato da input continentali sia naturali che antropogenici e controllato da fattori idrodinamici e climatici. Alcune zone costiere sono, con la loro geografia e geomorfologia, un recettore in cui sono presenti corpi idrici carichi di minerali esogeni e / o di materia organica derivanti dall'attività antropica. Il tempo di permanenza di questi corpi idrici è legato all'intensità delle correnti marine che controlla la distribuzione e la diluizione delle sostanze disciolte che possono influenzare l'ecosistema.

Al fine di valutare lo stato trofico delle acque marine costiere del Mediterraneo, la Direttiva Quadro sulle Acque (DQA) richiedeva il monitoraggio della concentrazione di Clorofilla-a (Simboura et al., 2005) e l'indice trofico TRIX proposto da Vollenweider et al. (1998), che tiene conto delle sostanze nutritive complessive, della clorofilla e dell'ossigeno disciolto nell'ambiente. I nostri risultati hanno fornito la classificazione dello stato di qualità ecologica (EQS) dei tre siti Sonactere, Cheliff e Sokhra rispettivamente come stato Scadente, in base alla concentrazione di clorofilla, e come Cattivo, secondo l'indice trofico (TRIX). Le acque costiere di Mostaganem nell'Algeria occidentale mostrano una situazione di grave eutrofizzazione. Tuttavia, per capire meglio lo stato dell'ecosistema, è essenziale esplorare l'intera area costiera di Mostaganem per un lungo periodo. Gli indici Chl-a e TRIX sono stati sviluppati per le regioni del Mediterraneo, ma dovrebbero essere adattati alle condizioni locali in modo che siano pertinenti e più affidabili e rappresentativi, dato l'aspetto eterogeneo delle zone costiere del Mediterraneo.

Keywords: Algeria, stato della qualità delle acque, clorofilla-a, indice trofico (TRIX), integrità ecologica.

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List of Abbreviations

ANOVA	Analysis of variance
TRIX	Trophic Index
EQS	Ecological Quality Status
EQR	Ecological Quality Ratio
ICZM	Integrated Coastal Zone Management
NS-ICZM	National Strategy-Integrated Coastal Zone Management
WFD	Water Framework Directive
NOS	National Office of Statistics (Algeria)
MLPE	Ministry of Land Planning and Environment (Algeria)
NOS/GCPH	National Office of Statistics, General Census of the Population and Habitats
ANRH	Agence National des Ressources Hydrauliques
Chl-*a*	Chlorophyll-*a*

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Chapter 1:

General Introduction

1 General introduction

Coastal areas are important for economic activities and are increasingly subject to pollution related to human population growth, accompanied by the very high anthropic impacts due to the socioeconomic activities implemented in the coastal zone -especially in the last decades-, such as tourism (Ghodbani et al., 2016; Taibi, 2016; Kies et al., in press a), urbanization, industrialization (Ghodbani, 2010; Ghodbani & Berrahi-Midoun, 2013). Consequently, Algerian coastal water quality and their aquatic ecosystem structures have been severely decreased (UNEP-MAP RAC/SPA, 2009). Their responses to the climate change, water quality contamination, sediment quality alteration, and hydrogeological structures changes, also act as stressors to different species such as *Posidonia meadows* and seabirds (Louzao et al., 2012; UNEP-MAP RAC/SPA, 2009).

Mostaganem coastal zone, east of Arzew Gulf, is one of the most ecologically and biologically important embayment along the Mediterranean coast of western Algeria (UNEP-MAP RAC/SPA, 2010). The ecological importance of the coast is attributed to the fact that it receives various types of impacts; tourism, agricultural, domestic, and industrial wastes (Figure 1.1) causing continuous changes in its water quality (Taleb et al., 2015).

FIGURE 1.1: Socioeconomic activities implemented in the coastal zone (Kies et al., in press a).

The coastal zone is also classified as highly productive and is considered one of the most highly rich Algerian coastal regions, providing a good environment for the fishing of many commercially important fish (Hansal, 2013; Kies et al., 2012).

The increase in water turbidity and nutrient loading in this coastal zone are among others the major factors in the regression of seagrass meadows (Leoni, 2005). In fact, an increase in the content of dissolved particles leads to an enrichment of the water bodies by phytoplankton organisms, which by their excessive development causes a qualitative and quantitative modification of the Light which affects the photosynthesis and the transparency of the waters (Peres & Picard, 1975). Due to stress from discharged wastewaters, the Bay has become a "hot spot" area, requiring permanent monitoring of its water quality and inhabiting biota (Bensahla Talet et al., 2014). In this context, many investigations were conducted including hydrographic conditions, pollution and variability in the plankton communities (Kies, 2015). The great majority of these studies were based upon either seasonal or single cruise sampling. Therefore, the present study was conducted monthly for a complete annual cycle in order to follow up the temporal pattern of hydrography, nutrient levels, and plankton abundance in different coastal zones of the Mostaganem province, exposed to the stress of industrial, domestic, and agricultural effluents (MATE, 2002).

The aim of this work is to determine ranges and variations of abiotic and biotic parameters (pH, NO_3, NO_2, NH_4, PO_4, SiO_2, COD, BOD, O_2, and Chl-*a*) in water samples collected in various stations of North-western Algeria coast (Mostaganem) and their impact on the environmental quality status. In fact, industrialization and the discharge of wastewater into inland and the marine environment have raised significantly over the last decade and become a serious issue. Intensive population growth, agriculture, and industrialization in Mostaganem area have led to a rise in trophic levels in the water, and in process of eutrophication. The main sources of nutrients are agriculture, urbanization, and industrial waste, and wastewater discharges without treatment.

The objective of this work was to characterize the water quality issues in national and local Algerian scale, to determine the importance of terrestrial and oceanic influences on the spatial heterogeneity and trophic state of Mediterranean coastal waters of the province in north-western Algeria. Finally, to propose the implementation of the required water framework directive (WFD) indices including TRIX, Chl-*a*. The WFD requires measures to be put in place to reduce or eliminate inputs of the polluting substance. Waters failing their WFD objectives will have a program of measures specified in the river basin management plan to restore these waters to good status. This research would provide a better understanding of the connectivity between terrestrial and coastal processes and characteristics of Mostaganem Mediterranean environments that will further promote the establishment of ecological baselines for coastal management and monitoring programs in similar Algerian coastal areas.

The thesis is presented in seven chapters.

Chapter 1 includes the statement of the research problem, the aim and objectives.

Chapter 2 present a literature review of studies treating relative to mapping, characterization, and health status assessment of the Algerian coastal zone.

The literature reviews of previous studies treating (mapping, characterization, and health status assessment) are presented in chapter 3.

Chapter 4 contains a review of coastal jurisdiction. It examines the management and administration of rights, restrictions, and responsibilities in Algerian coastal environments.

Chapter 5 focuses on the physicochemical water bodies characterization through different descriptors used to assess the ecological health status of the phytoplankton biomass and nutrient levels of the case study area (Coast of Mostaganem in Algeria).

In chapter 6, we tested the feasibility of the assessment of the trophic conditions by the adoption of a trophic index (TRIX) developed by Vollenweider et al. (1998), and Chl-*a* (Simboura et al. (2005). TRIX and Chl-*a* were drawn up according to the requirements of the Water Framework Directive. This index has been implemented on three coastal sites from the western Algeria (Sokhra, Cheliff, and Sonactere), locating in the wilaya of Mostaganem.

Finally, chapter 7 discusses and summarizes the overall research findings.

Chapter 2:

Algerian Coastal issues

Objective:

Characterization of the Algerian coast and macroscale assessment of the "pressure-impact"

2.1 Introduction

The functioning of the coastal marine ecosystem depends on the influence and interaction of two different environments, the marine environment and the continent (Nixon, 1988). Along the Algerian coast, the circulation of Atlantic water (Algerian current) leaves an indelible mark on the coastal waters (Muñoz et al., 2015). It induces a fairly characteristic coastal dynamic that ensures the renewal of bay waters and contributes to the undeniable determination of trophic fertility levels (Morán et al, 2001). The influence of the sub-aerial environment depends on the quantity and the quality of these contributions. These are themselves in relation to the natural and anthropogenic conditions of the catchment areas of the coastal fringe (Lotze et al., 2006; Fabricius et al., 2016).

2.2 Coastal Oceanography

In the Mediterranean Sea, evaporation is responsible for a sea level decline estimated at 1 m per year, which is not remedied by river inputs and precipitation (Millot et al., 2005). This deficit is offset by an inflow of superficial Atlantic water through the Strait of Gibraltar (Millot et al., 1990). The circulation of the Atlantic current, from the Strait of Gibraltar to the Sicilian Channel, presents strong differences (Millot, 1987). In the West, it is relatively stable and closely related to the geography of the Strait of Gibraltar and the Alboran Sea. The waters form at the surface a layer of modified Atlantic water MAW (Figure 2.1) that flows from west to east along the African coast forming large anticyclonic eddies (Millot, 1999). At the exit of this sea, the circulation is practically permanent, directed from the Spanish coasts towards the Algerian coasts, this current flows eastward along the African coast and generally become unstable from along Mostaganem coast. Arrived at the Algerian coast, the current is called "Algerian current". Meanders cyclonic and anticyclonic eddies develop; the vortices drift eastwards at velocities of a few cm/s, but only the anticyclonic can reach 100 km in diameter, then move away from the coast, they can reach dimensions of more than 200 km and return to the coast interact with the current vein directed from the Spanish coasts 2° W towards the Algerian coasts 1° W (Millot, 1987).

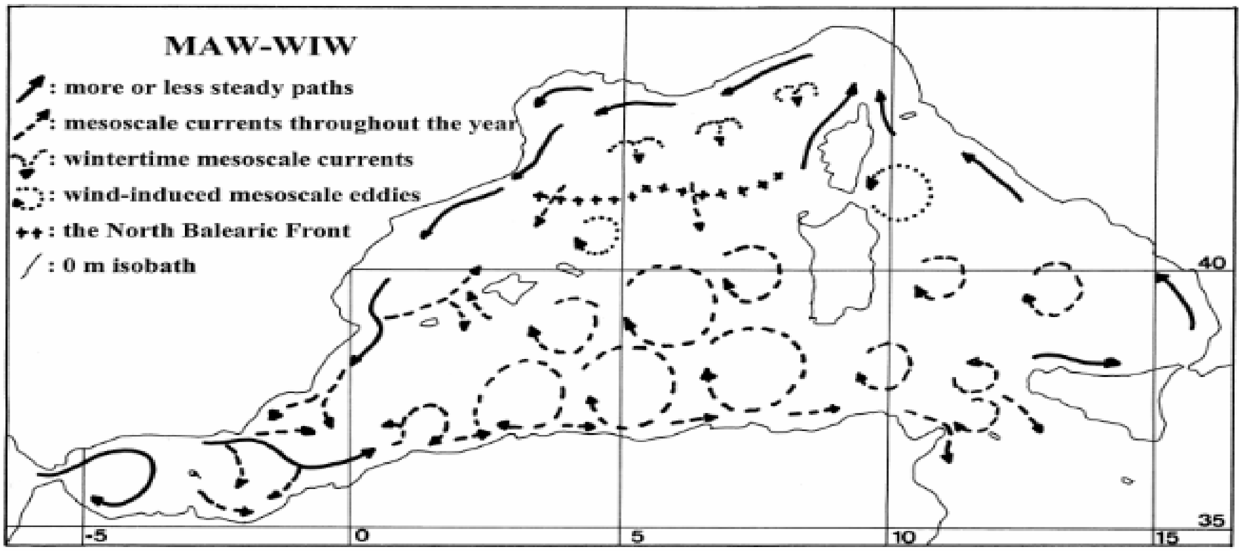


FIGURE 2.1: Surface water circulation in the western Mediterranean Sea (Millot, 1999)

This water is subject to evaporation and mixing with the underlying Mediterranean waters; it can reach salinity of 38.3 psu in the Strait of Sicily. In the Strait of Sicily, Levantine intermediate water LIW (Figure 2.2) contributes to flows out of the eastern basin and enters the western basin through the Tyrrhenian Sea (Millot, 1999).

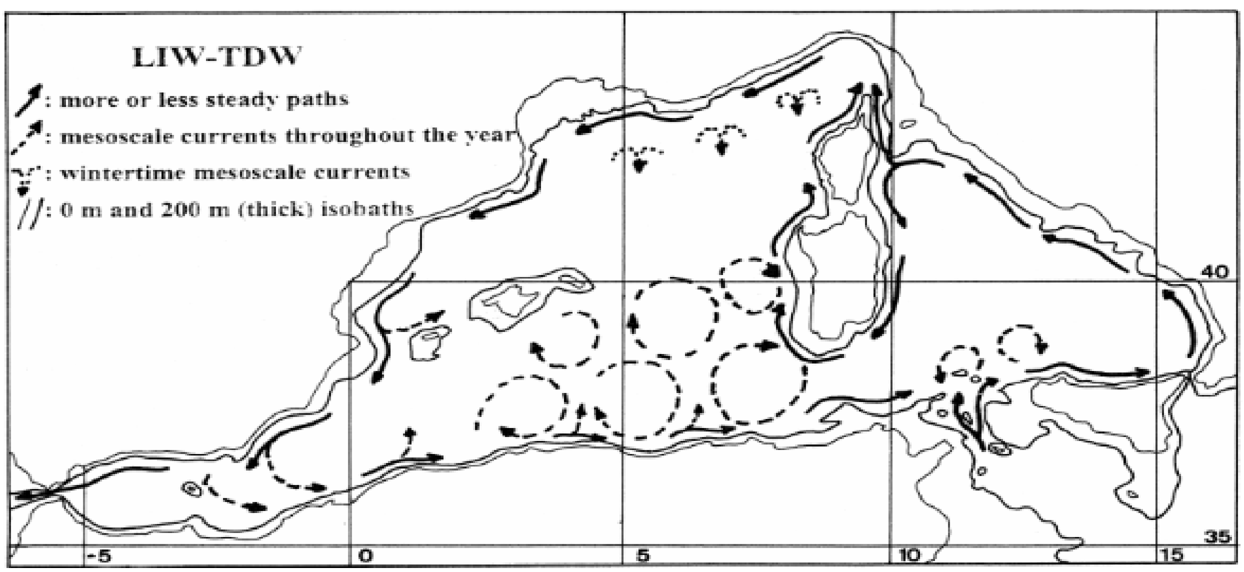


FIGURE 2.2: Circulation of intermediate waters in the western Mediterranean (Millot, 1999).

It circulates under surface modified Atlantic waters and actively participates in the formation of the deep waters of the western basin. The mixture of Atlantic surface water and LIW form the deep water of the West Mediterranean basin "WMDW, West Mediterranean Deep Water", which plunges into the central area of the Lion Gulf to line the bottom of the western basin. The winter intermediate water "WIW" originates on the continental shelf of the Lion Gulf and in the Ligurian Sea and forms a vein of water between the MAW and the LIW, which is found in the Algerian basin (Benzohra and Millot, 1995).

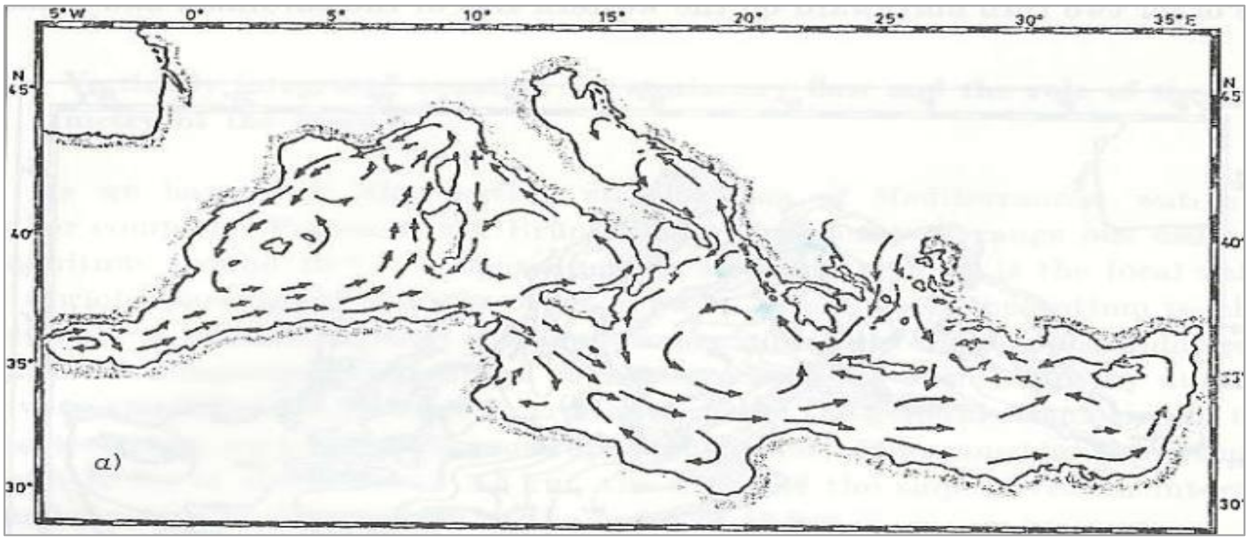


FIGURE 2.3: Summer Surface circulation (Pinardi et al., 1985).

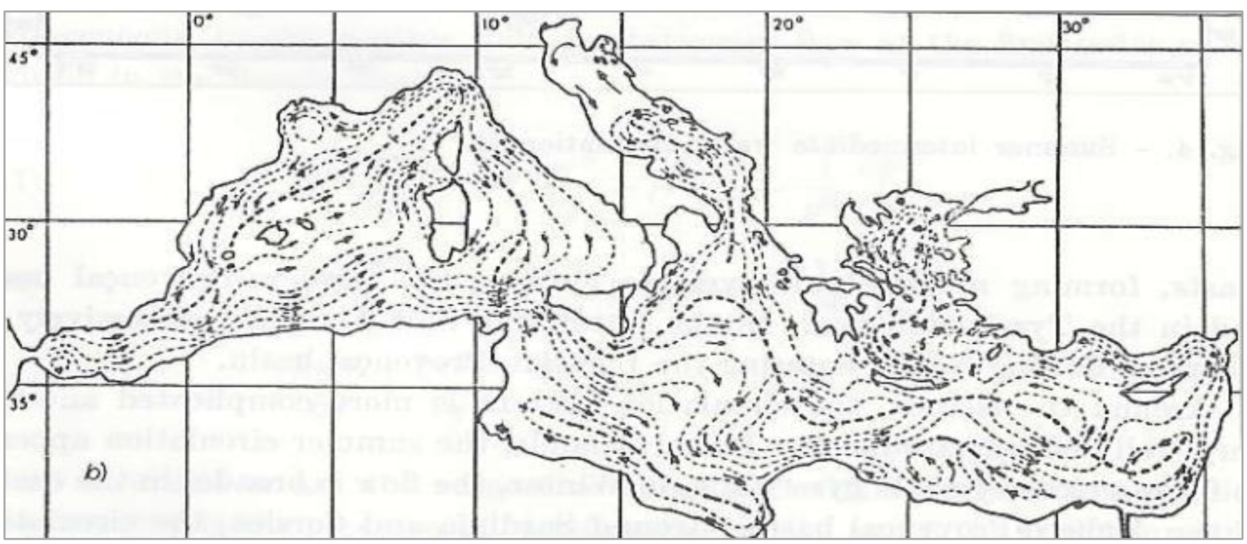


FIGURE 2.4: Winter Surface circulation (Pinardi et al., 1985).

Figure 2.3 and Figure 2.4 illustrate the global surface waters circulation in the Mediterranean for summer and winter (Pinardi et al., 1985). The western Mediterranean basin is composed of several sub-basins: the Alboran Sea, the Algerian basin, the Balearic Sea, the Liguro-Provençal basin and the Tyrrhenian Sea.

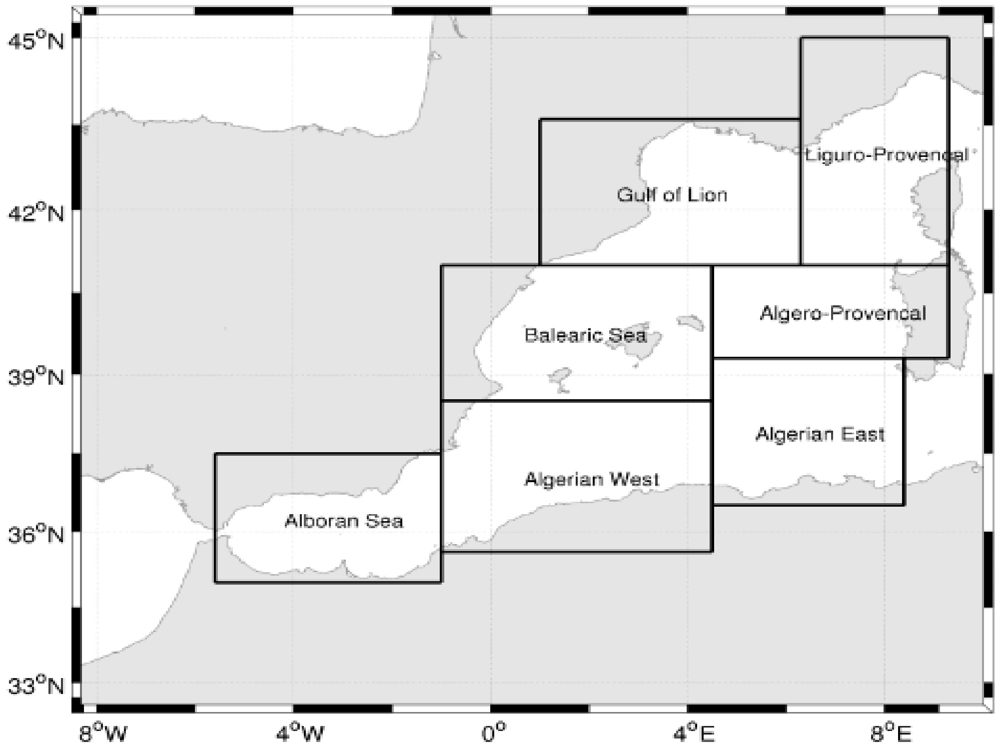


FIGURE 2.5: Different areas of the WMed as defined by Manca et al. (2004)

Manca et al. (2004) separate the basin into different regions according to their general circulation patterns (Figure 2.5). The Algerian basin is located south of the WMed, along the Algerian coast and can be separated into a western and an eastern part (Figure 2.5). In this region, the Algerian current is very unstable and the circulation is dominated by strong mesoscale eddies (Beckers & Nihoul, 1992). Such mesoscale eddies, known as Algerian Eddies have been observed since the 1970s (Katz, 1972) and have been described (Benzohra and Millot, 1995). The Algerian mesoscale eddies are generated as a result of baroclinic instability (Beckers & Nihoul, 1992). The eddies of the Algerian basin are probably a determining factor in the distribution of nutritive salts, planktonic biomass along the Algerian coast (Riandey, 2005).

In addition, they disturb the circulation of Levantine Intermediate Water (Millot, 1987) and cause the water of Atlantic origin from the Algerian coast to the sea their influence can be felt far to the North of Mediterranean Sea (Figure 2.6).

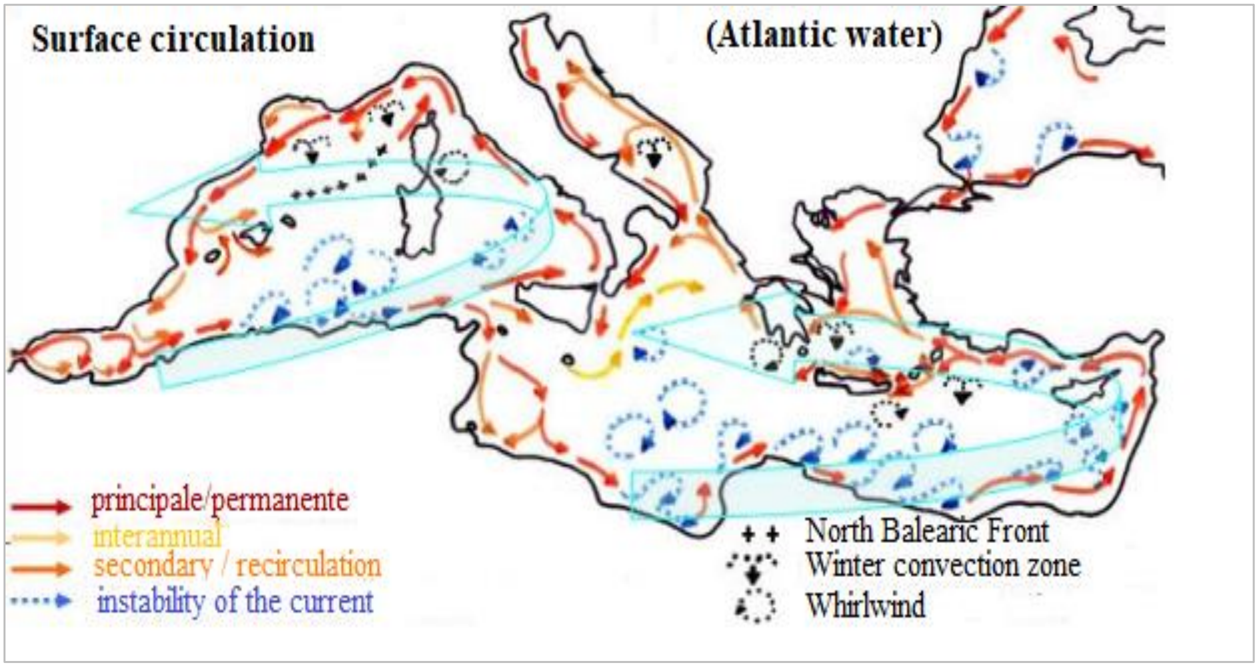


FIGURE 2.6: The general circulation of the Mediterranean Sea (Millot et al., 2005).

The dynamic of the Atlantic inflow along this biogeographic area is characterized by the Algerian Current instabilities (Morán et al., 2001) in addition to the large river nutrients inputs create zones of enhancement of productivity. In this area, *chlorophyll a* concentration is higher at cyclonic eddies linked to higher zooplankton abundance (Riandey, 2005). Across the current, large horizontal gradients exist in hydrography (e.g. salinity) as well as in phytoplankton and zooplankton biomass and species composition (Raimbault et al., 1993; Seridji and Hafferssas, 2000). Productivity is particularly high at the offshore part of the Algerian Current where high concentrations of nutrients and *chlorophyll a* contribute to high zooplankton biomass levels and abundances (Morán et al., 2001; Hafferssas and Seridji, 2010).

2.3 Climate changes

2.3.1 Impacts changing in temperature and rainfall

Due to the combined influence of the sea, the relief, and the altitude (Figure 2.7), the climate is extra-tropical Mediterranean temperate on the coastal area but with a continental trend inland with greater temperature differences (Millot, 1994). The thermal amplitude, both between day and night, is seasonal and varies naturally depending on the altitude of the localities, having a direct impact on the evaporation of surface water (NOS, 2013). The spatial distribution of rainfall is characterized by a variation of the rainfall gradient from East to West and from North to South (Figure 2.8).

FIGURE 2.7: The relief of Algeria (Microsoft Encarta Encyclopedia, 2006, *in* Alloui, 2012).

Geomorphologically and climatically, three strongly contrasting sets are distinguished over the whole of Algeria. The Tell in the North represents only 4% of the total area of the territory. It enjoys a Mediterranean climate with precipitation that can reach 1600 mm on the reliefs but which have an interannual irregularity and an uneven spatial distribution from west to east.

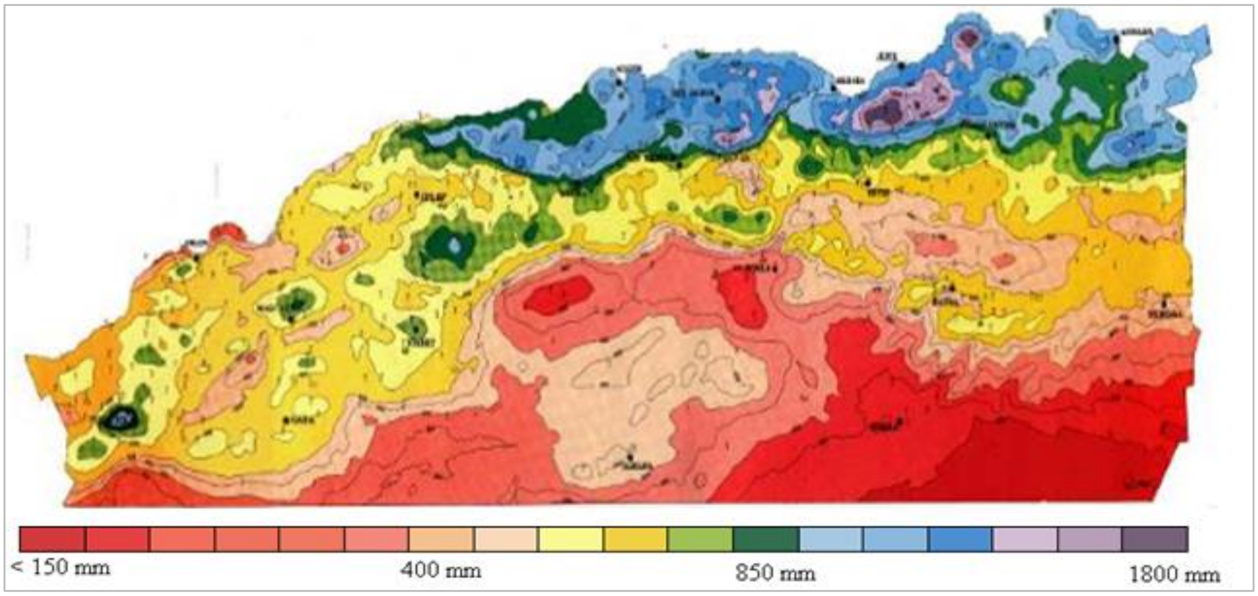


FIGURE 2.8: Rainfall map of northern Algeria (ANRH, 1993).

There is a climatic gradient of the Algerian coastline from East to West (Figure 2.9). In the Algerian west coast, the quantity and frequency of rainfall are low, ranging between 250 and 500 mm with an average temperature of 18 °C, placing it in the semi-arid bioclimatic stage, then that the center with the same average temperature and a rainfall of 645 mm is in the floor bioclimatic sub-humid. The Algerian east coast with a rainfall of between 600 and 1150 mm and an average temperature of 20 ° C, is in the sub-humid bioclimatic stage to per-wet.

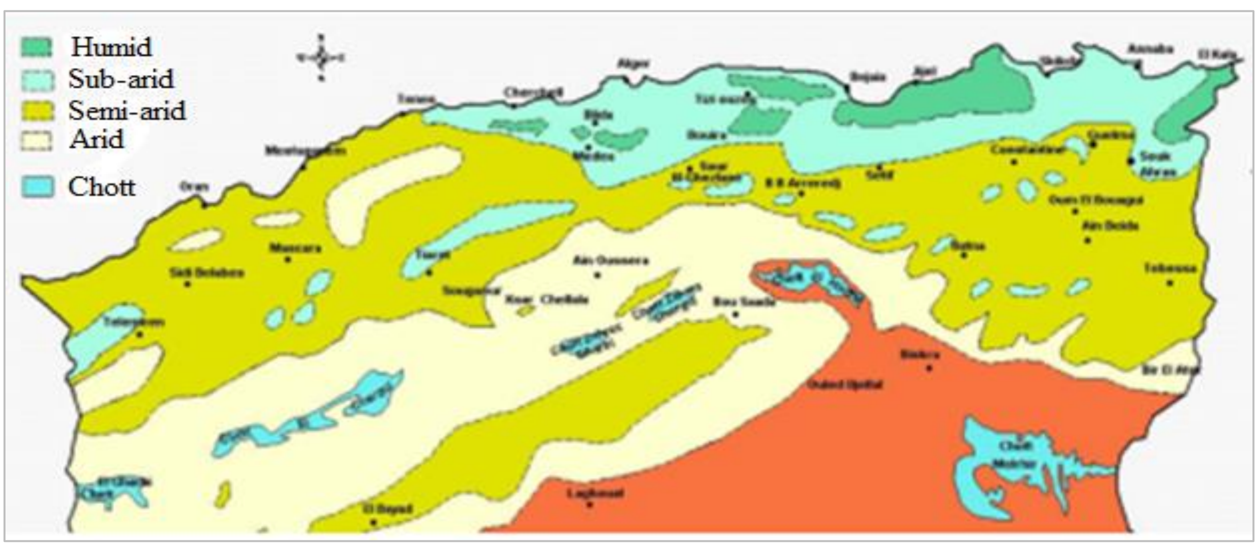


FIGURE 2.9: Bioclimatic map of northern Algeria (ANPS, 2004).

2.3.2 Impacts changing in surface waters

With an area of more than 225 000 square kilometers, northern Algeria is between -2.23 ° and + 8.67 ° in latitude and 32.74 ° and 37.12 ° in longitude. It is limited to the North by the Mediterranean Sea, to the East by Tunisia, to the West by Morocco, and to the South by the Algerian Saharan Atlas (MATE, 2002).

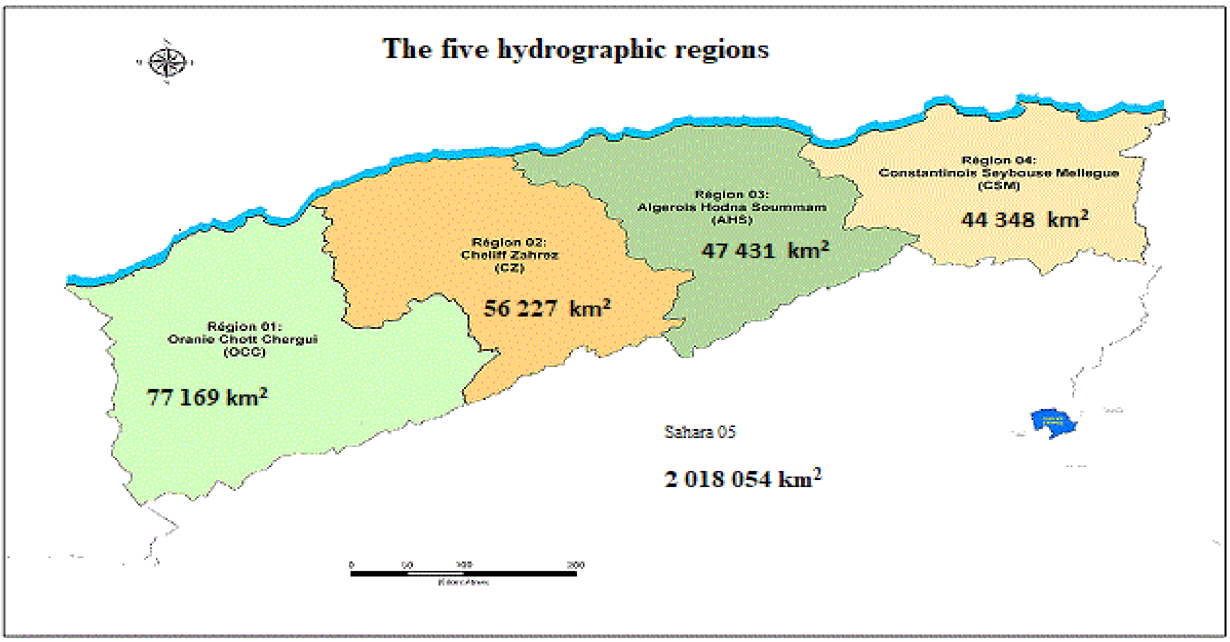


FIGURE 2.10: Map of hydrographic areas of northern Algeria (Source: ANRH, modified).

Hydrographically (Figure 2.10), this area consists of seventeen (17) large hydrological basins of which fifteen have an outlet to the Mediterranean Sea along a coastal line of 1622 Km. In general, the hydrographic network is rather dense, as a consequence of a lithology with a high clay fraction of the lands constituting the watersheds (ANRH, 1993). The derived hydrological regimes determine: (*i*) an extreme seasonal and interannual irregularity of the flows which is accentuated by long periods of drought; (*ii*) violent and rapid floods; (*iii*) intense erosion and strong solid transport (Kadi, 1997; Metouchi & Haddoum, 2012; Harkat et al., 2012). A Total number of 54 flood events, selected by the MEDEX project (1996-2004), were recorded as the most catastrophic windstorm and flood event in recent years, causing human deaths and damage in Algeria (Llasat et al., 2010).

2.3.3 Impacts changing in vegetal cover

Acording to Ammari (2012), the vegetation cover in Algeria is rather dense in the Sébaou especially on the maquis rather high the density decreases towards the West. The density of the vegetation cover varies with precipitation, it is very dense in the wetlands of more than 850 mm/year and gradually decreases (Figure 2.11).

The most cultivated area is the Mitidja with an area of 140000 hectares, where the main crops are vegetables, citrus fruits and vineyards, the region of Sebaou is also an agricultural region characterized by mountain crops, such as arboriculture. West of Tipaza, the cover is less dense to degraded especially due to the decrease of precipitation compared to the east, and the crops are mainly market gardeners concentrated on the thin strip of plain near the coast. The last decade has been catastrophic for the country's forest cover, where almost half of the country's plant cover has been exposed to fires, with serious consequences including soil degradation by hydric and wind erosion acceleration (MATE, 2002), and in light of recent developments, the updating of the old vegetation cover data has become indispensable.

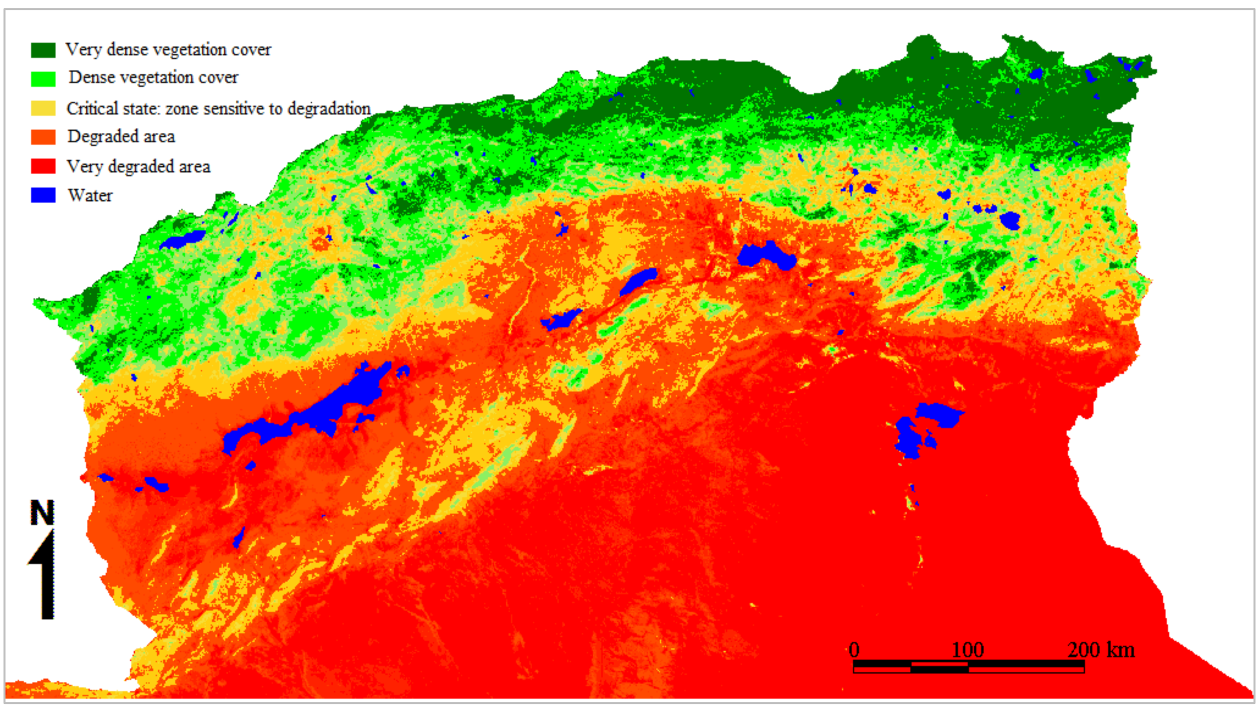


FIGURE 2.11: Map of vegetation cover of northern Algeria (Benslimane et al., 2008).

2.4 Morphology- Continental shelf

The Algerian coast is of general direction SW-NE, it extends from Marsat Ben M'Hidi in the West to Cape Roux in the East for 1622 kilometers. It presents as a succession of bays and more or less open gulfs. The high cliffs that generally line this coast are naturally exposed to hydric, marine, and wind erosion. The hydrographic network (Figure 2.12) leading to the sea includes 17 rivers, the most important are the rivers Tafna, Cheliff, Mazafran, El Harrach, Soummam, Sebaou, Isser, El Kebir, Saf-Saf, and Seybouse River. This network provides the marine environment with terrigenous inputs. Rivers are collectors of all pollutants from human, agricultural and industrial activities.

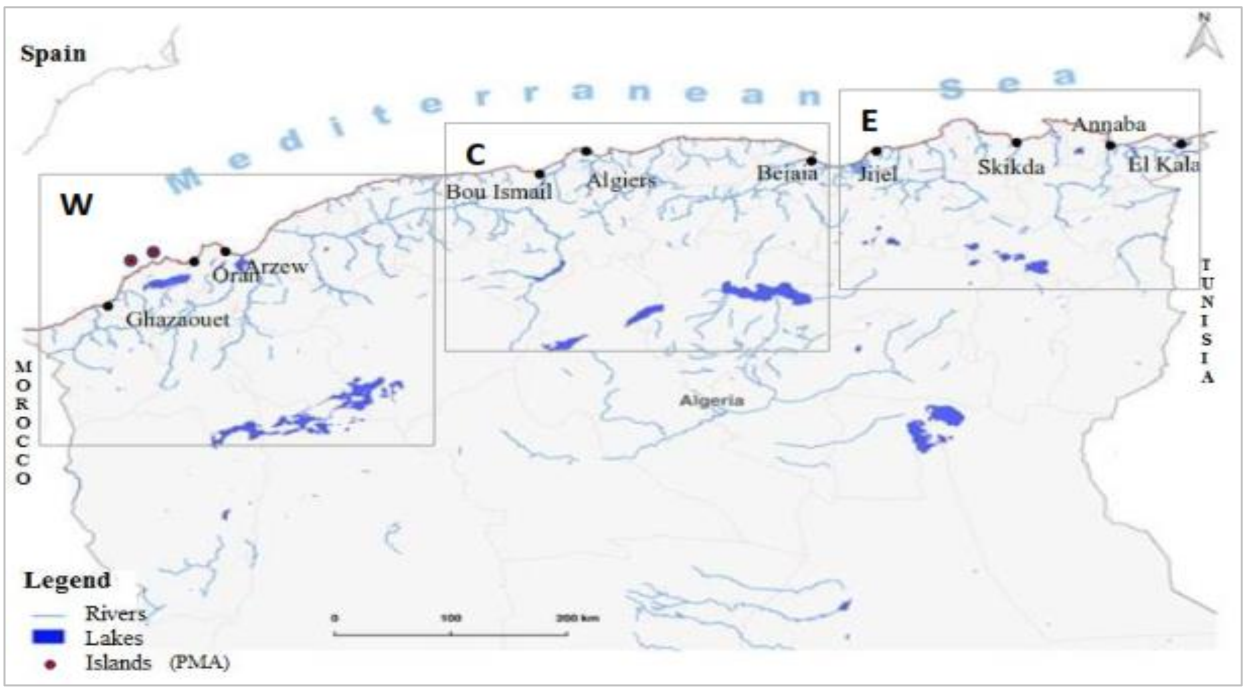


FIGURE 2.12: Location and morphology of the Algerian coastline (W: Western Algeria, C: Center Algeria, and E: Eastern Algeria).

According to Grimes et al. (2004), the area from the Algerian-Tunisian border to Bejaia is, on the whole, very diversified. This sector is characterized by a set of more or less high cliffs (<40 m) cut in hard igneous and metamorphic rocks, whose slopes are steep and covered with soil and vegetation and whose lower part is beaten by the sea.

The geological structure individualizes rocky massifs, separated by valleys, with rivers flowing into the sea. The coastal lagoons between El-Kala and Annaba give an originality to this sector of the Algerian coast. The beaches stretch to the bottom of the bays, from a few meters to a few tens of meters wide, are almost exclusively sandy. Contributions to sandy elements are made by Seybouse and Kebir rivers.

From Dellys to Cape Matifou, the coastal morphology is controlled by Sebaou river and Isser river. The coastal strip is covered with quaternary formations. Between Cape Matifou and the crystalline massif of Algiers, the bay of Algiers is hollow. From Sidi-Fredj to Mount Chenoua (Bou-Ismaïl Bay), there is a succession of beaches. Douaouda Marine marks the beginning of more or less steep cliffs cut in quaternary sandstones. From Mount Chenoua to Cherchell scatters cliffs and rocky areas as well as sediment beaches provided by the erosion of the Devonian shale rocks. Mousselmoun river (West of Cherchell) finishes this succession of cliffs. From there Cape Tenes, it is the domain of very high cliffs sometimes reaching 300 m of uneven and plunging to important depths. This is the sector in Algeria where the continental slope is very small.

Between Tenes and the mouth of the Cheliff River, the cliffs dominate, and are mainly formed in the Miocene or Quaternary sandstones and clays. Further west, the Jurassic and Cretaceous hard rock formations are highlighted throughout the Cape Carbon area in the Arzew area. Only the Tafna sector, the Habibas Islands and Rachgoun Islands (Figure 2.12) make up a set of hard volcanic rocks. In the lower Tafna (Rachgoun), the predominance of the localized beaches to the outlets of the rivers or to the foot of the cliffs is noted, and cliffs which finish the downstream part of a plateau. In the extreme west, the coast of Traras is a maritime facade that extends over a hundred km. It starts in Rachgoun (mouth of the Tafna river) near Beni Saf in the East and ends in the West near Foum Kiss on the Algerian-Moroccan border. This layout has a very sinuous design and follows almost regularly the general orientation of the Algerian coast which is in respect with the main lines telloatlasic structure. Between Cape Tarsa in the East and Cape Milona in the West, there are two morphological types: cliffs that form the bulk of this sector and specific beaches and often located at the mouths of rivers.

2.5 Large sedimentological features

Works done at all the Algerian Gulfs, Bays, and ports by Leclaire (1972); Bakalem (1979); Kerfouf (1997); Grimes et al. (2004); UNEP-MAP RAC/SPA (2009); Grimes, (2010); MREE-PAP RAC/PAM (2015); Bouhmadouche & Hemdane (2016); Hadef & Labii, (2017); and (Bouhmadouche et al., 2018) provide information on the sedimentary cover of the Algerian coast (Tables 2.1, 2.2, and 2.3).

TABLE 2.1: Main sedimentological characteristics of the western Algerian sector.

Regions		**Dominant sedimentary facies**
Ghazaouet	Gulf	-The very low arenitic limestone sediments in the Gulf of Ghazaouet, sediments Pelitic limestones and calcareous-clayey vases are highly developed and more abundant. -The sandy coastal fringe is very small, it is located at Cape Figalo in Ghazaouet and gradually takes a major extension from Cape Milona (Leclaire, 1972; Grimes, 2004). - Coastal erosion risk (UNEP-MAP RAC/SPA, 2009).
Oran	Gulf	-A zone of fine sandy gravel located in the eastern part of the Gulf (-49 to -100 m), off the harbor (-60 m), -A zone of silty gravelly sands located near the coast, in the center of the Gulf and extends out to sea, near the port of Mers-El Kebir and at the tip of Kristel, -A zone of slightly silted gravelly sands located off the port of Mers-El Kebir (from -61 to 90 m), and in the western part of the Gulf (facing the tip of Mers-El Kebir) and extending towards the wide (from -80 to -102 m), -A zone of fine sands silted at the extension of the tip of Mers-El Kebir, near the coast (46 m), -An area of gravelly sand facing the cliffs of Canastel (-39 m), -A zone of reduced black mud located near the Oran port pass (near the main sewage outfall of the city of Oran) (Kerfouf, 1997; Grimes, 2004).
Arzew	Gulf	-The sharply pelitic limestone sediments represented by calcareous-clay vases cover a large area of the Gulf, -The clay-silicious sludge with a continental rim thus covering the gulf of a large mudflat, - An alternation of terrigenous sand and mixed or purely organogenic sediments on the littoral border from Cape Carbon to Mostaganem (Grimes, 2004). - Coastal erosion risk (UNEP-MAP RAC/SPA, 2009).

Table 2.2. Main sedimentological characteristics of the Algerian Center sector.

Regions		Dominant sedimentary facies
Alger	Bay	-The silted sand (Ss) occupies a very large part of the bay, from the town of Bou Ismail (-88 m) to Ras Acrata (-32 m) in the East and Chenoua (-44 m) until 'off in front of Bou Ismail (-96 m), -The sandy mud (Sm) covers the center of the western sector of the bay (from -49 to -90 m) and the east of Sidi Fredj (-34 m), -Vaso-gravelly sand (Vgs) occupies a large part of the western sector of the bay (from Tipaza to Ain Tagourait), the coast (-47 m) offshore (-86 m) on almost the entire front East of the bay and east of Sidi Fredj, -The coarse sand occupies a small part of the bay near Mazafran River (coast and wide) and Ras Acrata (coast), -The sand covers a small part of the coast between Mazafran River and the city of BouIsmail. - Coastal Erosion risk of Bou Ismail, Sidi Fredj, and Zeralda (MREE-PAP RAC/PAM, 2015; Grimes, 2010)
	Port	-The sand-gravelly silt is found exclusively in the basins of the port -The gravelly sand extends from the old port basin to the Mustapha basin with a large area towards the South pass, -The mud, sand silt, and sand occupy most of the small harbor, a large part of the Mustapha basin and some parcels at the Agha basin (near the jetty) and the old port (at near the north pass). - The siltation risk in the port (Grimes et al., 2004).
Boumerdes	Bay	- Erosion of a sandy coast: continuous follow-up of the coastal groynes of protection in Boumerdes (Bouhmadouche & Hemdane, 2016).
	Port	- The siltation risk in the port (MREE-PAP RAC/PAM, 2015; Grimes, 2010)

Table 2.3. Main sedimentological characteristics of the Algerian East sector.

Regions		Dominant sedimentary facies
Bejaia	Gulf	-The limestone sediments (sand, gravel and calcareous-siliceous vases) line the rocky border of the bay of Bejaïa, -The siliceous sediments (63 to 64% of the continental shelf and its edge) represented by the silico-calcareous vases and silico-clay vases, -The clay sediments represented by clay-siliceous sludge, -The sandy and gravelly sediments are represented in a secondary way (Leclaire, 1972). - Coastal erosion risk (UNEP-MAP RAC/SPA, 2009; MREE-PAP RAC/PAM, 2015) - Analysis of Hydrosedimentary Indicators for the Study of Coastal Erosion: Case of Bejaia Coast in Algeria (Bouhmadouche et al., 2018)
	Port	- The siltation risk in the port (MREE-PAP RAC/PAM, 2015; Grimes, 2010)
Jijel	Port	- Medium fine sand near the shore on the periphery of the harbor, - Sandy basement inside harbor influenced by dredging operations. - The siltation risk in the port (MREE-PAP RAC/PAM, 2015; Grimes, 2010)
Skikda	Gulf	-From the coast to the sea, fine sands, silted sands, sandy vases, sands and gravels, and pure vases, a sediment distribution according to the bathymetry (Leclaire, 1972). -Coastal erosion risk (UNEP-MAP RAC/SPA, 2009).

Table 2.3- Continued on next page

Table 2.3- Continued from previous page

Regions		Dominant sedimentary facies
Annaba	Gulf	-Clay-siliceous mud extends from Riviere Bou Alallah to Ras El Hamra, -The calcareous-siliceous sands and sand extend over most of the Gulf coast (from Ras Rosa to Ras El Hamra), -Silico-clay vases extend near the coast of Riviere Bou Alallah to Ras Rosa, -The calcareo-siliceous vases cover the broad of the center of the gulf, -The sands and limestone gravels cover mainly the Ras Rosa sea, -The limestone vases cover a small part of the center of the bay (Leclaire, 1972). - Erosion risk in the Coast (UNEP-MAP RAC/SPA, 2009; Grimes, 2010)
	Port	-The sandy mud (Sm) occupies the bottom of the small dock, the large dock, and part of the foreshore, -The gravelly mud (Gm) occupies the transition zone between the small and the large docks, -The pure mud occupies the entire basin of the foreshore (Grimes, 2010). - The siltation risk in the port (MREE-PAP RAC/PAM, 2015; Grimes, 2010)

2.6 Main anthropogenic pressures along the Algerian coast

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.

2.6.1 High density of population

According to NOS/GCPH (1998), it is characterized by an imbalanced distribution on the national territory. Nearly 45% of the Algerian population lives and works in the coastal Wilayas (provinces), which represents only 4% of the territory, while 8% of the population is dispersed across the Sahara, which covers 88% of the national territory. The littoral population increases considerably during the summer period. The density of the littoral population is also important. In 1998, it was 273 inhabitants/km² for a national average of 12.4 inhabitants/km², a factor of nearly 23.

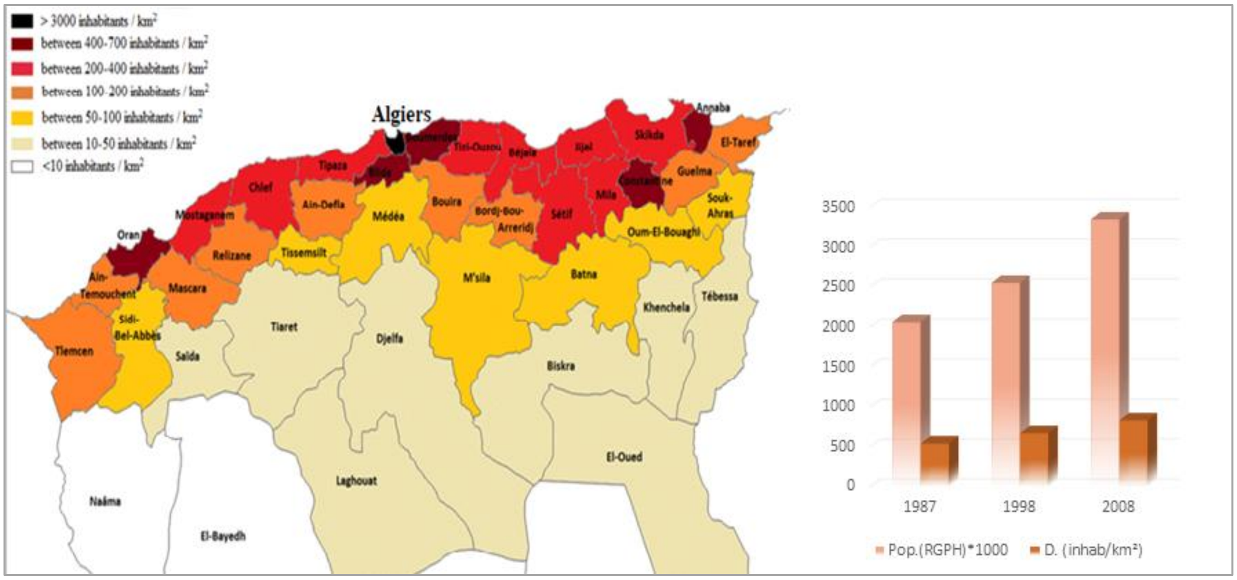


FIGURE 2.13: Geographical distribution of the population in Algeria (NOS/GCPH, 2008, modified).

In 2008, the population (Figure 2.13) of the exclusively coastal domain has a very **high density**, nearly 800 inhabitants / km², far below the national average (NOS/GCPH, 2008). This strong human pressure, which is most often explained by socio-economic considerations, generates strong multiform pollution (organic, chemical, thermal, bacterial, etc.) which necessarily have an impact on the organization of pelagic and benthic life in the coastal zone.

2.6.2 Urbanization increase

This high population concentration has led to **excessive urbanization**. The urbanization rate increased from 1987 to 1998, it recorded a relative increase of 32.25% (NOS, 2006). This urbanization has developed at the expense of agricultural land, the areas granted by agriculture have been estimated at 8790 hectares in the Mitidja, 2850 hectares in the Sahel hills, 1010 hectares in the central coastal plateaus and 5470 in the Oran region. These coastal areas around the three main coastal cities alone have lost 17% of their total farmland. Natural sites (beaches, dunes, etc.) around major agglomerations and coastal industrial perimeters (Algiers, Oran, Annaba, etc.) have not been spared either (MLPE, 2003).

2.6.3 Tourism seaside growth

The fall in oil prices - which accounted for more than 92% of the state budget - led to a number of political and economic restructurings, forcing governments at the time to give more importance to other wealth-generating economic activities such as **tourism seaside** [(1)] (Figure 2.14).

Over-frequented beaches suffer damage that not only threatens their physical integrity, but also their future as a tourist site. The growth of tourist flows becomes a real challenge in the future for the sites that are called to receive these flows (Alloui, 2012). Because the increase in tourism demand will also translate into the increased consumption of natural resources, nuisances and various types of pollution. During this planning period, the environmental vision was absent and many projects involved fragile sites in back-beaches, floodplains of rivers, and even in vulnerable wetlands (Kansab, 2014; Metouchi & Haddoum, 2012), with the absence of domestic wastewater treatment plants that are rich in organic matter, favoring the proliferation of bacteria.

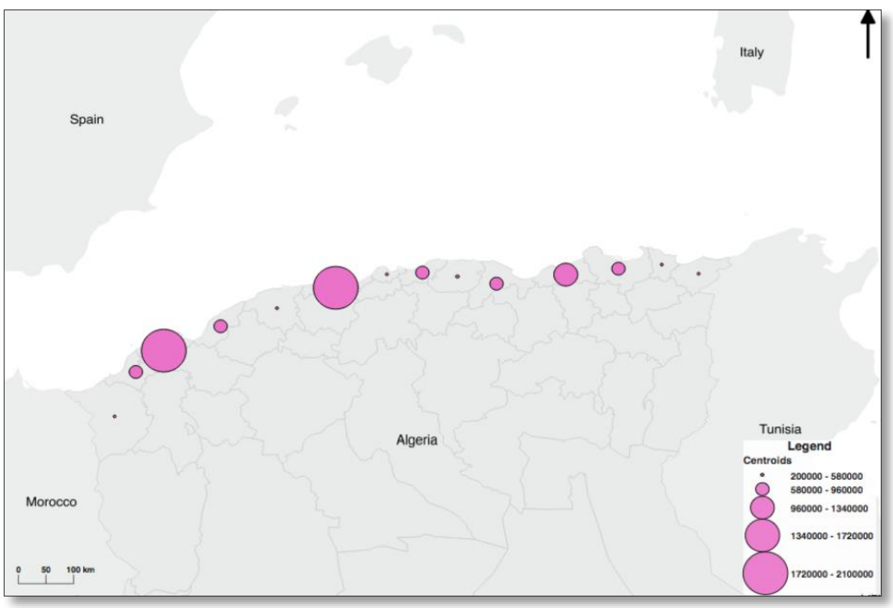


FIGURE 2.14: Map of the Algerian Tourism seaside in the year 2011 (Kies et al., in press a).

[(1)] Law No. 03-03 of 17 February 2003 on expansion zones and tourist sites (EZTS) aims to define the principles and rules for identification, protection, planning, promotion, and management of expansion areas and tourist sites.

2.6.4 Intensive industry

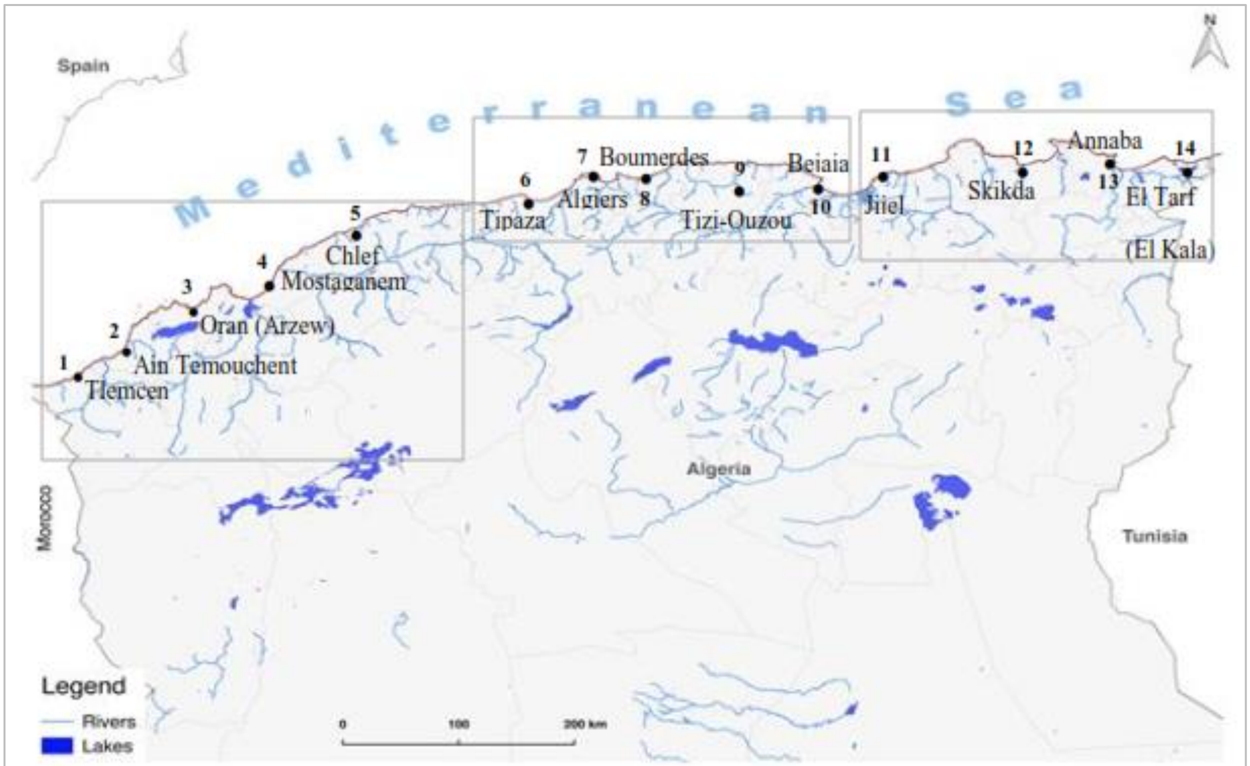
The **extension** of the Algerian **industry** dominated by the petrochemical, chemical, and agri-food industries has been concentrated in the coastal strip where more than 50% of the national industrial units are registered. The Algerian zone alone accounts for 38% of the country's industrial units. The cities of Arzew, Bethioua, and Skikda are poles of the Algerian petrochemical industry and as such, they are considered as the main sources of oil pollution to which are added in a lesser way the ports of Algiers and Bejaia (Figure 2.15).

The Waste Cadaster [(2)] produced by the Ministry of Territorial Development and Environment (MLPE) highlights the presence in the littoral zone of 786 industrial units, 21 activity zones, 13 industrial zones, 14 sand pits, 27 quarries and 91 industries at risk.

According to Grimes (2010), the coastal areas most affected by **water pollution**, are adjacent to the metropolitan areas (Algiers, Oran, Annaba) or neighboring industrial-port complexes which are Ghazaouet, Mostaganem, Arzew, Bejaia, Skikda. These areas are the receptacle for various sources of pollution (Figure 2.15). Domestic discharges of the metropolitan areas; Oran, Algiers, and Annaba are the cities most exposed to the consequences of organic pollution. Releases from the chemical and petrochemical industries; although it is difficult to be exhaustive and without hierarchizing them we find: heavy metals, hydrocarbons and organic compounds, sulfuric acid, fibrous materials and chromic substances, basic elements, nitrogen compounds, cyanides, used catalysts and tars, soda, pesticides, detergents and organochlorines.

Discharges from **thermal power plants**: cooling water from SONELGAZ units increases the temperature of marine waters and their chlorine content (Marsat El Hadjadj, Algiers, Cape Djinet). The leaching of soils from large agricultural areas raises the nutrient content of the surrounding marine areas (discards due to the production of agricultural fertilizers in Annaba).

[(2)] Achieved as part of the National Action Plan for Solid Waste Management. The policy of controlling, improving and modernizing the management of special waste materialized in the promulgation of Law 01 - 19 of 12 December 2001 on the management, control, and disposal of waste and the introduction of taxes to encourage the destocking of waste.



1	2	3	4	5	6	7
ALZINC	Cement, Sandpit, Ferphos.	Petro-chemical, NIGC, Alzofer, Fertalge	Soachlore, GIPEC,Giplait, Sugar, Food Industry.	SMI, Alufer, Alumetal, Glassware, GIPEC, Food Industry.	SMI, Alufer, Alumetal, Glassware, GIPEC, Food Industry.	Food Industry GIPEC, Cosmetics, Power plant, Tannery, Hydrocarbons .
8	**9**	**10**	**11**	**12**	**13**	**14**
Giplait, Food Industry. Aluminum Medications Power plant	Abattoirs Food Industry Giplait, Oil mill, Electo Industry, cotton	Packaging, hydrocarbons, Naphtal, Food Industry,	Cannery, Food Industry, Glass, Power plant, Tannery	Petro-chemicals, Power plant, Gas Industry.	Food Industry, Ferphos, Ferrovial Arcelor Mittal, Power plant, NP fertilizers.	Canning, Food Industry, Steel Mill, Cracking Center

FIGURE 2.15: Main sources of the domestic and industrial pollution of Algerian coastal Wilayas (Grimes, 2010; modified).

2.6.5 Hydrological alterations

The increase in drought which has an impact on the potential in the surface water of the north of the country with a trend decrease estimated at 6.5 billion m^3/year at the end of the 1970s, 5 billion m^3/year at the end of the 1980s, and 4 billion m^3/year at the end of the 2000s. Dams, reservoirs, diversions of canals, water withdrawals for irrigation, industrial uses and even domestic ones; deforestation and urbanization have an impact on the flow regime of surface water. The main water user sectors in Algeria are agriculture, industry and the domestic sector. In 2002, total water consumption reached 3.3 billion cubic meters, divided between agriculture (1.8 billion m^3), industry (0.2 billion m^3), and domestic uses were estimated at 1.3 billion m^3 (NOS, 2006).

Erosion threatens several million hectares. Soils are sensitive erosion caused by several factors (climate, overexploitation of land, etc.). A study carried out by the General Directorate of Forests (DGF), which affected 34 watersheds out of 52 existing at the national level, has shown that 13 million hectares are threatened by water erosion (NOS, 2013).

2.6.6 Domestic, industrial, and agricultural discharges

The domestic, industrial, and agricultural **discharges** [(3)] transported by rivers from the interior of the country for the discharges at the level of the Algerian Sea contain different forms of physicochemical pollutants such as the metallic, the nutrients, the bacteria, the detergents, and solid rejects, etc. Wastewater is one of the major causes and an important source of degradation of the Algerian coastal marine ecosystem. These wastewaters, which are mainly loaded with organic matter, suspended solids, detergents and lubricating oils, generate organic and chemical pollution.

[(3)] Urban discharges, wastewater treatment plants, and industries (partial mapping). Executive Order No.: 06-141 of 20 Rabie El Awwal 1427 (corresponding to 19 April 2006) defining the concentration limits in industrial effluent discharges. In addition, the ANRH has its own qualifications scale.

This situation is aggravated by the lack of water treatment before being discharged at sea in most cases. Almost all treatment plants are either inoperative or operating intermittently or partially. The lack of pre-treatment in the companies and the lack of care provided by the disposal of sewage sludge complicates the situation.

Coverage in treatment plants in the coastal zone remains low, in fact, of the 68 treatment plants surveyed for the entire Algerian territory, 17 are located in the littoral zone, of which 10 are at a standstill (Grimes, 2010). In terms of capacity, treatment plants operating normally in the coastal zone represent only 25.6 % of coastal stations and 14.5 % of national treatment plants. A treatment capacity of 1 723 000 equivalent/inhabitant is low compared to the coastal population. Some coastal towns that are poorly equipped with industrial units in coastal areas are also responsible for specific pollution. This is the case of city of Annaba (ASMIDAL complex) for nitrogen and phosphate compounds. For the West region, the main sources of waste being the Arzew industrial zone that generates the most waste of sludge from oil refining, cleaning, and maintenance of the hydrocarbon storage tanks. The central region is characterized by a large production of lead waste.

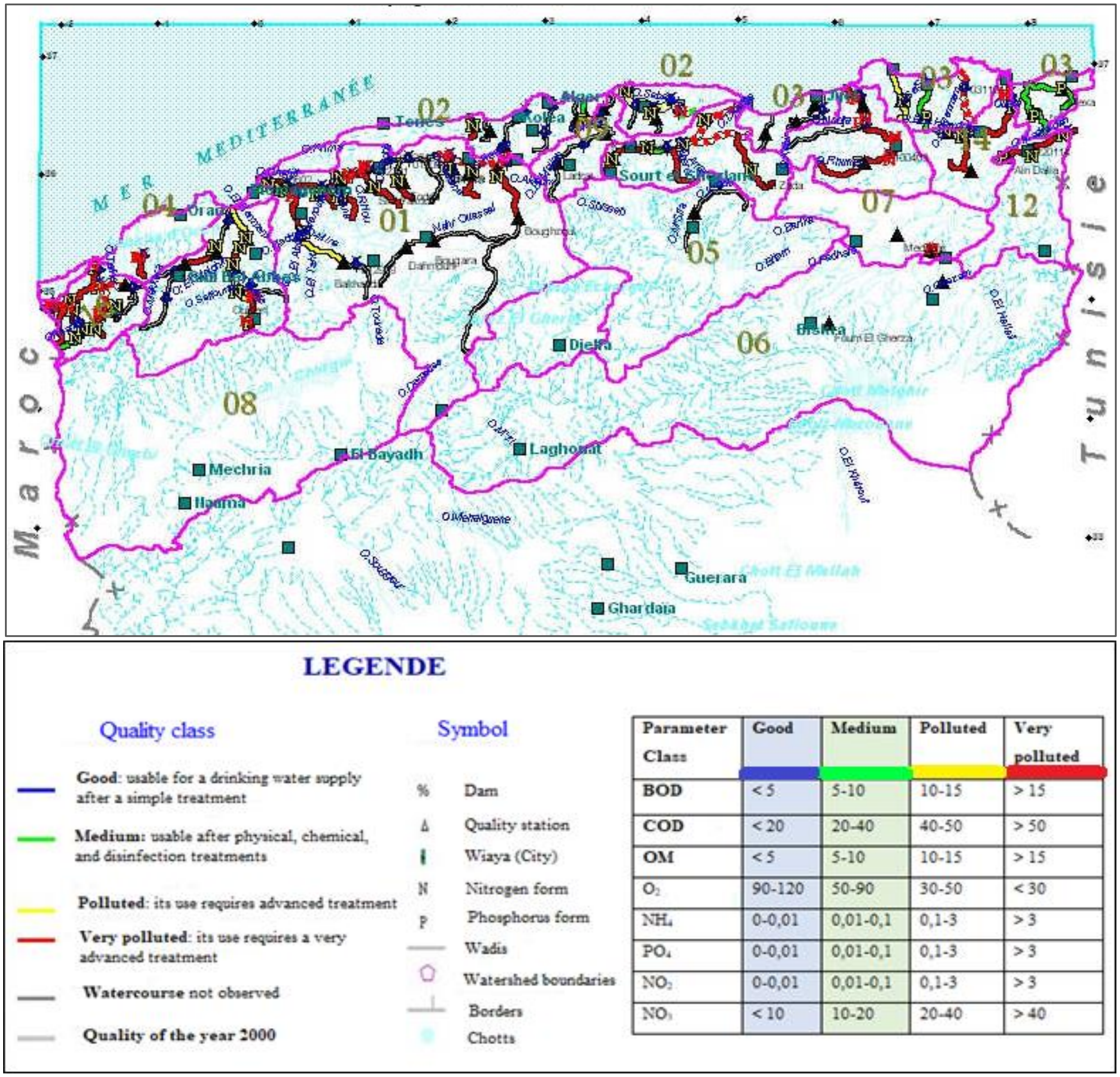
2.7 Water pollution

2.7.1 Rivers water contamination

Before the industrialization program, the only polluted river in Algeria was El-Harrach river in Algiers. Today, because of the inappropriate implementation of many industries, on the model of those of the industrialized countries, the result has become disastrous (Figure 2.16). Pollution affected most of the river and coastal waters of different wilayas (Sutton & Zaimeche, 1992; UNEP-MAP RAC/SPA, 2009).

In the east of Algeria, exactly in the wilaya of Annaba, the Seybouse river which received daily 50,000 m^3 of waste from the phosphate complexes of the city. In the same area, the Saf Saf river near Skikda was severely polluted by the marble complex dust as well as spills of oil, tar and another refinery waste. In Azzaba, near Skikda, all water resources were dangerously affected by releases from the mercury complex so that water consumption became very risky (Nehar, 2016).

At the west of Algeria, Cheliff River, the largest watercourse has been reported to have contained various pollutants from nine wilayas of the country it passes through including Mostaganem, Relizan, Ain-Defla, Chlef, and others (Kies & Taibi, 2011).



Parameter Class	Good	Medium	Polluted	Very polluted
BOD	< 5	5-10	10-15	> 15
COD	< 20	20-40	40-50	> 50
OM	< 5	5-10	10-15	> 15
O_2	90-120	50-90	30-50	< 30
NH_4	0-0,01	0,01-0,1	0,1-3	> 3
PO_4	0-0,01	0,01-0,1	0,1-3	> 3
NO_2	0-0,01	0,01-0,1	0,1-3	> 3
NO_3	< 10	10-20	20-40	> 40

FIGURE 2.16: Map of surface water quality **monitoring** [(4)] for the year 2001 (source: http://www.anrh.dz/).

[(4)] Monitoring networks to inland and coastal waters are established and managed by the public sector: ANRH and MATE. The coastal waters monitoring data record is incomplete.

The Cheliff river showed that its pollution reached chronic proportions. Its waters are filled with all kinds of impurities, heavy metals (zinc, chromium, acetone, etc) and nutrients. Pollution levels in the Cheliff were two to four times higher than the safety levels of international standards (Belhadj, 2001).

In the center of Algeria, around Algiers, more than one hundred enterprises industrial, public and private, reject waste in the Samar river and El-Harrach river while the Boudouaou river has become even more polluted by the industrial zone of Rouiba as the domestic water of the region of Rouiba-Reghaia. This river has become unfit for consumption. As a result, samples of seawater and crustaceans caught between Algiers and Bordj El Kiffan showed alarming amounts of microbes (Nehar, 2016).

Water treatment plants are so much in demand that these anti-pollution systems have failed completely. By the end of 1988, only 20 water purification plants (El Kalla and Bejaia) were operating correctly (MLPE, 2003). All this threatens the health of people who use unsafe water. 19 cases of water-related diseases were reported in 1988 in the region of Ain Temouchent and 28 in Skikda, but in general this problem was underestimated. In Oran, drinking water pollution caused an outbreak of gastroenteritis and 400 cases of typhoid were reported throughout the country in 1988 (Sutton & Zaimeche, 1992). In the 2000s, a total of 17 major rivers and 15 Algerian estuaries were cited as receiving each year, on average, 65 000 tons of waste from poultry farming, 60 000 tons of slaughterhouse impurities, 54 000 tons of wine industry residues, 30,000 tons of impurities in the edible oil industry, and 500 000 tons of hydrocarbon waste (NOS, 2006).

2.7.2 Coastal water quality alteration

According to Nehar (2016), the telluric inputs of pollutants are important. The volume of untreated wastewater from urban populations and industrial centers arriving at ports is estimated at 1 million m^3 / day. Pollution flows to ports reveal significant loads sometimes exceeding 88 000 tons / year of BOD and 186 000 tons/year of COD. In terms of heavy metal pollution, 5 ports exceed the standards for mercury, 3 for lead, 4 for copper, 4 for zinc, and 1 for chromium.

Finally, 5 ports exceed the limit value for microbial pollution (> 100,000 E. coli/100 ml). Outside the port areas, many sites are prohibited from swimming because of poor bacterial water quality: 36 zones are prohibited from swimming on 292 zones that were analyzed in 2009 (MATE-PAP CAR/PAM, 2013)

The increases in nutrient concentrations (N, P, and Si) depending on the flow of water resources of the large River Basin and soil leaching (Kies and Kerfouf, 2014) which are high in wet periods (winter mixing in December) and are low in dry periods (May), also related to the strong coastal circulation (winter mixing in December and summer upwelling-stratification in August) in this zone. The strong dynamics of the Atlantic coastline along the western zone of the Mediterranean Sea characterized by the dominance of the Algerian Current. Let us think about the exchanges that can take place between the East of Morocco, West of Algeria, and Spain especially (Morán et al., 2001). According to Louzao et al. (2012), the strong concentration of nutrients and *chlorophyll a* can migrate from the south-west of the Mediterranean by the Algerian current to reach other regions such as Spain located in the north-west of the Mediterranean.

2.8 Loss of biodiversity

In Algeria, the absence of systematicians of different groups hampers the improvement of knowledge about specific diversity, in fact very few specialists currently exist for phytoplankton, zooplankton, macrophyte algae, zoobenthos, selachians as well as some seabirds. Grimes et al. (2004) count for the entire Algerian coastal marine area to 3183 species of which 3080 were confirmed after 1980.

This wealth is divided between 720 genera and 655 families, the marine flora is estimated at 713 species grouped into 71 genera and 38 families, with littoral and insular vegetation, marine and coastal ornithological fauna, the known biodiversity of the Algerian marine ecosystem is 4150 species, of which 4014 confirmed (950 genera and 761 families). It should be noted that this assessment of biodiversity remains below the actual value because most of the surveys are conducted at accessible depths limited to less than 40 m for hard bottom benthos. The available data are fragmented for the three sectors (East, Center, and West), and there is a lack of an inventory of Algerian freshwater and estuarine biodiversity and their dynamics with respect to the coastal zone. The main constituents of national biodiversity remain representative of Mediterranean marine and coastal biodiversity, while the level of endemism of this biodiversity remains to be assessed (Vaissière R. & Fredj G., 1963), and entire segments of the coast remain unexplored to date, due to the scarcity of marine and freshwater taxonomists. Many groups are marginalized such as the benthic macrofauna of hard substrates, especially coralligenous (sponges, actinians, etc.) as well as certain groups of soft substrates such as sipunculidiens, nematodes, nemertes, oligochaetes, isopods, etc. (Grimes, 2011).

Intensive fishing results in the loss of some marine species and the depletion of fish stocks (Jarboui et al., 2003). The disappearance of the Mediterranean monk seal from its last refugia sites which are marine protected areas (MPA) in western Algeria near the Habibas and Rachgoun Islands and in El Kala located Eastern Algeria (UNEP/MAP. 1994), and the marine flora is in many places in poor condition, in particular the Posidonia meadows and Cystoseira grasslands are a serious indication of the **degradation of the quality of the environment** (CAR/ASP, 2003), although the disappearance of this species is a trend in the Mediterranean. Does the disappearance of the monk seal announce other extinctions for other species along the Algerian coast? In the absence of a real device of continuous observation, it is difficult to answer, even if our own observations indicate the rarefaction of certain species including the big mother-of-pearl, the giant limpet in certain segments of the Algerian coast, and the dynamic (Figure 2.17) of certain seabirds such as shearwaters (Louzao et al., 2012).

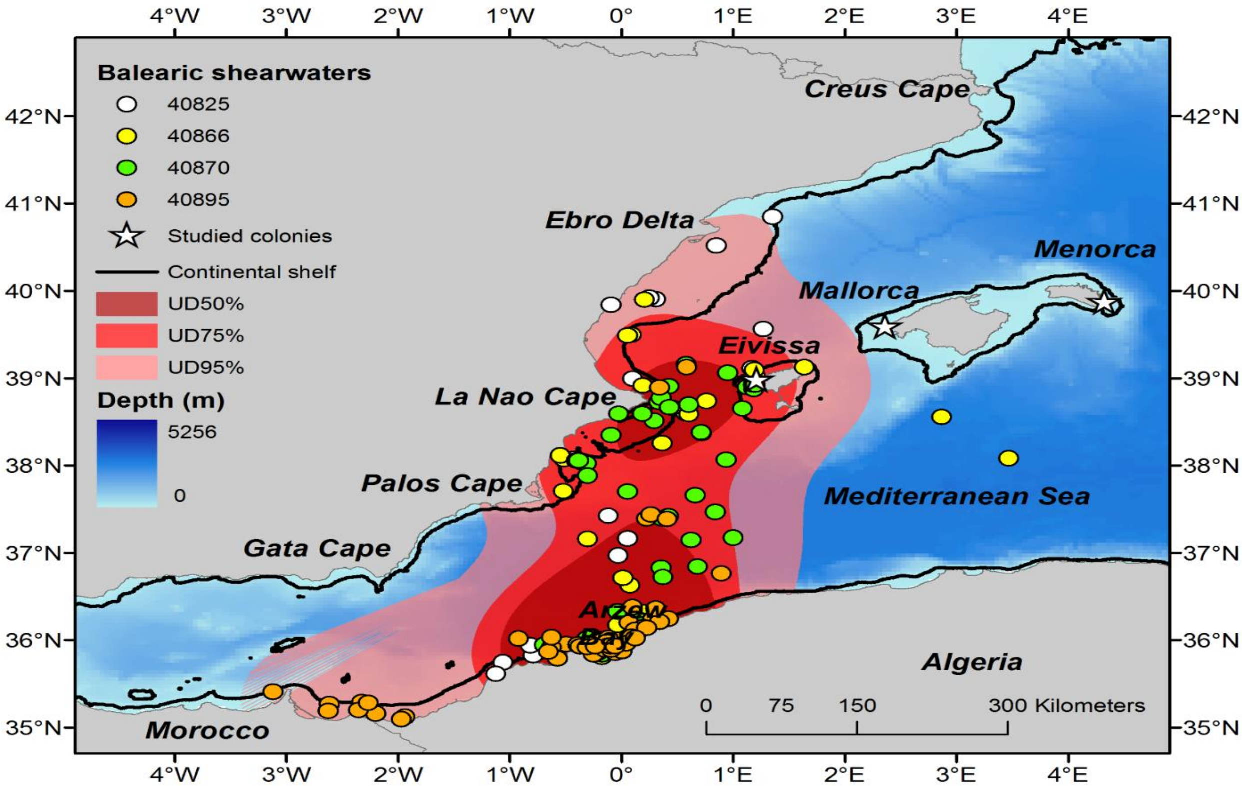


FIGURE 2.17: Shearwaters locations in the western Mediterranean Sea (Louzao et al., 2012)

More than 70 marine and coastal species belonging to many taxonomic groups (sea cucumbers, bivalves, gastropods, cephalopods, sponges, crustaceans) are untapped in Algeria (Grimes., et al 2004; Grimes, 2011). This valuable part of biodiversity requires evaluation studies to objectively consider their economic returns and the sustainability of these resources (Seridi, 2007). Biodiversity data also suffer from their punctual, sporadic and episodic nature, not necessarily reflecting the dynamic and evolving aspects of different populations (Grimes et al., 2000). The rare work on this dynamic concerns exploited populations (small pelagic, mollusc, cephalopods, sharks and rays, sea urchins, shrimps, etc.). This deficit in terms of dynamic study does not allow a correct assessment of the factors controlling the evolution of this biodiversity and the interactions it may have with the environment (Grimes et al., 1999). Finally, the introduction of some **invasive species** (Figure 2.18) produces the destruction of the natural balance and causes the extinction of species from the environment in question, as *Caulerpa racemosa* was identified in Algeria at depths ranging from 0.3 to 29 m for the first time in Algiers in 2006 (Ould Ahmed and Meneisz, 2007) and in Mostaganem in 2008 (Bouidjra et al, 2010 a, b).

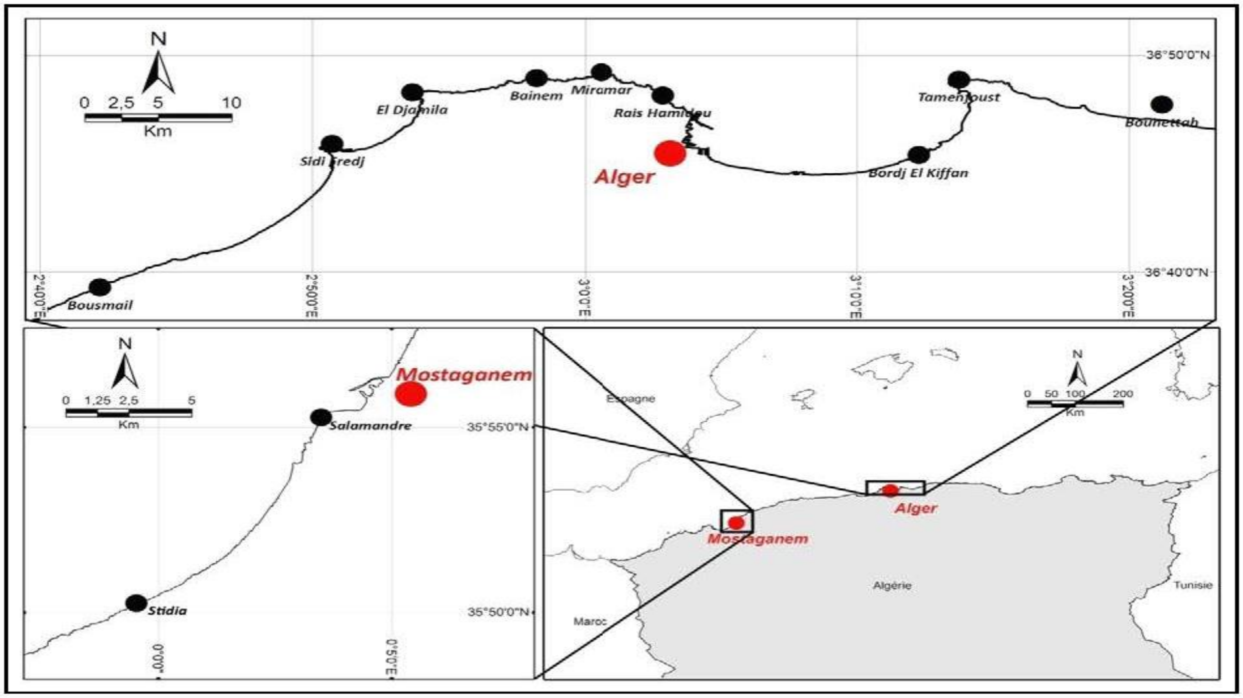


FIGURE 2.18: Locations of *Caulerpa racemosa* determined from (black points) the Algerian coast (*in* Bentaallah and Kerfouf, 2013).

2.9 Conclusion

Algeria, with its geographical location and ideal geomorphology, its rich but fragile environment, makes it a dynamic area and a region that is changing rapidly. In addition to climate change impacts, demographic and urban growth, as well as the development and concentration of most of these tourist, fishing, agricultural, and industrial activities on the coastal strip, have generated serious environmental problems, some of which are irreversible. The analysis of the different forms of degradation of the environment studied in this chapter, allowed us to have an idea, more or less exhaustive, on the impact of this development on the coastal and estuarine zone at the national scale of Algeria (macroscale). Admittedly, this country has experienced an economic and social boom in recent years, but has also caused a series of environmental problems, especially those of pollution and environmental degradation. 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). We have devoted the next chapter to the study of the evolution of the Mostaganem coastal zone (wilaya from the west of Algeria).

Chapter 3:

Mostaganem Coastal issues

Objective:

Characterization of Mostaganem coast and microscale assessment of the “pressure-impact”

3.1 Climate change

3.1.1 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 the months of October to December are 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 (Bensahla Talet et al. 2014).

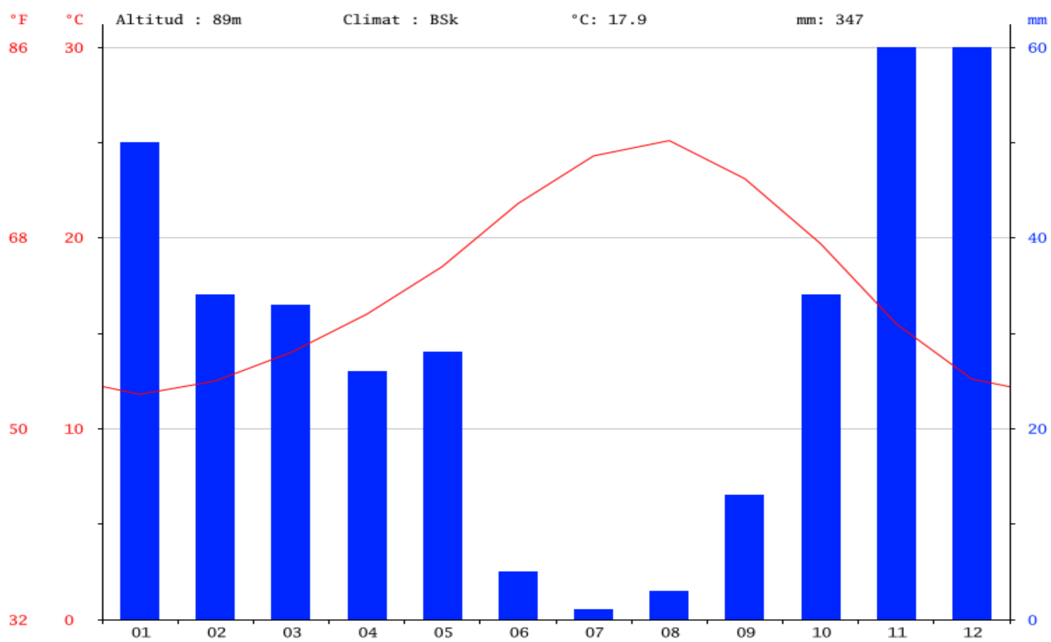


FIGURE 3.1: Bioclimatic diagram of Mostaganem (*Source: https://fr.climate-data.org*)

Taibi et al. (2015) 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 3.1).

3.1.2 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 (Remini et al., 2015). 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 estuarine.

Erosion is very important in the Cheliff watershed (Harkat et al., 2012; Remini et al., 2015). Demmak (1982) showed that erosion rates specific reach 4000 t / km2 / year on the chain of coastal Dahra. According to the MATE (2002), Floods of the city of Mostaganem caused by Ain Safra River on November 1900 with discharges of 25 m3/s, November 1927 with discharges of 35 m^3/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 3.2).

FIGURE 3.2: Flood of Cheliff river in December 2017.

3.1.3 Land-Coastal dynamic

According to Badji et al. (2015), on land, Mostaganem area (Figure 3.3) 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.

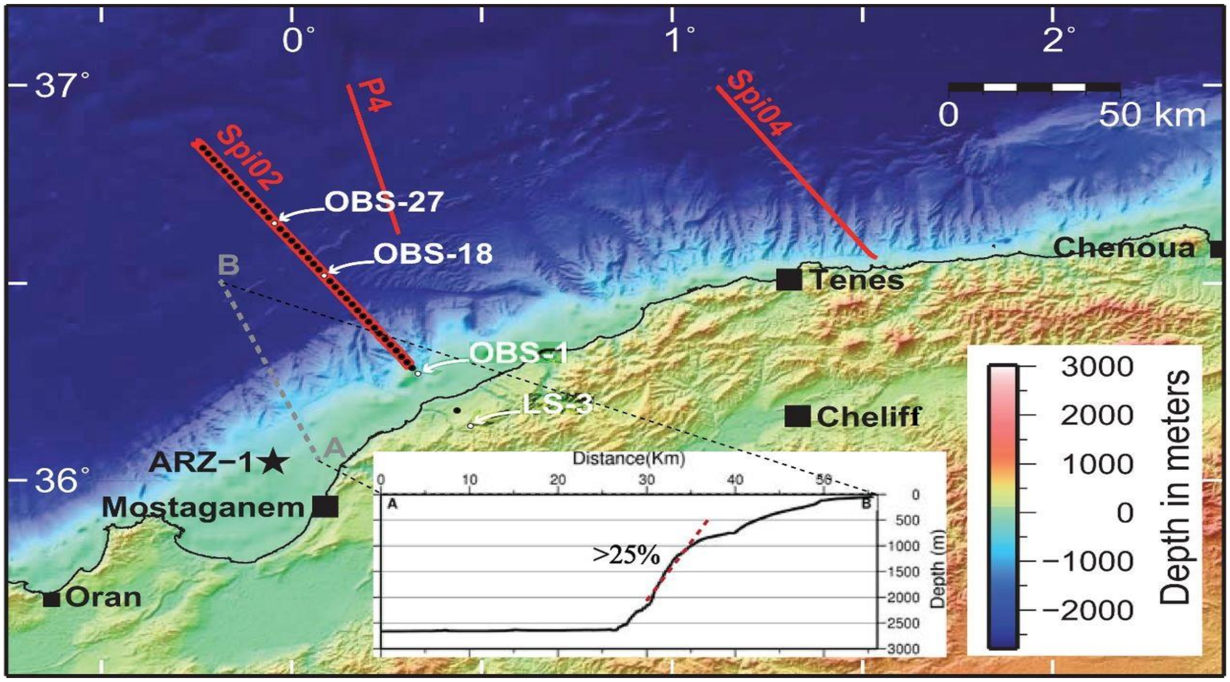


FIGURE 3.3: Land-coastal dynamic according to Badji et al. (2015).

In the sea, Mostaganem area (Figure 3.3) is considered part of 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), calculated speeds are 30 to 40 km from the coast and 50 m depth, reaching 20 to 30 cm/sec at 300 m depth. This current generates an opposite circulation, its speed is very low, it can increase when the winds blow from the North. They are of 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 Atlantic and Mediterranean waters.

3.1.4 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 with respect to the sea level. Rocky shores are more common in the west than in the east (Grimes et al., 2003). 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, fueled more particularly by the contributions of Cheliff basin (Kies & Taibi, 2011). 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 " (Kies & Taibi, 2011), as well as natural factors (degraded forests and relatively low vegetation cover).

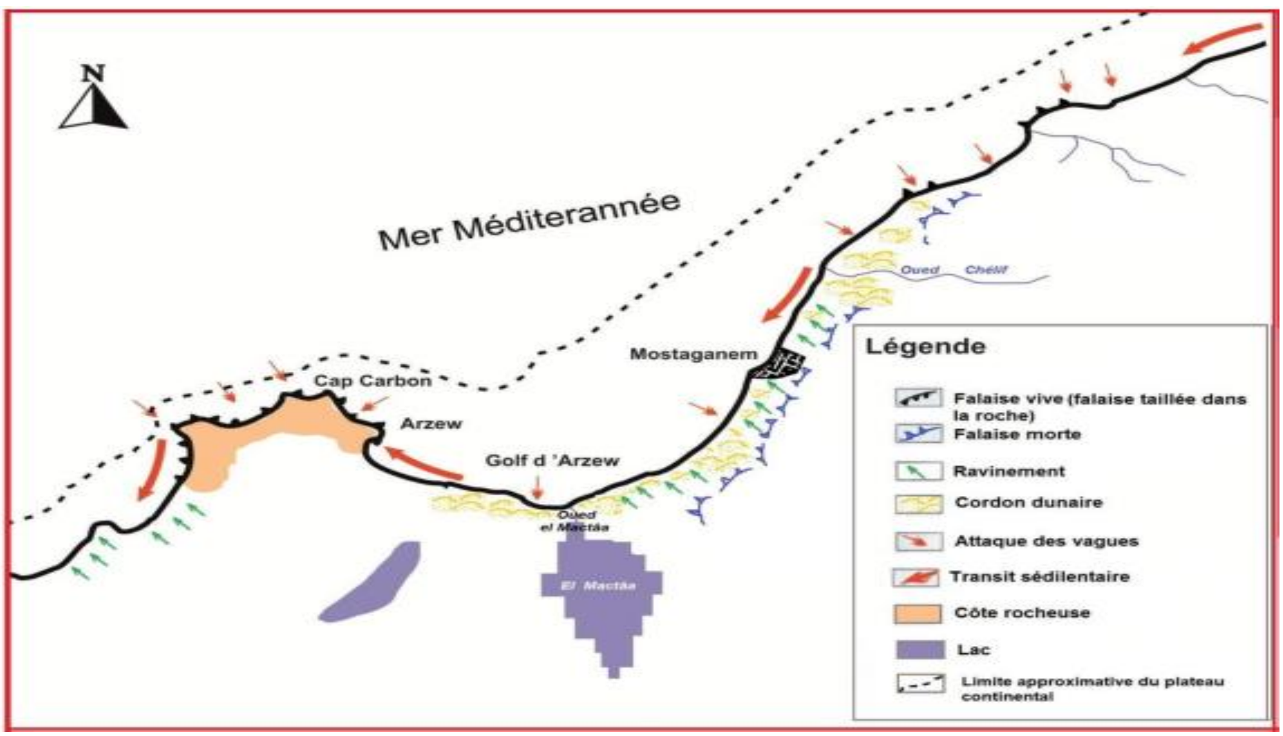


FIGURE 3.4: Morphological sketch of the Gulf of Arzew (Aggoun, 2013).

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 (Grimes et al., 2003). This mudflat is the consequence of the contributions of fine elements of Cheliff basin (Kies & Taibi, 2011; Kies et al., in press b).

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 (Kies et al., in press b). The geomorphological aspect is reflected by the presence of cliffs, more or less high, subject to marine erosion, thus participating in the feeding of the adjacent beaches (Figure 3.4). 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 (Kies et al., 2012; Kies et al., in press b).

3.2 Anthropic pressures

3.2.1 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 (NOS, 2013).

This concentration of the population and the activities on the coastal fringe thus leads to strong tensions (Figure 3.5) in the use of the water resource (see Annex I). In addition, the population discards thousands of tons of solid urban waste, evacuated to 9 wild dumps located on the coastal strip.

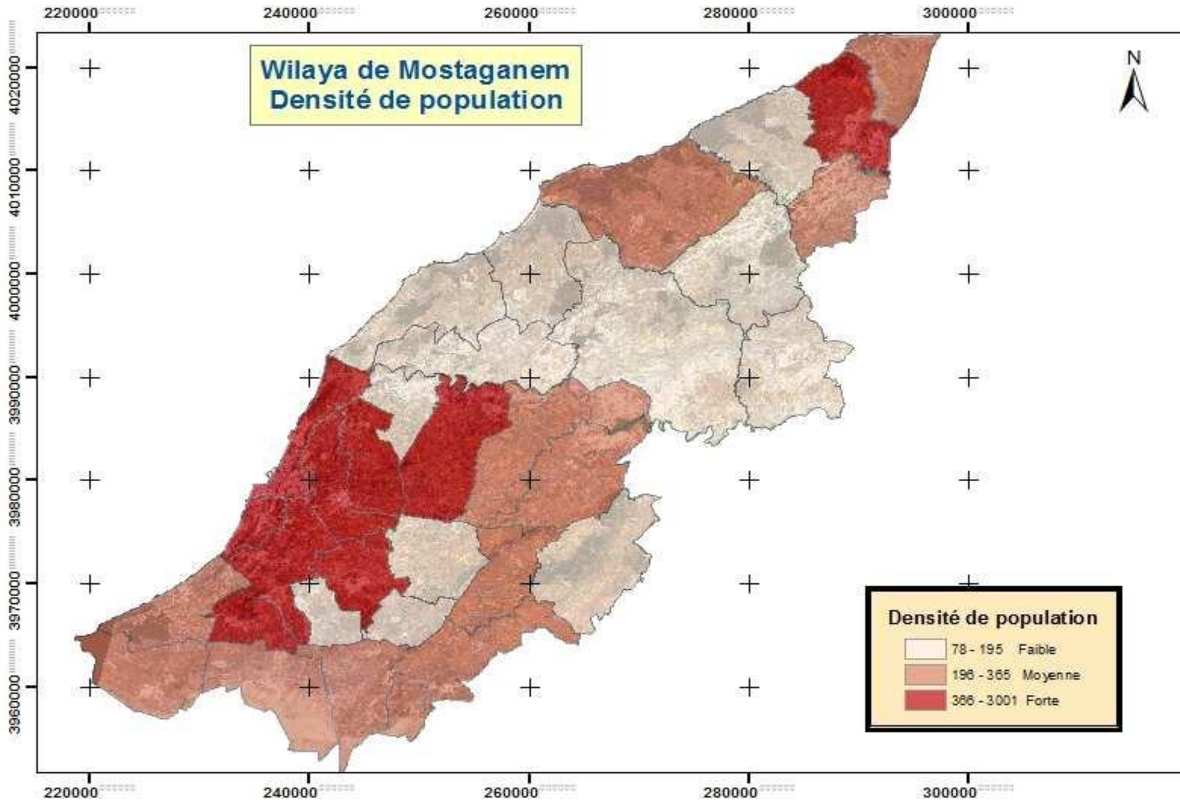


FIGURE 3.5: Population density of the wilaya of Mostaganem

3.2.2 Urbanization

Coastal linear urbanization threatening the 300 m zone: 254 ha of the urbanized area encroaches on the 300 m band. In addition, 18 km of coastline of the coastal zone are already urbanized in Mostaganem (Figure 3.6).

The longitudinal extension of the urbanized perimeter beyond 3 km: Agglomerations in the coastal domain exceeded 15 km (Figure 3.6).

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 with Mazagran, Kharouba and Hassi Mameche.

Extraction of sand: destined for urbanization, generating intense erosion notably in Sidi Lakhdar (300 000 T / year).

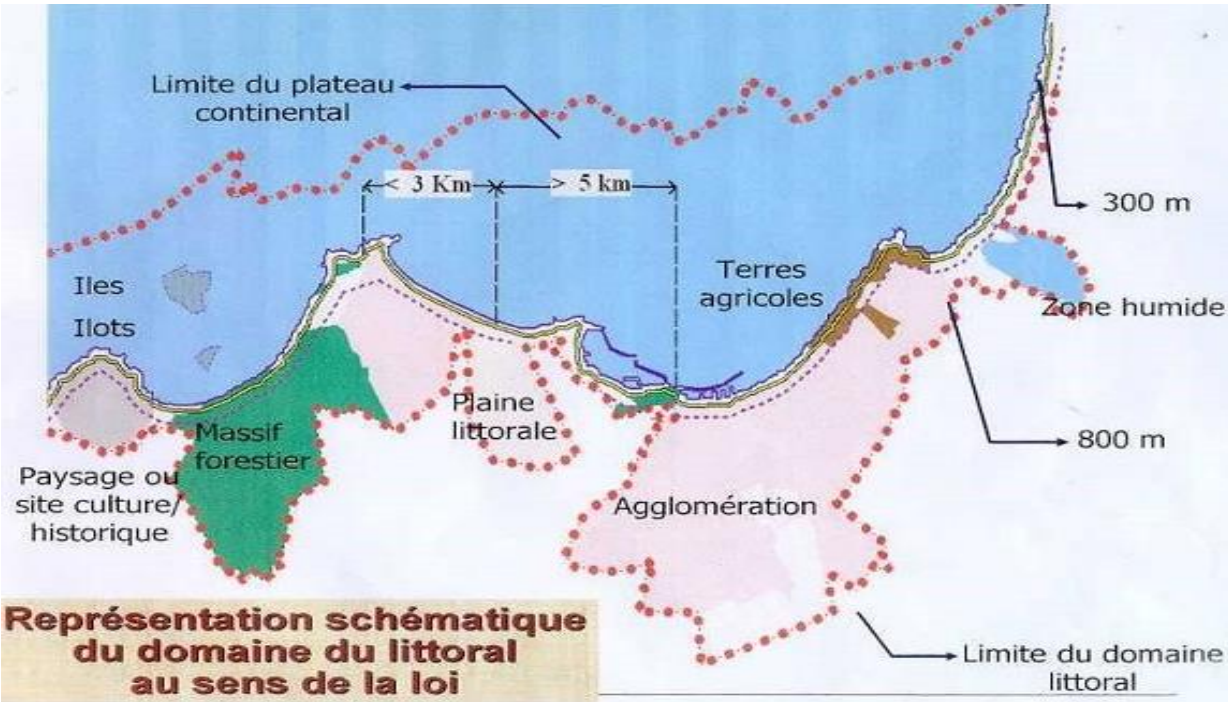


FIGURE 3.6: Schematic representation of the coastal zone in the sense of Algerian law

3.2.3 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 3.5).

Table 3.2: Physico-chemical characteristics of liquid industrial discharges at Mostaganem (ANRH, 2005 *in* Aggoun, 2013)

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

3.2.4 Agriculture

Mostaganem has more than 14000 ha of agricultural land (Figure 3.7), is considered the most fertilizer consuming province in Algeria with an average of 8375 T.

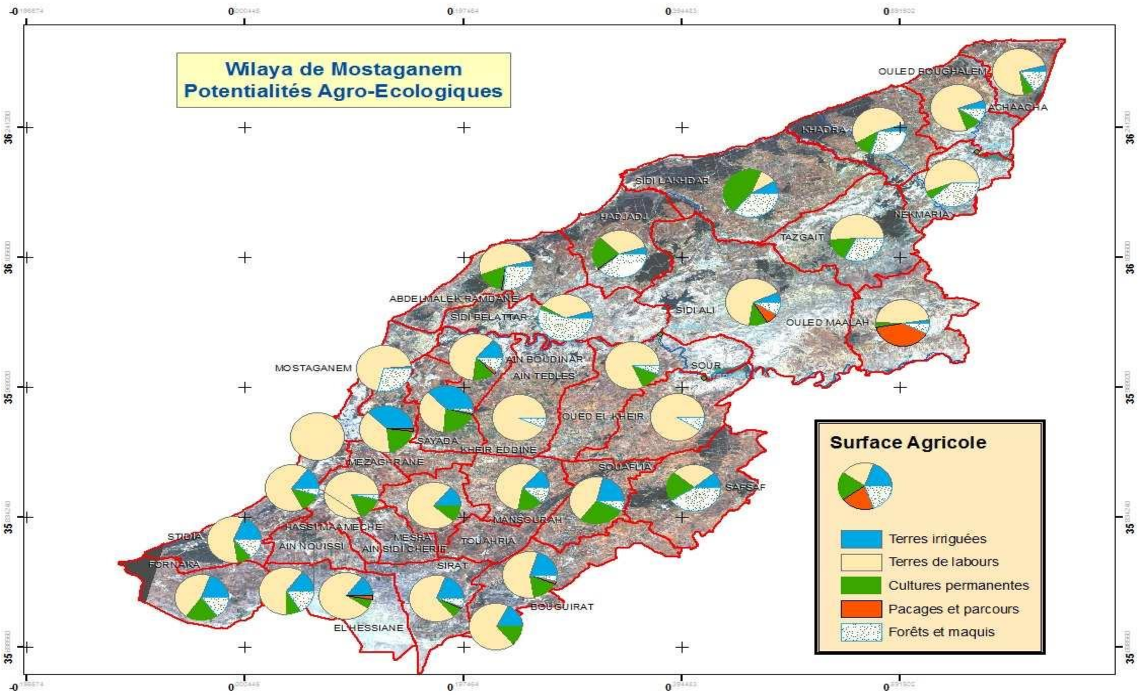


FIGURE 3.7: Agro-ecological potentialities of the wilaya of Mostaganem

3.2.5 Fishing

Intensive fishing in the area of 3 nautical miles. During the period from 2001 to the year 2008 (Figure 3.8), there was an 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.

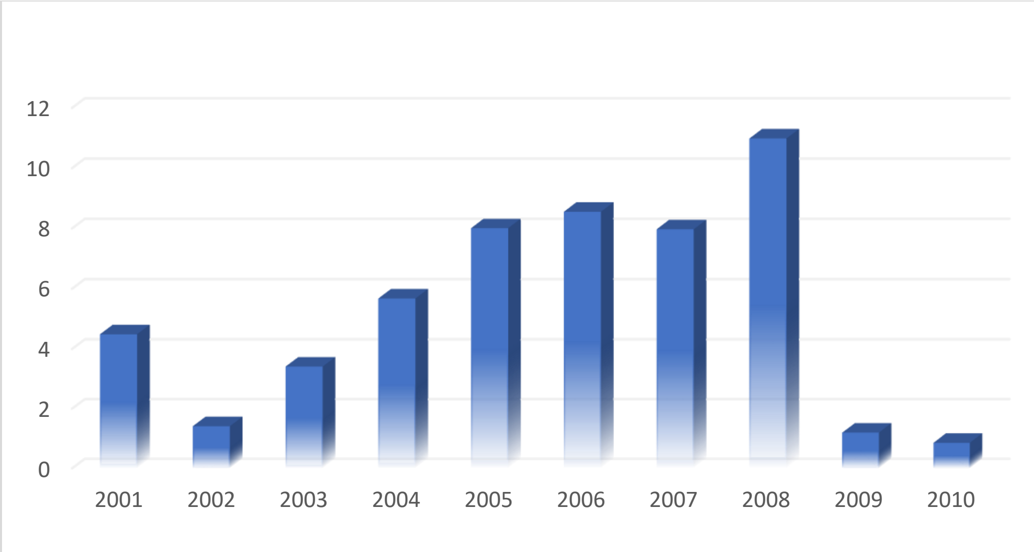


FIGURE 3.8: Pelagic landings / Demersal landings

Agglomeration wastewater is discharged directly into basins for both types of ports, commercial and fishing ports (Figure 3.9 and Figure 3.10).

FIGURE 3.9: Agglomeration wastewater discharged into the harbor basin of Mostaganem (PHOTO by KIES F)

FIGURE 3.10: Water pollution of the harbor basin of Mostaganem
(PHOTO by KIES F)

3.2.6 Tourism seaside

Intensification of activities related to seaside tourism (Figure 3.11, Figure 3.12, and Figure 3.13), 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 Z.E.T, decrees are the wilaya (province) of Mostaganem with 16 Z.E.T, a surface of 4724.8 ha, an occupancy rate of 64.49 %, and a remaining area of 1677,4 ha (Figure 3.11). Mostaganem has 10 classified sites and monuments, with a classification rate of 20%.

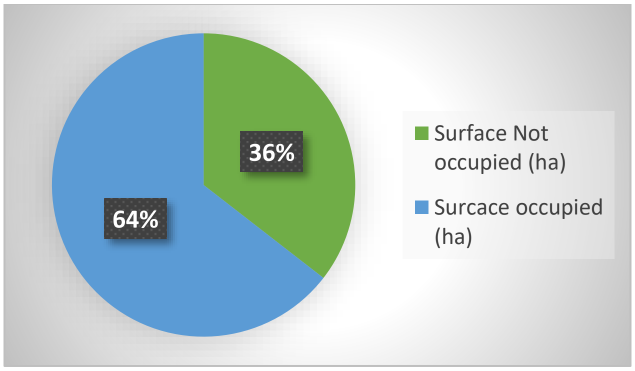


FIGURE 3.11: Occupancy rate of tourism seaside

FIGURE 3.12: Coastal linear urbanization in Sidi El Majdoub threatening the 300 m zone (PHOTO by KIES F)

FIGURE 3.13: Disturbance of coastal water transparency in Sidi Majdoub (PHOTO by KIES F)

3.2.7 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 (Taki et al., 2013; Metouchi & Haddoum, 2012).

Hydrographic changes due to dam construction, consumption of different socio-economic activities, and climate change (Ammari, 2012). Freshwater, estuarine, coastal, and marine pollution with invasive species abundance such as *Caulerpa racemosa,* and toxic algae bloom including *Pseudo-nitzschia*. Regression of Seagrass meadows and other endemic species in some areas of Mostaganem coast. Different pollution indicator species have been highlighted in the coastal areas of Mostaganem, including *Capitella capitata*, *Scolelepis fulginosa*, *Audouinia tentaculata*, *Corbula gibba* (Grimes, 2010; Grimes et al., 2010).

3.2 Water pollution

3.3.1 Coastal water degradation

In the coastal zone, the main sources of water degradation are the polluted rivers, urbanization, wastewater discharge directly into water sea without treatment (Figure 3.14 and Figure 3.15), population growth.

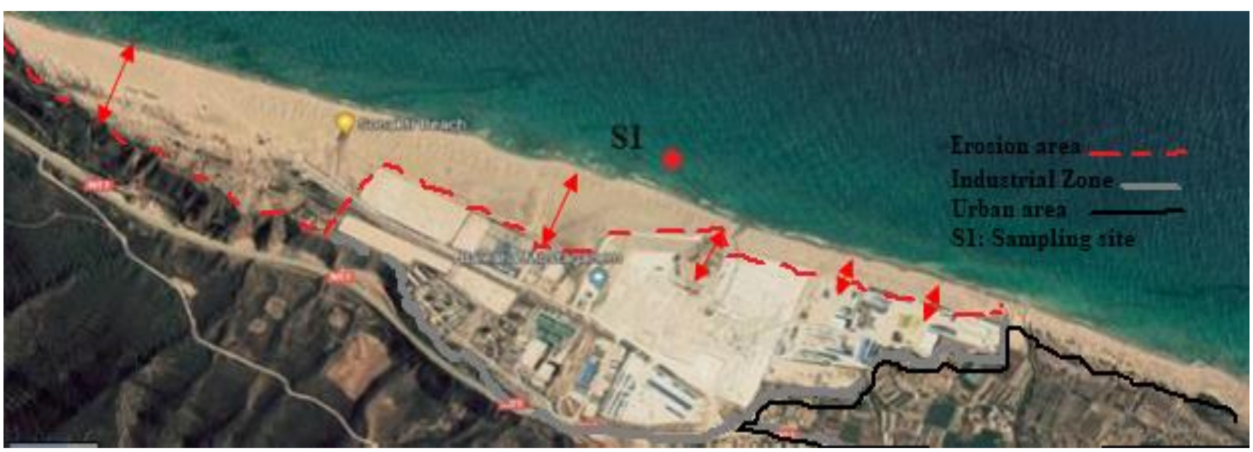


FIGURE 3.14: Coastal linear urbanization and industrialization in Sonactere in 300 m zone (Source Google maps, modified).

However, two other issues arise with greater acuity in the coastal zone the 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 (Kies et al., 2012), macroinvertebrates (Grimes, 2010; Grimes et al., 2010; Kies et al., in press b), micro-algae (Nehar, 2016; Kies et al., 2015), macro-algae (Kies et al., 2015), certain of which are harmful to the coastal and marine ecosystem (Bouidjra, 2010a; Grimes, 2010; Nehar et al., 2015; Nehar, 2016).

FIGURE 3.15: Pollution from land-based sources (*in* Aggoun, 2001, modified).

3.3.2 River water alteration

In addition to the Mactaa with its area of 14389 km^2, which is classified as a wetland of international importance signed at RAMSAR, Cheliff river is the longest wadi in Algeria with its area of 43 750 km^2, its average yield of 1 540 hm^3 / year, and its 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 (Belhadj, 2001). The domestic wastewater treatment system is estimated at only 2.8% (MATE, 2002).

Drainage of the basins downstream to the west during floods and eastwards during periods of drought (Table 3.6). The large total population in the Cheliff catchment area is estimated at more than 3 000 000 inhabitants, the estimated discharge rate of sewage having an impact on water quality is 72 000 m^3/d. Cheliff River has its source in the Saharan Atlas, near Aflou in the mountains of Jebel Amour. The Cheliff wadi (Table 3.6 and Figure 16) is fed by several tributaries and groundwater, by the Ghrib dam situated upstream, or by tributaries (Mina wadi).

Table 3.3: Characteristics of the altitudes and Slope-indices of Cheliff sub-basins

Sub-basins	Station	Altitudes characteristics					Slope index characteristics (SI)		
		Code	Max (m)	Min (m)	Mean (m)	SD (m)	SI %	SI m/Km	Relief according to SI
Ghrib Cheliff 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

Source: ANRH, modified

The results of the Table 3.6, according to the Slope Index (SI) classification, show that the whole basin ranks in the very strong relief class. The area below the Cheliff Basin of Mostaganem (Cheliff Maritime Wadi) is the highest (993 ± 1,635).

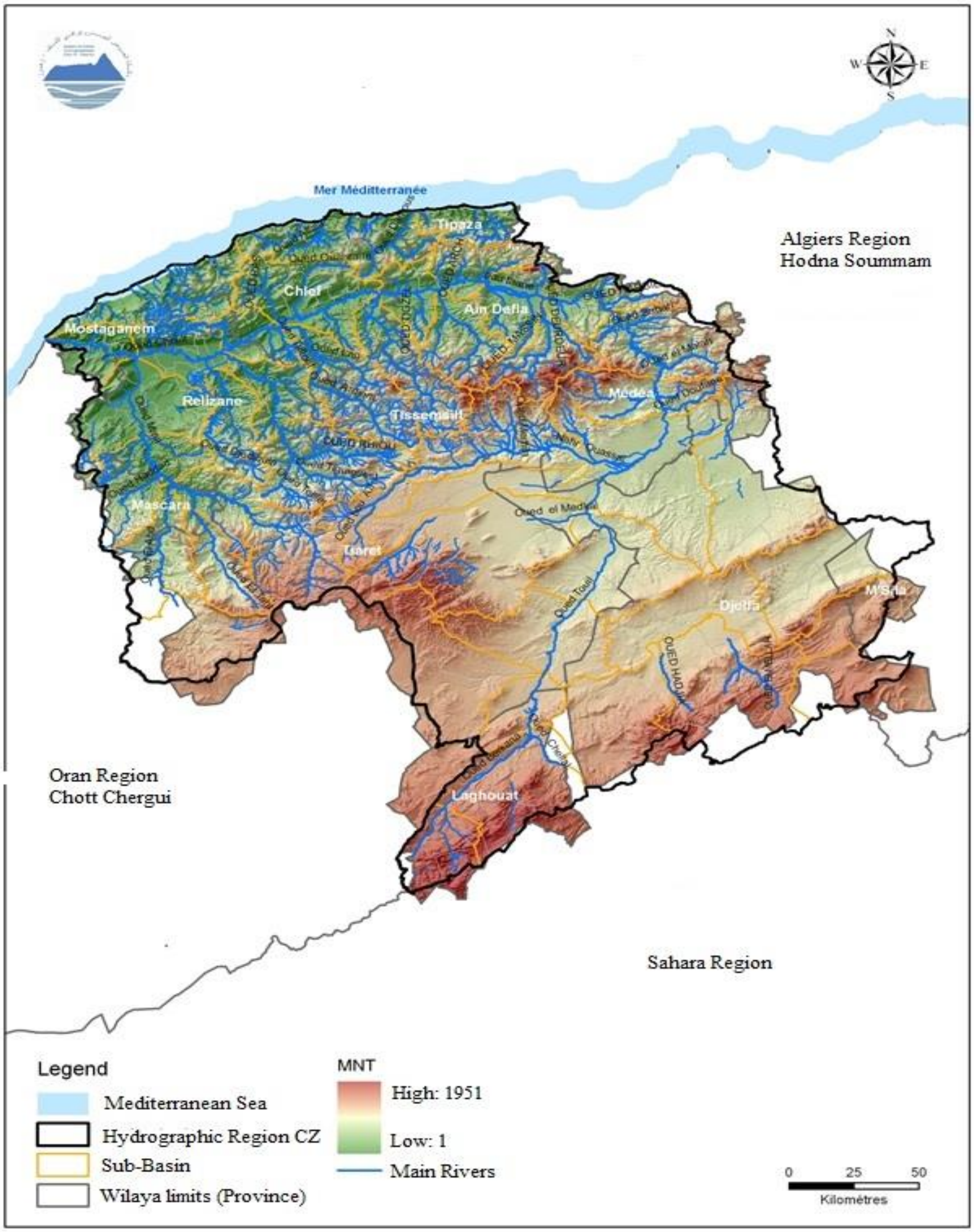


FIGURE 3.16: Natural Framework of the Hydrographic Region Cheliff Zahrez (CZ)

Source: http://www.abh-cz.com.dz

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 its downstream in Mostaganem (Belhadj, 2001; Kies & Taibi, 2011). The monthly and annual flow of Cheliff river is extremely irregular. The water supply of 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 fresh water and the sea water make that the sands and the silts in suspension are deposited. The main deposit of the estuary is mud (Grimes, 2003; Kies & Taibi, 2011). 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 (Kies & Kerfouf, 2014). The ecosystem characterizing the estuarine zone plays an important role for many species of anadromous and catadromous migratory fish (Nisbet & Vernaeaux, 1970).

3.4 Conclusion

The Mostaganem wilaya, because of its ideal geographical location, its 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 its coast area, makes of it a dynamic area, and a region that is changing rapidly. The development of the wilaya, its 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 of alarming environmental problems, some of which are irreversible. The analysis of the various forms of environmental degradation studied in this chapter, 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 problems, especially those of pollution includes nutrient enrichment caused eutrophication of continental, estuarine, 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 (microscale). However, it will be discussed in the next chapter of this thesis, the management, planning, and the responsibilities of Algeria in the coastal areas at the local and national levels.

Chapter 4:
Management and planning framework

Objective:

Assessment in the large and local scale of the coastal zone management, planning, and responsibilities in Algerian coastal environments.

4.1 Introduction

Through historical periods, the relationship between humans and coastal areas has become increasingly marked on the Mediterranean Algerian Sea increasing land degradation (Grimes et al., 2010; UNEP-MAP RAC/SPA, 2010), and transitional and coastal waters deterioration (Debieche, 2002; Karrouch & Chahlaoui, 2009; Boukli-Hacenes, 2012; Djemai, 2012; Reggam et al., 2015). Social evolution has led to an inappropriate spatial reconfiguration of cities and consequently, to an evident environmental imbalance (Nakhli, 2010; Yamani & Brahimi, 2013; Ghodbani & Berrahi-Midoun, 2013). The littoralisation of the City of Mostaganem and other coastal cities in Algeria, is the result of a coastal urbanization in continuous spatiotemporal evolution (Ghodbani, 2010), which is at the origin of the continuous artificialization of the littoral in the framework of the economic development of industrial sectors (Bouroumi, 2014), seaside tourism (Ghodbani et al., 2016), and agricultural (Boulkaddid, 2014), based on social advancement in relation to the protection and sustainability of coastal ecosystems. For Integrated Coastal Zone Management as regards increasing land tensions need the critical look of urbanization on the Mediterranean coast (Daligaux & Minvielle 2010; Kacemi, 2009; 2013).

4.1.1 Impacts on coastal zone

Several eutrophication phenomena have been reported along the Algerian coasts. These events have intensified since summer 2003, summer 2009, and summer 2013 (Figure 4.1). The phytoplankton composition of the Algerian coasts indicates the presence of toxic species such as *Pseudo-Nitzschia* as well as Dinoflagellate Genus *Dinophysis* and *Alexandrium* which counts very toxic species observed in the Gulf of Oran (Nehar, 2015, 2016), the bay from Mostaganem (Kies et al., 2012, Kies 2015, Nehar 2016), and the Gulf of Annaba (Hadjadji et al., 2014) during the eutrophication period. These phenomena are of concern to the public, fish farmers and the scientific community.

FIGURE 4.1: Eutrophication phenomenon observed in Algeria during the summer of 2013 (MATE-PAP RAC/PAM, 2013).

A study of the spatial and temporal evolution of eutrophication in relation to littoralization and its impact on the Global Change has become a necessity in the Mediterranean countries (Gennaro, 2014) and the Algerian coasts. This is to ensure sustainable planning within the Framework of Integrated Coastal Zone (Bald et al., 2005; Rossberg et al., 2017).

Coastal zones, subject to reasonably rapid changes in global and local driver variables, will require that assessment and management of transitional and coastal eutrophication (Bricker et al., 2003; Ignatiades, 2005) include adaptive strategies that capture effects of changing baselines (Hartnett et al., 2012; O'Brien et al., 2016).

4.1.2 Water Quality management

Algeria is reforming and restructuring the water sector. The new water sector policy aims to (*i*) centralize water management activities and (*ii*) gradually increase the involvement of the private sector. Within the new institutional framework, the Ministry of Water Resources (MWR) and the Ministry of Land Planning and Environment (MLPE) will be responsible for water, wastewater and irrigation planning, management, monitoring, and coastal and inland pollution control.

4.1.3 Spatial and temporal scope of Algerian NS-ICZM

The control of the spatial and temporal scope of the Algerian national strategy related to integrated coastal zone management (NS-ICZM) is one of the keys to the success of the approach advocated for the preservation of the national coastal zone and for its balanced development. This question raises, in addition, the problem of sizing the so-called ICZM projects, the nature and level of the actors involved in the process, and especially the financial mobilization required to implement projects. According to the ICZM Protocol, the coastal zone is defined: (*i*) to the sea, by the limit of the coastal zone defined by the outer limit of the territorial sea (*ii*) to the land, by the boundary of the coastal zone defined by the boundary of competent coastal entities. In this case, the NS-ICZM will, therefore, cover a territory already defined by the coastal law and including a marine one covering the territorial waters, and an earthly part that will extend to the administrative limits of the wilayas Coastal areas. In addition to being practical, this option has many advantages, including having clearly identified boundaries and actors. This option also allows control over the implementation of operations, particularly through the empowerment of stakeholders (wilaya, Municipal People's Assemblies, etc.). The management unit approach simplifies the budgeting process. This approach largely allows for integrating ecosystem and watershed considerations, although in some cases Management by watershed (case of coastal aquifers and estuaries) or by ecosystem (case of protection) requires an intercommunal or inter-wilayas approach, which reinforces inter-sectoral management and ICZM. The NS-ICZM is part of the general framework put in place by the Algerian public authorities to ensure the balanced and equitable development of territories. This vision is presented in the SNAT, which has the horizon of 2030. The NS-ICZM has, therefore, set the same deadline in 2030, with two intermediate deadlines in 2020 and 2025 to make the necessary adjustments and consolidations.

4.1.4 Need of ICZM/WFD

The Integrated Coastal Zone Management ICZM was defined -“*an Integrated coastal management is a dynamic process for the sustainable management and use of coastal areas, at the same time taking into account the sensitivity of coastal ecosystems and landscapes, the diversity of activities and use of space, their connectivity, maritime orientation of certain activities and uses, as well as* *their impact on sea and land areas*”- and adopted in the Mediterranean Sea during the Barcelona Convention in 2008 in Madrid (Boukhemkhem, 2016; Scoullos et al., 2012). As the first international legal document taking into account spatial planning; protection, and conservation of both environmental and cultural heritage; as well as policies for sustainable development the economic activities including tourism (UNEP, 2009). The main objective of the ICZM implementation in the Mediterranean region supported by different projects in Algeria including the “MedPartnership” project (Figure 4.3), is to ensure that national legislation of the Mediterranean countries, prescribes that all the activities which are carried out in this area should be included in the integrated management (Shipman et al., 2009). Also, it is important *i*) to provide vertical and horizontal coordination at different level *ii*) to improve cooperation and coordination of management mechanisms at the local and state levels, also between them *iii*) and to ensure the sustainable use of coastal areas and resources in a manner to allow the enduring stability of ecosystems and economic growth, with an emphasis on planning as an instrument precedes the management.

According to Valavanidis (2018), these require an ICZM approach as a basis for sustainable coastal spatial planning (Figure 4.2). Sustainable Ecosystem-based on management of coastal socio-economic activities affecting water-column, seafloor, and their biodiversity, requiring knowledge of a wide variety of ecological and biological variables such as the multi-level water characteristics and their interconnection, biodiversity, life cycles, functional variables, trophic interactions, and organic-matter cycling, supported by abiotic measurements and detailed habitat mapping (Noges et al. 2016; Valle et al. 2015), as well as focus on the long-term interrelatedness between socio-economic activities, nature, and between them as integrated complex adaptive economic-ecological entities (UNEP, 2009) and well-being of local people.

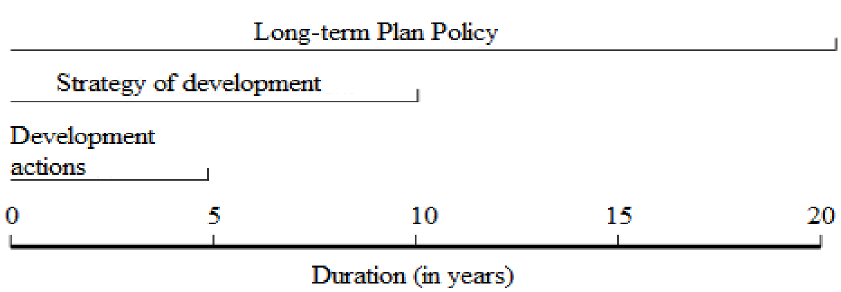


FIGURE 4.2: Relationship between long-term planning and strategic planning (UNEP, 2009)

Management initiatives will be constrained by spatial scale of driver variables (Lemley et al., 2017). Every local effort may address wastewater and fertilizer N and P sources, but also the N atmospheric sources requiring national and/or international attention for its socio-economic benefits (de Groot & Warner, 2011).Therefor, both Marine Strategy Framework Directive (MSFD) and Water Framework Directive (WFD) aim to achieve a Good Environmental Status (GES) in the European and the Mediterranean Waters (Borja et al., 2010). However, the WFD is established for the protection of transitional and coastal waters, which is a challenge for water resource management based on ecosystem integrity and health (Borja, 2005).

4.2 International conventions ratified by Algerian Government

Optimizing the framework for international and regional cooperation requires greater visibility of all funding related to coastal areas. This visibility requires the establishment of a framework or mechanism for coordinating, monitoring and evaluating this type of financing. This mechanism should ensure a regular exchange between focal points of all actual or potential donors of actions, projects, and programs related to coastal areas or dealing with issues related to coastal areas (Figure 4.3).

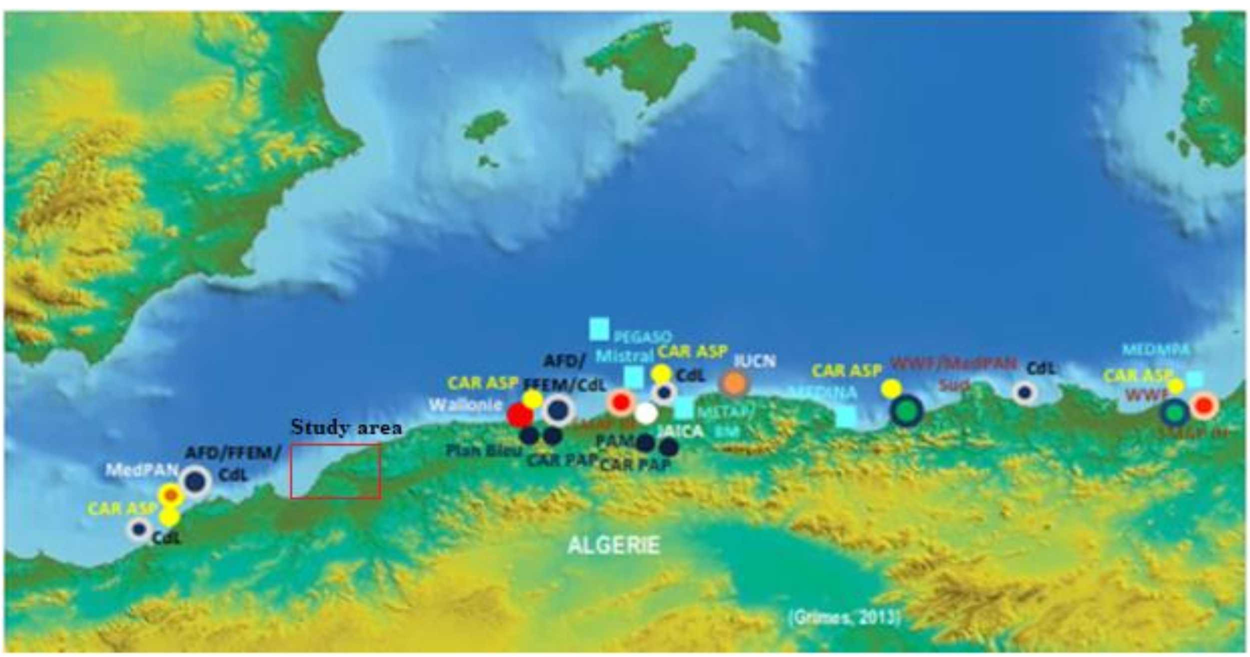


FIGURE 4.3: International Collaboration Projects implemented in the Algerian coastal zones (*in* MATE-PAP RAC/PAM, 2013, modified).

However, the focal points of the following entities are concerned by this mechanism: GEF, World Bank, European Investment Bank, African Development Bank, WFP and all its priority activity centers (and in particular RAC/SPA, PAP/RAC, Blue Plan, CP/RAC), WWF, IUCN, H2020, United Nations Framework Convention on Climate Change, Convention on Biological Diversity, RAMSAR, UNESCO/IOC, World Organization for Agriculture (FAO), International maritime organization, bilateral framework (GIZ, AFD, Belgian Technical Cooperation, Japanese Cooperation Agency, etc.). This type of mechanism could be domiciled either at the level of the Ministry of the Environment or at the Ministry of Foreign Affairs and International Cooperation.

4.3 Bodies and measures supporting coastal sustainable development

The Algerian Government considers ICZM a high priority and has recently developed an ambitious program to implement the coastal law including;

- Law No. 02-02 of February 05, 2002 on the protection and enhancement of the coastline. It is responsible for the national policy of regional planning and protection of the environment and it involves all the parties acting on this sensitive and fragile territory (state, local authorities and non-governmental associations, etc.);
- Law No. 83-03 on the protection of the environment;
- Water Law No. 83-17 “Le Code des Eaux” (revised in 1996 under law No. 96-13).
  This code includes several articles related to wastewater discharge, pollution abatement, the protection and preservation of water bodies and wastewater reuse for agricultural and industrial purposes.
- Provide the PACO (Figure 4.4) areas with a Master Plan for Regional Coastal Development articulated in the National Master Plan of Coastal Development as provided for in articles 7 and 38 of the 01-20 of December 12, 2001 relative planning and sustainable development of the territory.

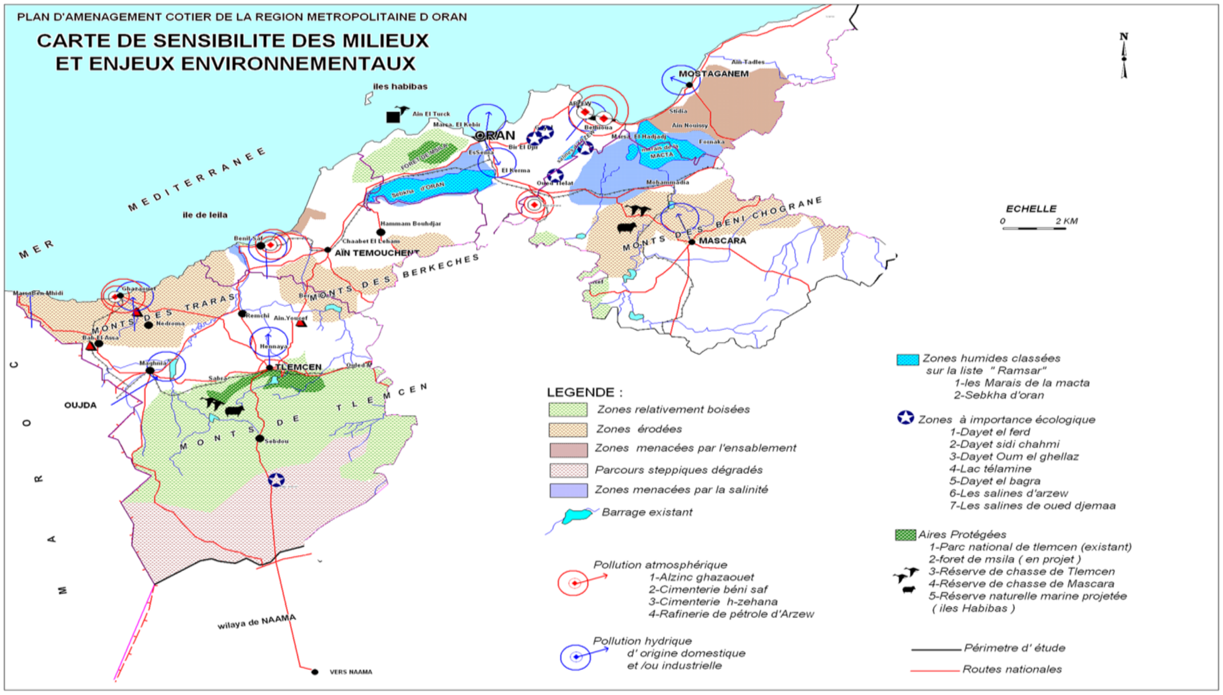


FIGURE 4.4: Map of environmental issues and sensitivity within the Master Plan for Regional Coastal Development (Source: MLPE).

4.4 Management instruments

In Algeria, Ministry of Land Planning and Environment (MLPE) is in charge of coastal water and represents the main body responsible for quality monitoring.

In order to better monitor the objectives, set by the State, with regard to the promotion of sustainable coastal zone management, support organizations have been set up including

- The National Commissariat of Littoral (C.N.L);
- The Coastal Coordination Council (C.C.C);
- The Littoral Fund (F.L);
- Emergency Response Plans (P.I.U) in case of pollution;
- Coastal Development Plans at the level of each municipality;
- Classification in critical zones or protected areas of sensitive coastal zones;
- Development of a comprehensive system of information and mapping of coastal areas;

- Monitoring of the quality of the water of swimming and the control of the urban, industrial and agricultural discharges at sea; economic and fiscal incentives.
- Sea Science and Coastal Development Institute (ISMAL),

4.5 Conclusion

In the face of the negative consequences of urban developmental, the effects of coastal erosion, and biological invasions, likely to cause major ecological disruptions, the development of NS-ICZM represents a new approach to coastal zone governance in Algeria. This strategy provides elements of the response to the shortcomings posed by the "littoral" law. The full implementation of the coastal law should halt or at least reduce the process of coastal zone degradation. In addition, this strategy, which considers the environmental, economic and social dimensions equally important, also takes into account the spatial dimension of coastal planning in the context of an integrated coastal policy.

Offshoring of damaging activities on the coast has become a necessity. This will have the direct consequence of strengthening planning, monitoring, warning and coastal zone management capabilities and, consequently, improving the resilience of coastal areas to the many threats they face. For Algeria, all these measures will have the direct consequence of increasing the resilience of coastal ecosystems.

However, we took the opportunity to evaluate the management, planning, and the responsibilities of Algeria in the coastal areas at the local and national levels, and we hope to dedicate the next chapter of this thesis, to the characterization of the coastal water quality and ecological health of the wilaya of Mostaganem under this policy.

Chapter 5: Characterization of water quality through the west Algerian coasts

Objective:

Physicochemical water bodies characterization through different descriptors used to assess the ecological health status of the phytoplankton biomass.

5.1 Introduction

The increase in the human activities (AbadaBoudjema & Dauvin, 1997; Venturini et al., 2012) and atmospheric deposition was large enough to increase the imbalance in land-derived nutrient loads, thus over-enrichment trophic by transitional and coastal waters change significantly especially last decades in the Mediterranean Sea (Cataudella et al., 2015; Ounissi et al., 2016). Changed N and P regimes were corroborated by finding differences in estuarine nutrient (Haridi et al., 2011, Ounissi & Bouchareb, 2013; Ziouch, 2014; Ounissi et al., 2014), algal harmful (Nehar et al., 2015), Chlorophyll *a* concentration and oxygen depletion (Kies, 2015). This has a directly and/or indirectly impact on the pelagic and benthic waters quality and its biodiversity (Basilone et al., 2004; Bacha & Amara, 2009; Hafferssas & Seridji, 2010), and human well-being (Pinto et al., 2014).

Mostaganem coastal zone receives urban and industrial discharges via the hydrodynamics of water, swells brewing phenomena and water circulation. Because of the intensification of effluent discharges and many leisure complex construction. The coastal zone of Mostaganem which was in the past a little disturbed natural environment, is about to turn into a real dump of urban waste.

Nutrient availability at Cheliff River upstream controls the abundance and structure of phytoplanktonic populations at the Cheliff River downstream, and the Coast Waters of Mostaganem (Kies, 2015; Nehar et al., 2015). Eutrophication problems are clearly identified in this body of water with micro invasive algae covering its surface at certain times of the year. Some work on the Cheliff River have indeed established direct links between pollution of the sea state and domestic and industrial wastewater directly discharged into the Cheliff River without any treatment (Bettahar et al., 2009; Nehar, 2016). Thus, a study has tracked the temporal and spatial changes in **Depth**, biotic including chlorophyll-*a* (**Chl-*a***) and abiotic (Thermal conditions, oxygenation conditions, salinity, acidification status, nutrient conditions) physico chemical parameters including temperature (**T**); salinity (**S**); potential of hydrogen (**pH**); dissolved oxygen (**%O_2**); % deviation of the oxygen concentration from saturation conditions (**D%O_2**); dissolved inorganic azote (**DIN**= ammonium N-$NH4^{+}$ + nitrate N-$NO3^{-}$ + nitrite N-$NO2^{-}$); **P** = ortho phosphates $PO4^{3}$-; Silicate (**SiO_2**); turbidity (**TRB**); biological oxygen degradation (**BOD**); and chemical oxygen degradation (**COD**) of the year 2014.

5.2 Material and methods

5.2.1 Sampling area

Description and localization

The study sites are located on a fringe of the coast (Figure 5.1), near the Estuary of Cheliff river located in Mostaganem, North-western Algeria. This coastline is supplied by waters of Atlantic origin (see Chapter II and Chapter III).

Sampling sites

Sampling and selection of sites

Sample sites (Figure 5.1) are represented by the main urban effluent of the city. Several agriculture areas and industrial units are located around this area, which represents an important source of several pollutants.

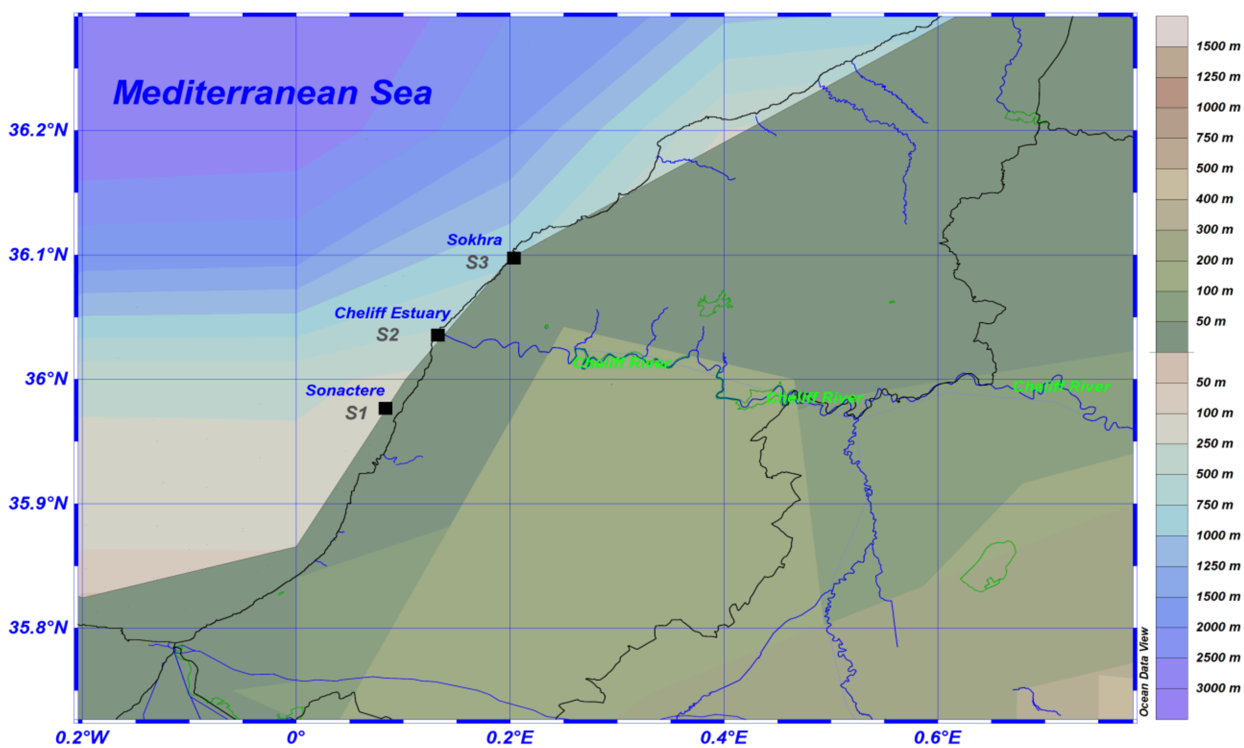


FIGURE 5.1: Sampling sites location (Schlitzer, 2016).

The *samples* of the coastal region were collected in 3 stations (Figure 5.1 and Figure 5.2) differently subjected to the influences of the hydrological and terrigenous inputs of the watershed of the Cheliff river. The stations are placed (Figure 5.1) according to a reasoned sampling plan. The first site, Sonactere (S1) is located west of the Cheliff estuary; the second site, parallel to the Cheliff estuary (S2), and the third site, Sokhra is located east of the mouth of Cheliff (S3). The station ID, positioning, depth of all these stations are shown in Annex II.

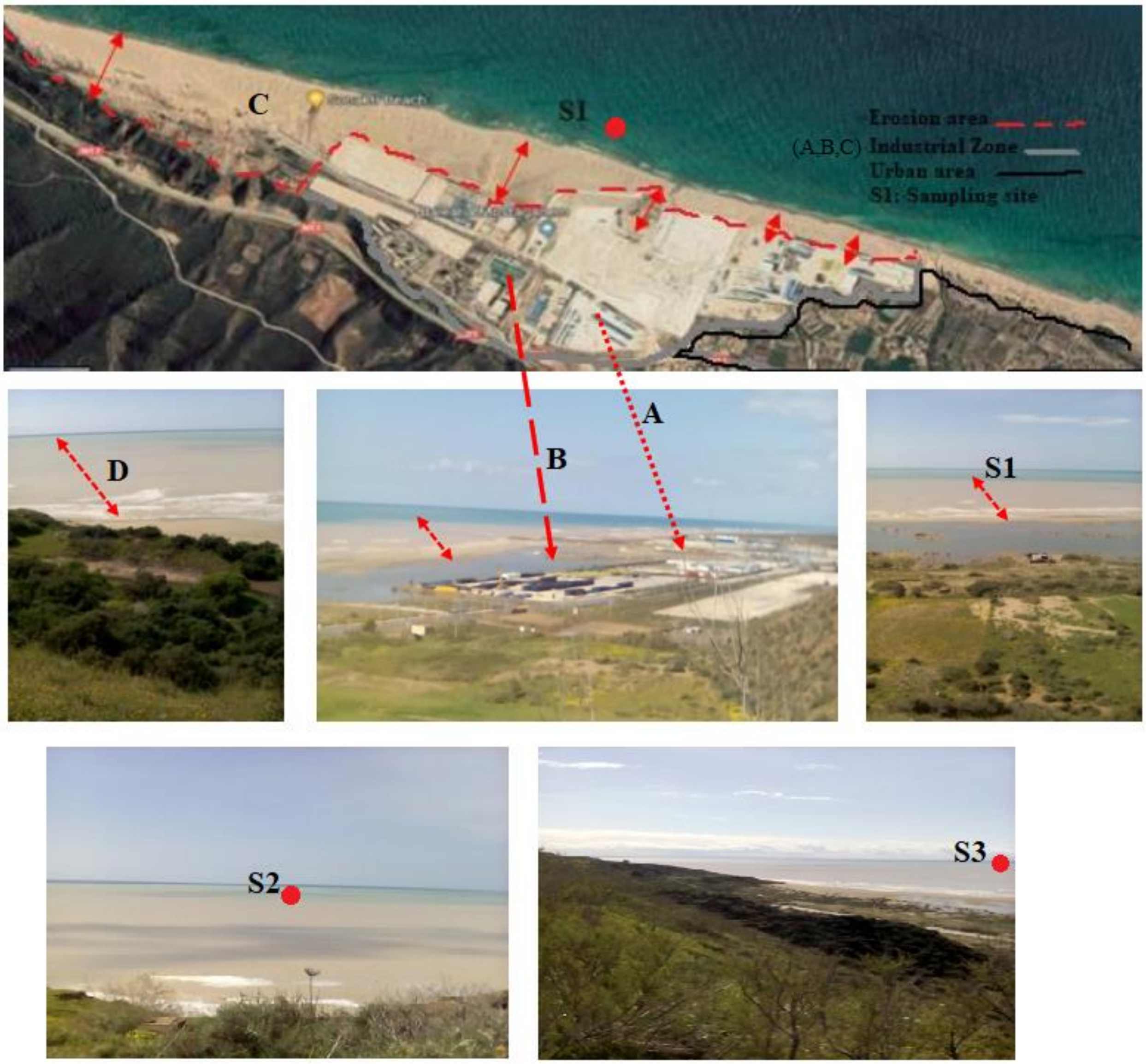


FIGURE 5.2: Sampling sites characterization. **S1**: Sonactere, **S2**: Cheliff, **S3**: Sokhra, **A**: Power plan, **B**: Water desalinization unit, **C**: zone extension touristic (ZET), **D**: diameter Cheliff water impact on sea water at 5 Km from its estuary (PHOTO by KIES F).

Sampling and analysis of physicochemical parameters

Three samples monthly have been taken with haphazardly along a transect parallel to the shore using Hydrobios water sampler. Seawater samples were at depths of 15m and 30m for 12 months (January to December 2014). Moreover, temperature, pH, dissolved oxygen, have been performed with intervals in the water column using IDS depth probes (model MPS 930 IDS).

Water samples were collected in accordance with AFNOR (Association Française de Normalisation) guidelines to obtain a representative sample (Rodier et al., 2009). Sample transport, preservation and maximum holding periods proposed by the AFNOR guidelines were adopted for this research. The laboratory analyses of the different chemical elements were undertaken according to AFNOR guidelines.

5.3 Results and discussion

5.3.1 Characterizations of water bodies and health status quality

During the study period in the year 2014 (Figure 5.3 and Annex III), the values of the physicochemical parameters studied were highly significant (ANOVA, $p<0,05$) in the western coastal zone of Mostaganem (Sonactere, Cheliff, and Sokhra). The average temperature was (18.58 ± 2.55 °C), the mean salinity of (37.15 ± 0.20 psu), the mean pH of (7.97 ± 0.24), the dissolved oxygen was (7.70 ± 1.11 µg/l), % deviation of the oxygen concentration from saturation conditions was (78.13 ± 12.18 %), and the mean turbidity was (826.86 ± 887.98 µg/l).

Highest concentrations of nutrient salts were (1067.81 ± 2008.06 µg/l) for phosphates, (0.28 ± 0.27 µg / l) for nitrite, (8.34 ± 5.99 µg/l) for nitrate, and (0.92 ± 1.63 µg/l) for ammonium. The average concentration of chlorophyll-*a* was (13.17 ± 11.90 µg/l).

The distribution of most of the abiotic parameters was closely related to the Cheliff river and favored by the Algerian current which transports them towards the western coastal zone of Mostaganem (Sonactere), this highlights the high dilution of the waters of the western part of the bay of Mostaganem in western Algeria by the freshwater inputs and the significant mineral pollution that joins the bay through the Cheliff river.

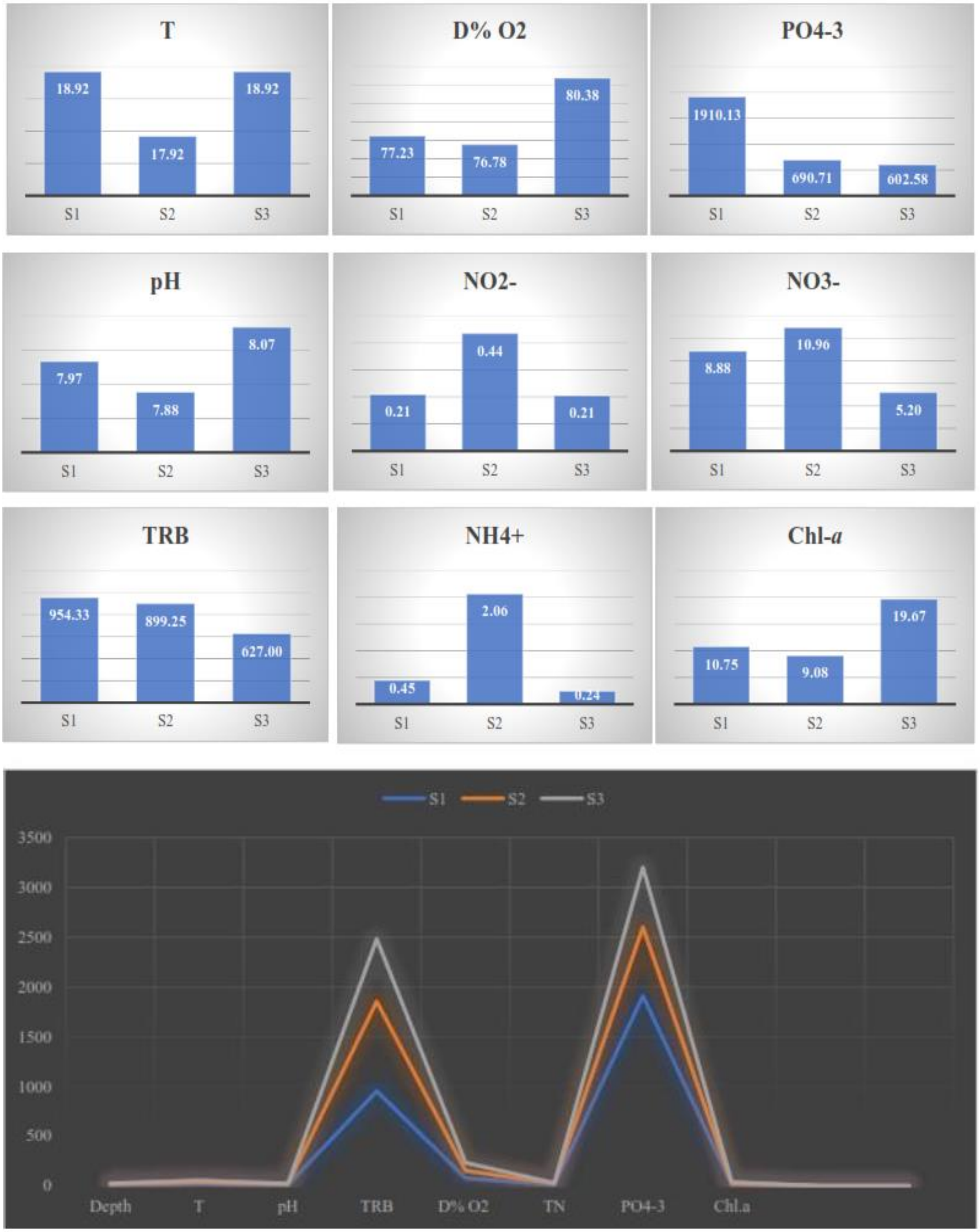


FIGURE 5.3: Average biological and physicochemical values in the three sites (**S1**, **S2**, and **S3**). Units used: m (Depth), °C (T), and µg/l (Chl-*a*, TRB, D%O_2, TN <NO_3, NO_2, and NH_4>, $PO4^{3}$-).

Some abiotic parameters can be used as indicators of eutrophication. According to Beaupoil & Bornens (1997), an oxygen content> 5 mg / l, would qualify an estuarine environment of excellent quality to acceptable. According to Simboura et al. (2005) and Karydis (2009), a concentration of chlorophyll-*a* between 0.1 and 0.4 µg/l denotes good water quality.

However, nutrient levels put the waters of the western zone of Mostaganem Bay in a severe eutrophication situation based on the average water quality values described by Karydis (2009), which are 0.34. µg/l of PO_4, 0.53 µg/l of $NO_3 + NO_2$, and 1.15 µg/l of NH_4.

The physicochemical parameters studied made it possible to determine the quality of the waters of the coastal zone of Mostaganem Bay in Algeria, qualifying them as mediocre. Indeed, the waters were very rich in phosphate ions, nitrites, nitrates, and ammonium, which classifies the environment in a state of strong degradation by increased eutrophication by human activities. The coastal stations were particularly distinguished by this degradation in this coastal area of the Bay of Mostaganem and especially the station located at the west of the Cheliff Estuary (Sonactere coastal zone).

5.3.2 Water bodies Classification

Table 5.4: Typologies for Mostaganem coastal water bodies using the salinity classes (Carletti & Heiskanen, 2009).

Wilaya	Site	Mean Depth (see Annex II)	Mean Salinity	Classification	Water bodies (Typology)
Mostaganem (Western Algeria coastal zone)	Sonactere	7.80 ± 3.18	37.4 ± 0.26	Type II	Coastal bodies water moderately influenced by freshwater inputs.
	Cheliff	8.90 ± 4.51	36.6 ± 0.14	Type II	
	Sokhra	10.11 ± 5.84	37.45 ± 0.21	Type II	

According to Table 5.4 and Figure 5.4, the three sites in the Mediterranean coastal zone of the wilaya of Mostaganem including Sonactere, Cheliff, and Sokhra, are classified as Type II according to their salinity mean values (Carletti & Heiskanen, 2009), which correspond to (37.4 ±

0.26 psu) in Sonactere, (36.6 ± 0.14 psu) in Cheliff coastal zone, and (37.45 ± 0.21 psu) in Sokhra coastal zone.

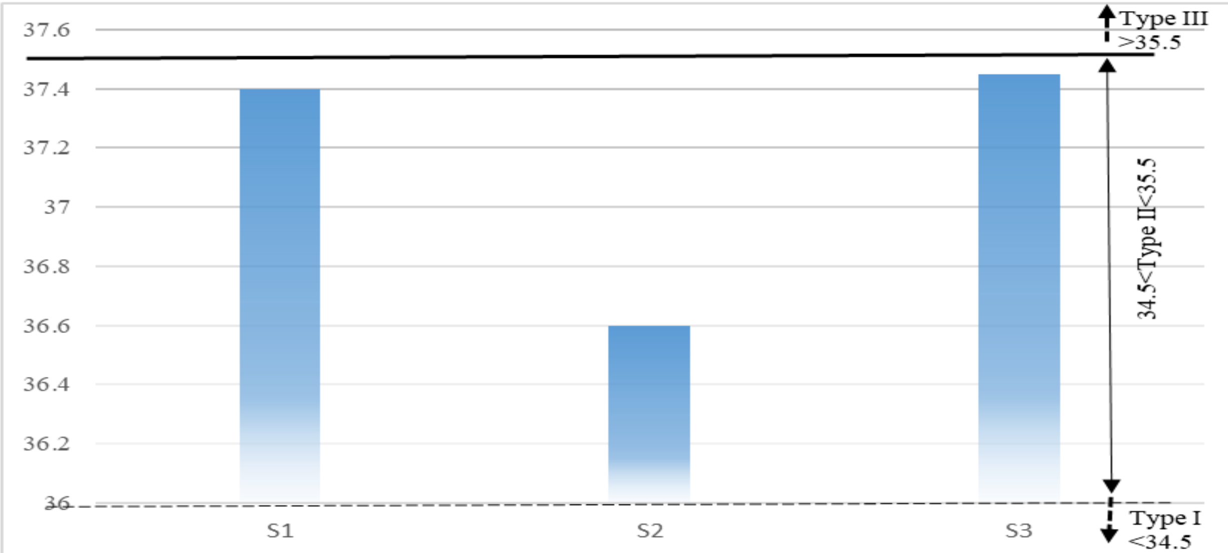


FIGURE 5.4: Water bodies typology according to their salinity (Carletti & Heiskanen, 2009).

5.4 Conclusion

For the year 2014, the results highlighted the water quality of the three coastal zones including Sokhra, Cheliff, and Sonactere sites of Mostaganem Bay have proved to be in a severe eutrophication situation, exceeding the recommended international standards for the Mediterranean Sea, with excessive nutrient enrichment. However, to better understand the state of the ecosystem, it is essential to survey the entire bay of Mostaganem over a long period. The implementation of a certain index including TRIX and Chlorophyll-*a* will be recommended to limit the quality of the ecological state for Mediterranean regions but it should be adapted to local conditions so that it will be relevant and more reliable and representative in view of the heterogeneous aspect of the Mediterranean coastal zones. For this reason, we will devote the following chapter to the assessment of the ecological status of coastal water using the nutrient concentration and Chlorophyll-*a* biomass in the western Algerian zone (Mostaganem Wilaya) according to the recommendations of the Water Framework Directive (WDF, 2000/60/EC).

Chapter 6: Assessment of the ecological status of coastal water using nutrients concentration and Chlorophyll-*a* biomass

Objective:

Implementation of the TRIX and chl-*a* for the ecological quality assessment of water bodies using nutrients and phytoplankton biomass.

6.1 Introduction

Coastal environments constitute an environment dynamic influenced by exogenous continental inputs, loaded with mineral and / or organic matter, resulting from anthropic activity and controlled by hydrodynamic and climatic factors. To appreciate the balance or dysfunction ecosystems, ecological indices are generally used; they integrate data relating to physico-chemistry, biology, productivity or diversity (Pavlidou et al., 2015).

Evaluating the eutrophication (Figure 6.1) and its risks in the estuaries and coastal waters plays a significant role. For the eutrophication, many classifications have been made based on nutrients (phosphate, nitrate, and ammonium) and biological elements (chlorophyll-*a* concentration, macroinvertebrates, and fish).

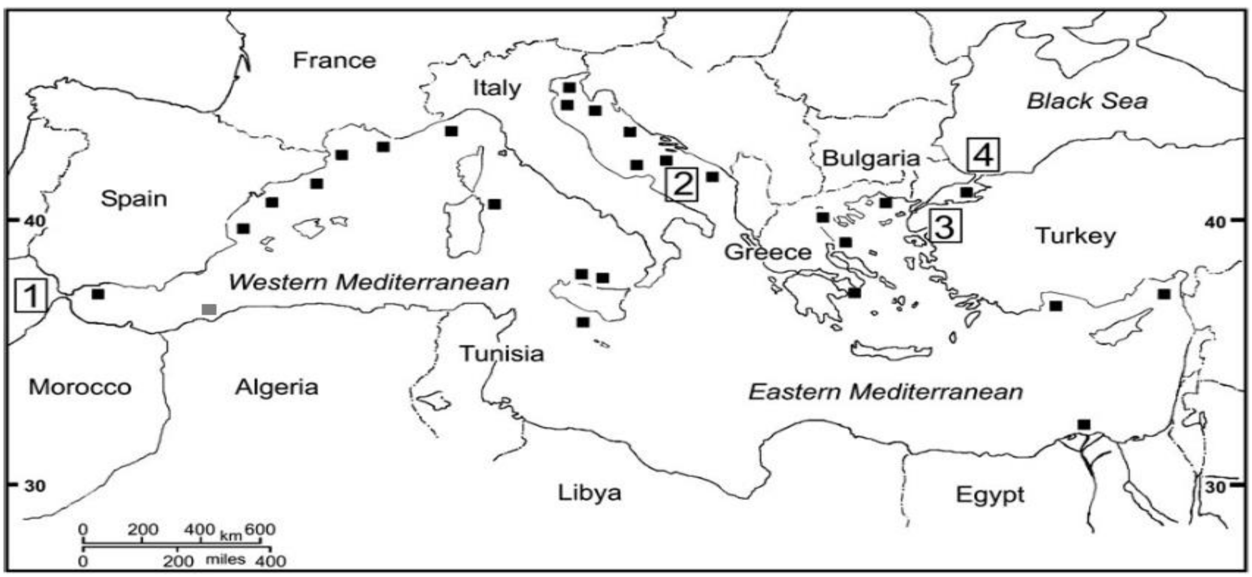


FIGURE 6.1: The places where eutrophication phenomena have been marked with black squares by Primpas & Karydis (2011) and grey square according to Benhalima (2016).

Vollenweider et al. (1998) proposed a relevant trophic index (TRIX) to evaluate the trophic conditions of Mediterranean coastal marine waters. This index takes into account nutrients, chlorophyll-*a*, and dissolved oxygen in the environment. According to UNEP (2003), TRIX index required to be monitored by the Mediterranean countries. It has been applied in several regions in the Mediterranean Sea (Ben Lamine et al., 2011; Primpas & Karydis (2011).

According to Simboura et al. (2005), Chlorophyll-*a* values characterize a very simple and integrative determinant of the phytoplankton community response to nutrient improvement. An increase in the phytoplankton biomass can be detected as an increase in the chlorophyll-*a* values. Chlorophyll-a is a profit parameter of phytoplankton and algae biomass and is arguably the single most responsive indicator of N and P enrichment in the estuarine and coastal ecosystem.

All regulations conducted for the improvement of European coastal waters, surface waters and seawaters (Figure 6.2) are explained in Water Framework Directive (EU WDF, 2000/60/EC).

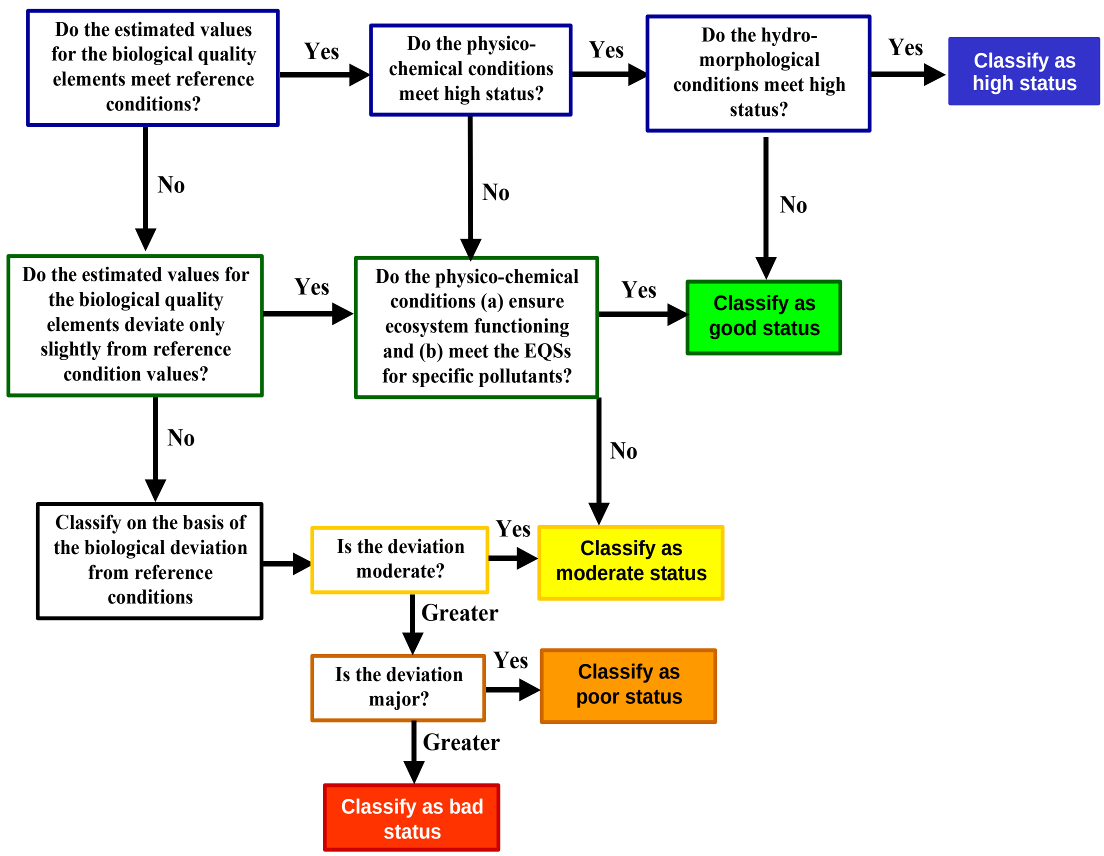


FIGURE 6.2: The procedure for assigning ecological status to a natural surface waterbody according to the definitions of high, good, moderate, poor and bad status in the WFD Directive.

Several studies in the Algerian coastal zone focus on hydrology, but the classification of water quality using indices remains very rare. Algeria represents the natural outlet of the largest watercourse, which is Cheliff river (see Chapter 3).

6.2 Material and methods

Data from Mostaganem coastal zone and pelagic seawater (Figure 6.3) from the area of NW of Algeria in the Mediterranean Sea, including nutrients, chlorophyll-*a*, hydrology (see Chapter 5) and supporting parameters (see Chapter 3) was used.

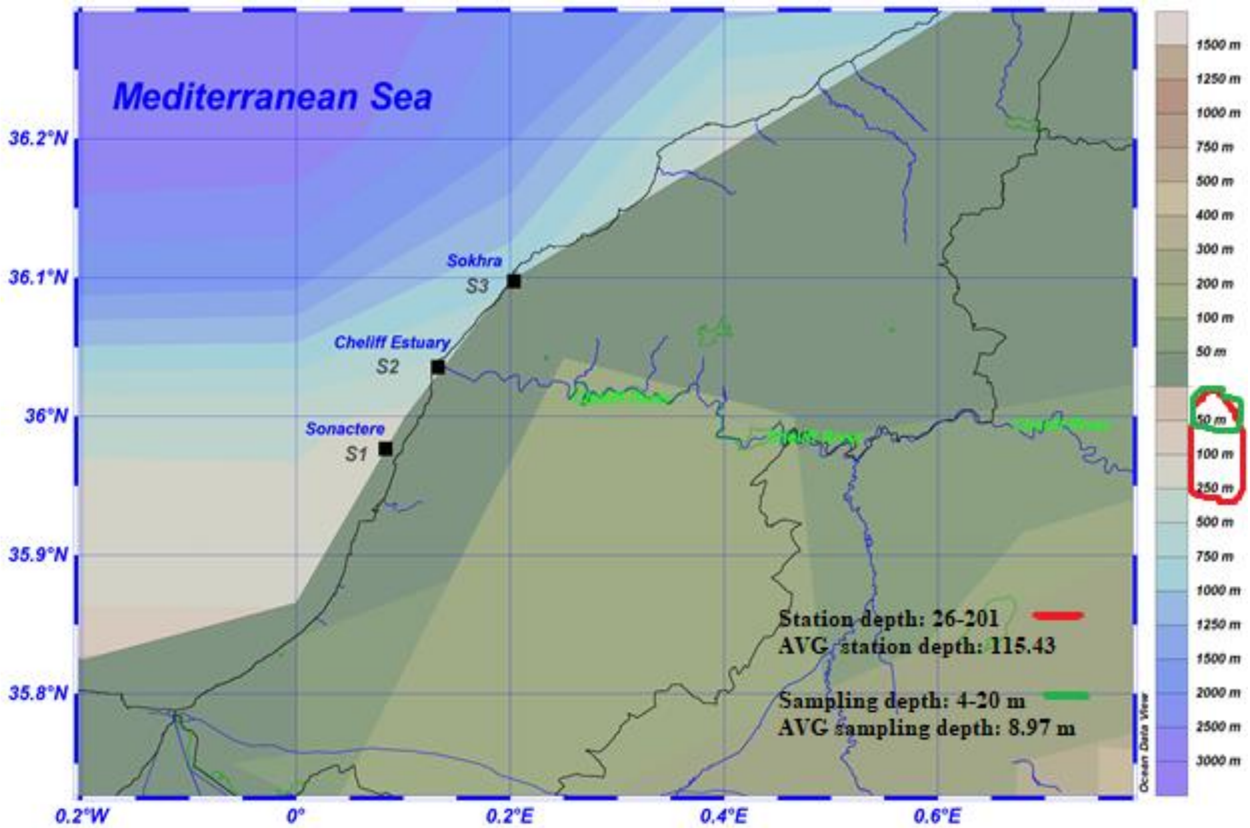


FIGURE 6.3: Sampling depth in the coastal zone of the wilaya of Mostaganem (NW of Algeria). S1: Sonactere, S2: Cheliff Estuary, and S3: Sokhra (Schlitzer, 2016)

Methodological tools, indicators, range used or tested for Algerian coast areas, for eutrophication assessment according to trophic index TRIX (Vollenweider et al., 1998) and Chl-*a* concentration (Simboura et al., 2005) of the study area including the three sites S1, S2, and S3 (Figure 6.3) were summarized in Table 6.1.

Table 6.1: Methodological tools, indicators, range tested for Algerian coast areas, for eutrophication assessment.

Methods	Indicators	Eutrophication Status (EQS)	Eutrophication Range	Eutrophication Scale
TRIX by (Vollenweider et al., 1998) **	$D\%O_2$, DIN, PO_4^{3-}, Chl-*a* (µg /l)	High	<1.6	Oligotrophic
		Good	1.6-2.8	Lower Mesotrophic
		Moderate	2.8-4.0	
		Poor	4.0-5.3	High Mesotrophic
		Bad	>5.3	Eutrophic
Chl-*a* biomass classification by (Simboura et al., 2005) *	Chl-*a* (µg /l)	High	<0.1	Oligotrophic
		Good	0.1-0.4	Lower Mesotrophic
		Moderate	0.4-0.6	
		Poor	0.6-2.21	High Mesotrophic
		Bad	>2.21	Eutrophic
EU WFD (2000/60/EC)	Median Chl-*a* (µg/l)	High	0.1-0.4	Oligotrophic
		Good	0.4-0.6	Mesotrophic
		Moderate	-	Eutrophic

Median Chl-*a* (*) values used in Greece and TRIX (**) used in Italian sea.

The trophic index (TRIX) used in the present work has been given by the following formulation Vollenweider et al. (1998):

$$TRIX= [Log10 (PO4 *TN*Chl\ a*D\%O2) + 1.5] /1.2$$

Where

Chl-*a* Chlorophyll-a concentration as micrograms per liter

D%O2 The % deviation of the oxygen concentration from saturation conditions

TN Mineral nitrogen; dissolved inorganic nitrogen, DIN=N (as N-NO3+N-NO2+N-NH4) as micrograms per liter

[PO4] Total inorganic phosphorus as P–PO4 (micrograms per liter)

6.3 Results and discussion

6.3.1 Eutrophication status: spatial evolution

Table 6.2: Spatial evolution of EQS according to the Ch-*a* concentration

(Simboura et al., 2005)								
Year	**Chl-*a* S1**		**Chl-*a* S2**		**Chl-*a* S3**		**Mean Chl-*a***	
TOT	10.75	B	9.08	B	19.67	B	13.17	B

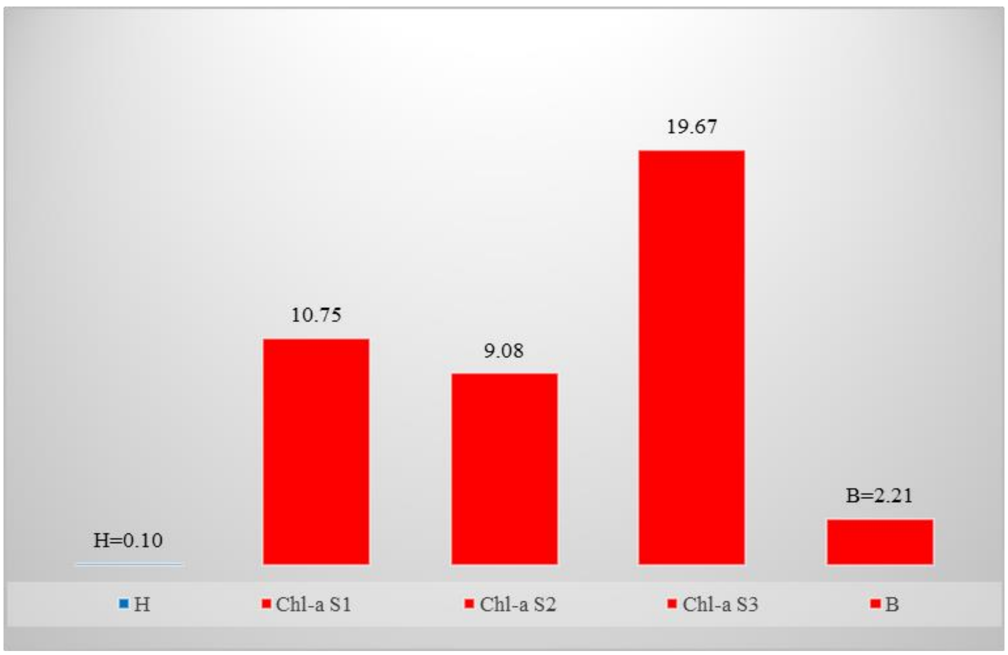


FIGURE 6.4: Spatial evolution of EQS according to the Ch-*a* concentration (Simboura et al., 2005)

Our studied coastal zone analysis results (Table 6.2 and Figure 6.4), according to the classification of Simboula et al. (2005) using the Chlorophyll-*a* concentration required by the water framework directive (WFD), mentioned a mean of 19.67 µg/l at the Sokhra coastal site, which classified it as the Eutrophic coastal site with a Bad status, a mean of 10.75 µ g/l at the Sonactere coastal site, which classified it as the Eutrophic site with a Bad status, and finally a mean of 9.08 µ g/l at Cheliff coastal site, which classified it as the Eutrophic site with a Bad status.

The ecological quality status of the studied coastal zone of the three sites during the year 2014 is ranked as a Bad status with a mean equal to 13.17 µ g/l and considered as coastal areas with Eutrophic status.

Table 6.3: Spatial evolution of EQS according to the TRIX scale

Vollenweider et al. (1998)								
Year	**TRIX S1**		**TRIX S2**		**TRIX S3**		**Mean TRIX**	
TOT	4.49	P	4.44	P	3.69	M	4.21	P

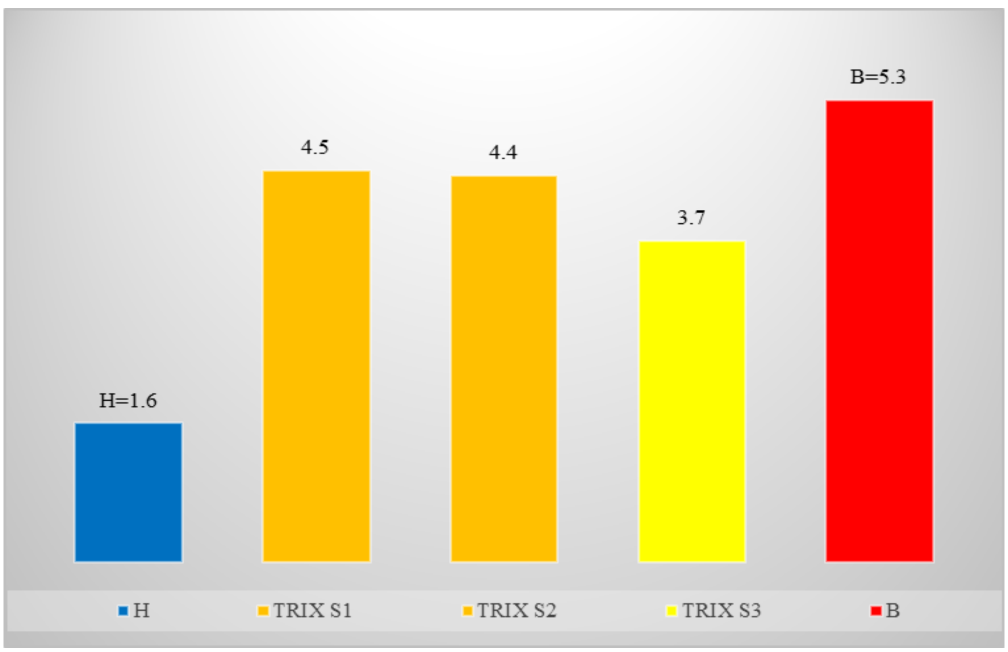


FIGURE 6.5: Spatial evolution of EQS according to the trophic index TRIX (Vollenweider et al., 1998)

Our studied coastal zone analysis results (Table 6.3 and Figure 6.5), according to the classification of Vollenweider et al. (1998) using the trophic index TRIX required by the water framework directive (WFD), highlighted a mean of 3.7 at the Sokhra coastal site, which classified it as the Mesotrophic site with a Medium status, a mean of 4.5 at the Sonactere coastal site, which classified it as the High Mesotrophic coastal site with a Poor status, and finally a mean of 4.4 at Cheliff coastal site, which classified it as the High Mesotrophic coastal area with a Poor status.

The ecological quality status of the studied coastal zone of the three sites during the year 2014 is ranked as a Poor status with a mean of 4.21 and considered as coastal areas with High Mesotrophic status.

6.3.2 Eutrophication status: temporal evolution

Table 6.4: Temporal evolution value of EQS according to the Chl-*a* concentration

<table>
<tr><td colspan="7">(Simboura et al., 2005)</td><td></td><td></td></tr>
<tr><th>Month</th><th colspan="2">Chl-a S1</th><th colspan="2">Chl-a S2</th><th colspan="2">Chl-a S3</th><th colspan="2">Mean Chl-a</th></tr>
<tr><td>1</td><td>3</td><td rowspan="10">B</td><td>2</td><td>P</td><td>0</td><td>H</td><td>1.67</td><td>P</td></tr>
<tr><td>2</td><td>15</td><td>10</td><td rowspan="9">B</td><td>35</td><td rowspan="11">B</td><td>20.00</td><td rowspan="9">B</td></tr>
<tr><td>3</td><td>18</td><td>14</td><td>34</td><td>22.00</td></tr>
<tr><td>4</td><td>28</td><td>23</td><td>45</td><td>32.00</td></tr>
<tr><td>5</td><td>18</td><td>16</td><td>42</td><td>25.33</td></tr>
<tr><td>6</td><td>16</td><td>10</td><td>28</td><td>18.00</td></tr>
<tr><td>7</td><td>11</td><td>13</td><td>16</td><td>13.33</td></tr>
<tr><td>8</td><td>7</td><td>10</td><td>12</td><td>9.67</td></tr>
<tr><td>9</td><td>7</td><td>6</td><td>8</td><td>7.00</td></tr>
<tr><td>10</td><td>6</td><td>5</td><td>7</td><td>6.00</td></tr>
<tr><td>11</td><td>0</td><td rowspan="2">H</td><td>0</td><td rowspan="2">H</td><td>5</td><td>1.67</td><td rowspan="2">P</td></tr>
<tr><td>12</td><td>0</td><td>0</td><td>4</td><td>1.33</td></tr>
</table>

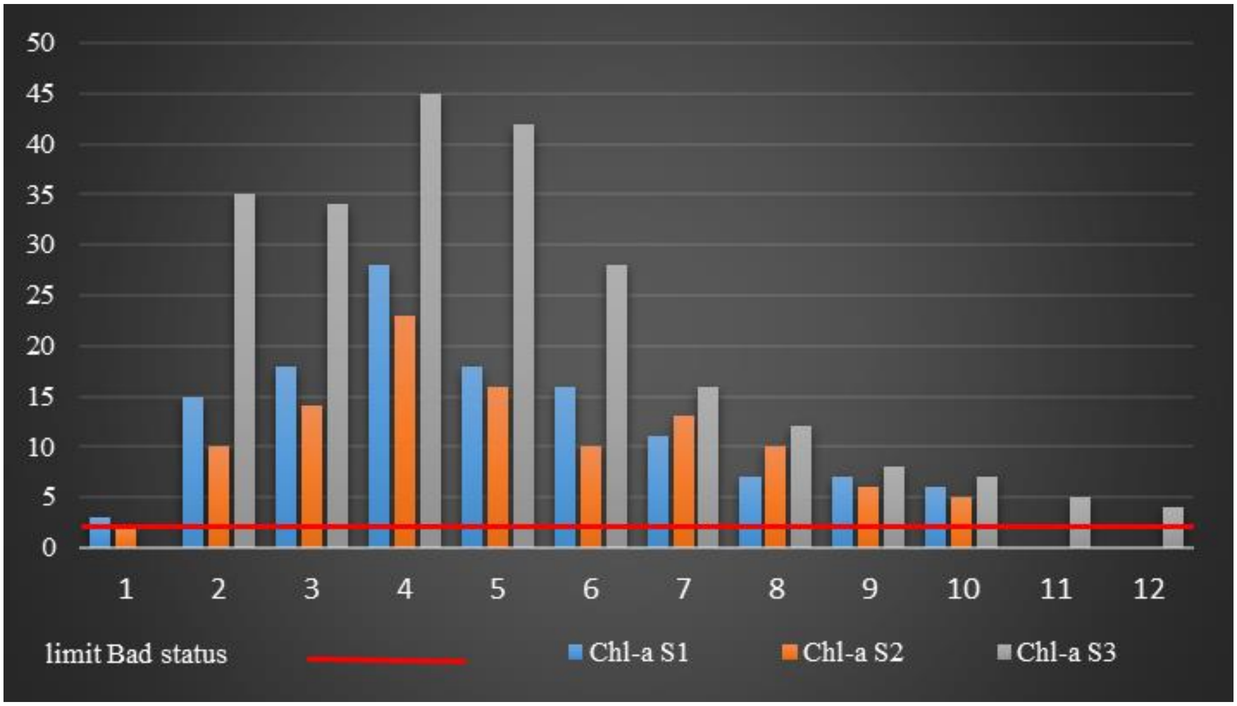


FIGURE 6.6: Temporal evolution of EQS according to the Chl-*a* concentration (Simboura et al., 2005).

The ecological quality status of the studied coastal zone of the three sites during the year 2014 is ranked as a Bad status, which classified them as the Eutrophic coastal areas (Table 6.5 and Figure 6.6). However, our analysis results highlighted the presence of two temporal evolution periods of the ecological quality status according to the Chl-*a* concentration (Simboula et al., 2005).

The first period marked by a High to Bad status (Oligotrophic to Eutrophic status) in the three studied coastal sites during November to January with a value of Chl-*a* concentration ranging between 0 to 3 µg/l in Sonactere site, 0-2 µg/l in Cheliff site, and a value of 0 to 5 µg/l in Sokhra coastal site. The second period is absolutely marked by the Bad status (Eutrophic status) in the three studied coastal sites from February to October 2014, with a value of Chl-*a* concentration ranging between 6 to 28 µg/l in Sonactere site, 5-23 µg/l in Cheliff site, and a value of 7 to 45 µg/l in Sokhra coastal site.

Table 6.5: Temporal value evolution of EQS according to the TRIX scale

<table>
<tr><td colspan="7">(Vollenweider et al.,1998)</td><td></td><td></td></tr>
<tr><th>Month</th><th colspan="2">TRIX S1</th><th colspan="2">TRIX S2</th><th colspan="2">TRIX S3</th><th colspan="2">Mean TRIX</th></tr>
<tr><td>1</td><td>7.43</td><td>B</td><td>7.06</td><td>B</td><td>1.03</td><td>H</td><td>5.17</td><td>P</td></tr>
<tr><td>2</td><td>2.95</td><td rowspan="8">M</td><td>3.18</td><td>M</td><td>3.06</td><td rowspan="5">M</td><td>3.06</td><td rowspan="5">M</td></tr>
<tr><td>3</td><td>3.78</td><td>4.05</td><td>P</td><td>3.34</td><td>3.73</td></tr>
<tr><td>4</td><td>3.16</td><td>3.31</td><td rowspan="3">M</td><td>2.97</td><td>3.15</td></tr>
<tr><td>5</td><td>3.95</td><td>3.91</td><td>3.00</td><td>3.62</td></tr>
<tr><td>6</td><td>3.65</td><td>3.47</td><td>2.94</td><td>3.35</td></tr>
<tr><td>7</td><td>3.94</td><td>4.07</td><td>P</td><td>4.13</td><td>P</td><td>4.05</td><td>P</td></tr>
<tr><td>8</td><td>3.75</td><td>3.93</td><td rowspan="2">M</td><td>3.81</td><td rowspan="3">M</td><td>3.83</td><td rowspan="2">M</td></tr>
<tr><td>9</td><td>3.31</td><td>3.17</td><td>2.95</td><td>3.14</td></tr>
<tr><td>10</td><td>7.37</td><td rowspan="3">B</td><td>7.10</td><td>B</td><td>2.78</td><td>5.75</td><td rowspan="3">P</td></tr>
<tr><td>11</td><td>5.26</td><td>4.79</td><td rowspan="2">P</td><td>7.20</td><td rowspan="2">B</td><td>5.75</td></tr>
<tr><td>12</td><td>5.32</td><td>5.21</td><td>7.06</td><td>5.86</td></tr>
</table>

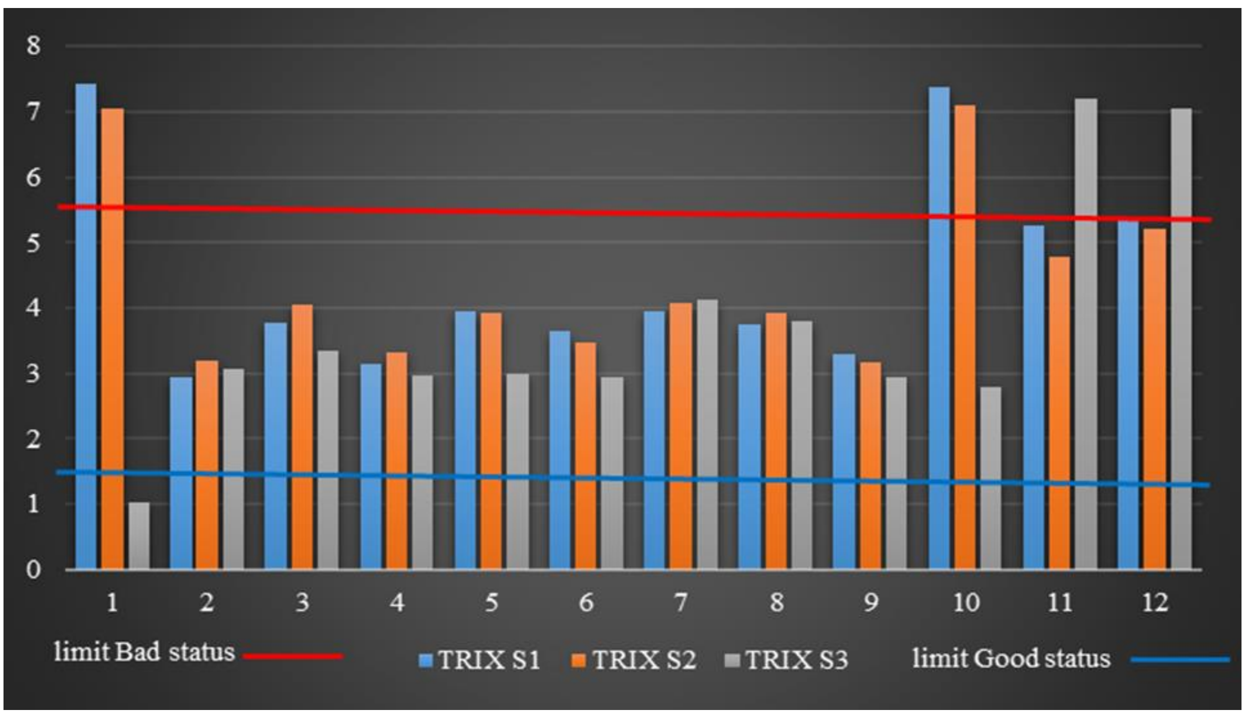


FIGURE 6.7: Temporal value evolution of EQS according to the TRIX scale (Vollenweider et al., 1998)

During the year 2014, the ecological quality status of the studied coastal zone is ranked as a Medium to Poor status, which classified it as the coastal area with High Mesotrophic status (Table 6.6 and Figure 6.7). However, our analysis results highlighted the presence of two temporal evolution periods of the ecological quality status according to the trophic index TRIX (Vollenweider et al., 1998). The first one marked by a Poor status in the studied coastal zone during October to January with a mean value of TRIX ranging between 5.17 to 5.86 and considered as coastal areas with High Mesotrophic status. In this period, the mean value of TRIX ranging between 5.26 to 7.43 in Sonactere site ranking it as Bad status with a marked Eutrophic status, 4.79-7.10 in Cheliff site ranking it as Poor to Bad status with a marked High Mesotrophic to Eutrophic status, and finally a mean value of TRIX ranging between 1.03 to 7.20 in Sonactere coastal site classified it as High to Eutrophic status.

The second period is marked by the Poor to Medium status in the studied coastal zone from February to September 2014, with a mean value of TRIX ranging between 3.06 to 4.05, which classified it as the High Mesotrophic coastal area. The calculated trophic index TRIX in this period highlighted the Medium status (High Mesotrophic status) with a mean value of TRIX ranging between 2.95 to 3.95 in Sonactere site, the Medium to Poor status (High Mesotrophic) with a mean value of TRIX ranging between 3.17 to 4.07 in Cheliff site, and the Medium to Poor status (High Mesotrophic) with a mean value of TRIX ranging between a value of 2.78 to 4.13 in Sonactere coastal site.

6.4 Conclusion

According to Simboula et al. (2004) using the Chl-*a* concentration required by the water framework directive (WFD), the ecological quality status of the studied coastal zone of the three sites during the year 2014 is ranked as a Bad status with a mean equal to 13.17 µ g/l and considered as coastal areas with Eutrophic status. While, according to Vollenweider et al. (1998) using the trophic index TRIX required by the water framework directive (WFD), the ecological quality status of the studied coastal zone of the three sites during the year 2014 is ranked as a Poor status with a mean of 4.21 and considered as coastal areas with High Mesotrophic status.

However, our analysis results highlighted the presence of two temporal evolution periods of the ecological quality status according to the Chl-*a* concentration (Simboula et al., 2005) and using the trophic index TRIX according Vollenweider et al. (1998). The first period marked by a High to Bad status (Oligotrophic to Eutrophic status) in the three studied coastal sites during November to January using a mean value of Chl-*a* concentration in the overall coastal sites, and the second period is absolutely marked by the Bad status (Eutrophic status) in the three studied coastal sites from February to October 2014 according to the Chl-*a* concentration (Simboula et al., 2005). While the classification according to the TRIX (Vollenweider et al. 1998) highlighted the first period by a Poor status (High Mesotrophic status) in the studied coastal zone during October to January and the second period is marked by the Poor to Medium status in the studied coastal zone from February to September 2014.

These results reflect a significant pressure on the studied coastal zone due to the nutrients discharge of Cheliff river and the presence of intensive coastal activities and other pressures implemented in this zone affecting water quality health (see chapter 3 and chapter 5), ranked the three coastal zones (Sonactere, Cheliff, and Sokhra) as failing to achieve good status (severe eutrophication) according to the Water Framework Directive (2000/60/EC).

The application of Chl-*a* (Simboula et al., 2005) and TRIX index (Vollenweider et al. 1998) in the three sites from the west Algerian coasts "Sonactere", "Cheliff", and "Sokhra" were covered by this chapter. Our results provide new data on the water quality assessment. The use of ecological indices may represent a convenient protocol that provides immediate information about the ecosystem health and that may be adopted by the Algerian authorities in specific inland and coastal water quality monitoring plans.

Chapter 7:

General Conclusion

7 General Conclusion

Algeria, with its geographical location and ideal geomorphology, its rich but fragile environment, makes it a dynamic area and a region that is changing rapidly. In addition to climate change impacts, demographic and urban growth, as well as the development and concentration of most of these tourist, fishing, agricultural, and industrial activities on the coastal strip, have generated serious environmental problems, some of which are irreversible. In addition, the Cheliff river showed that its pollution reached chronic proportions. Its waters are discharged with all kinds of impurities, heavy metals (zinc, chromium, acetone, etc), and nutrients to the Mostaganem coastal zone. Pollution levels in the Cheliff were two to four times higher than the safety levels of international standards. In the face of the negative consequences of urban development, the effects of coastal erosion, and biological invasions, likely to cause major ecological disruptions, the development of NS-ICZM represents a new approach to coastal zone governance in Algeria. This strategy provides elements of the response to the shortcomings posed by the "littoral" law.

For the year 2014, the results highlighted the water quality of the three coastal zones including Sokhra, Cheliff, and Sonactere sites of Mostaganem Bay have proved to be in a severe eutrophication situation, exceeding the recommended international standards for the Mediterranean Sea, with excessive nutrient enrichment of the coastal waters.

Every local effort may address wastewater and fertilizer N and P sources, but also the N atmospheric sources requiring national and/or international attention for its socio-economic benefits. Therefore, Water Framework Directive (WFD) aim to achieve a Good Environmental Status (GES) in the European and the Mediterranean Waters. Chlorophyll-*a* concentration and TRIX index required to be monitored by the Mediterranean countries. The TRIX index takes into account nutrients, chlorophyll-*a*, and dissolved oxygen in the environment and Chlorophyll-*a* is a profit parameter of phytoplankton and algae biomass and is arguably the single most responsive indicator of N and P enrichment in the estuarine and coastal ecosystem. It has been applied in several regions in the Mediterranean Sea because the implementation of these indices will allow a rapid estimation of the coastal environments status. And, even if Algeria is not involved in the European water framework directive legislation (EU WDF, 2000/60/EC), but it is necessary to take the European WFD requirements into consideration because of its sharing to the Mediterranean Sea boundaries. As all the Mediterranean countries that are required to protect the Mediterranean water quality because of their sensitivity and importance for the ecosystem health and integrity. However, the WFD is established for the protection of transitional and coastal waters, which is a challenge for water resource management based on ecosystem integrity and health.

Chlorophyll-*a* values characterize a very simple and integrative determinant of the phytoplankton community response to nutrient improvement. An increase in the phytoplankton biomass can be detected as an increase in the chlorophyll-*a* values. Chlorophyll-*a* is a profit parameter of phytoplankton and algae biomass and is arguably the single most responsive indicator of N and P enrichment in the freshwater ecosystem. Some indicators for evaluating trophic status based on physical, chemical, and biological parameters are recommended.

In the ecological classification based on phytoplankton, researchers used different methods in relation to the trophic status and ecological quality classification. Generally, classifications based on biomass are accepted in order to determine the eutrophication status. Simboura et al. base this eutrophication scale which was specifically developed for Greece sea on the nutrient concentrations range which includes phosphate, nitrate and ammonium and phytoplankton cell concentration and chlorophyll-a concentration parameters. These researchers classified the scale, which they formed by modifying it, as “eutrophic”, “high mesotrophic”, “low mesotrophic” and “oligotrophic” in order to fit the scale to the ecological quality classes of WFD, and they distributed mesotrophic chlorophyll values to the low mesotrophic range. This has been used to present the nature of the phytoplankton quality elements temporarily for median chlorophyll-a in the scale ecological quality classification.

EU WFD shows the biological quality elements for the type-specific reference conditions and high surface water type Reference conditions present a definition of high biological quality elements and ecological quality (EQR) ratios. These ratios must present the relationship between the biological parameters observed for a certain surface water and the acceptable values of the reference conditions in the structure of that water. This ratio must be a numerical value between “0” and “1”. It must be “1” for high ecological quality and “0” for bad ecological status (Annex V, 1.4.1 (*ii*) in WFD). In EQR classification, ratios between “0” and “1” are formed by finding the median value of the available data (reference condition) and dividing the data by the median value (reference value). These ratios must be represented with 5 ecological classes as “high”, “good”, “moderate”, “poor”, and “bad”.

The application of the TRIX index, which takes into account all the physicochemical parameters studied, made it possible to determine the trophic status of the waters of the coastal zone of Mostaganem Bay in Algeria, qualifying them as mediocre. Indeed, the waters were very rich in phosphate ions, nitrites, nitrates, and ammonium, which classifies the environment in a state of strong degradation by increased eutrophication by human activities. The coastal stations were particularly distinguished by this degradation in this coastal area of the Bay of Mostaganem and especially the estuarine station located at the west of the Cheliff river.

The general condition, according to the criteria of water framework directive, a study of long-term is required to evaluate more precisely the quality of Mostaganem Bay estuary and the seawater. "*For each of the priority substances, the directive requires a single standard that will separate the two chemical status classes: “good” and “failing to achieve good” set out in the Directive. Failure to achieve one of these standards will mean failure to achieve good chemical status. Failure to achieve good ecological status or good chemical status or both will result in failure to achieve good surface water status. In this event, the WFD requires measures to be put in place to reduce or eliminate inputs of the polluting substance. Waters failing their WFD objectives will have a program of measures specified in the river basin management plan to restore these waters to good status*”.

Annex I

Table 3.1: The DPSIR Framework is exemplified using population growth as a driver. Values are for north-western Algeria (Data about BOD, N, P, and SS are extracted from Tekfi, 2006).

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)

***BOD:** Biochemical oxygen demand, **N**: Azote, **P**: Phosphorus, a measure of water quality (organic pollution).*

Annex II

Table 5.1: Sampling depth characteristics (The station ID, positioning, depth of sampling stations).

Sonactere (S1)			Cheliff (S2)			Sokhra (S3)		
Station ID	Positioning		**Station ID**	Positioning		**Station ID**	Positioning	
1	0.086	36.008	**13**	0.145	36.065	**25**	0.197	36.130
2	0.097	36.001	**14**	0.133	36.061	**26**	0.197	36.115
3	0.090	35.983	**15**	0.126	36.056	**27**	0.239	36.130
4	0.094	35.984	**16**	0.109	36.041	**28**	0.188	36.104
5	0.090	35.988	**17**	0.090	36.038	**29**	0.238	36.126
6	0.085	35.998	**18**	0.101	36.022	**30**	0.232	36.132
7	0.089	35.015	**19**	0.101	36.041	**31**	0.221	36.133
8	0.094	35.973	**20**	0.118	36.042	**32**	0.217	36.133
9	0.089	35.977	**21**	0.108	36.041	**33**	0.182	36.107
10	0.086	35.999	**22**	0.107	36.051	**34**	0.193	36.116
11			**23**			**35**		
12			**24**			**36**		

Table 5.2: Statistics raw data depth (A: station depth, B: sampling depth).

A

Depth (m) /**Station**	**Sonactere (S1)**	**Cheliff (S2)**	**Sokhra (S3)**
AVG	88.40	100.40	157.50
STD	22.17	4.84	30.43
Min	26	94	122
Max	100	108	201

B

Depth (m) /**Station**	**Sonactere (S1)**	**Cheliff (S2)**	**Sokhra (S3)**
AVG	7.90	8.90	10.11
STD	3.18	4.51	5.84
Min	5	4	4
Max	15	19	20

Annex III

Table 5.3: Summary statistics raw data study area and by site.

Summary statistics raw data of Sonactere site (S1)

Var.	T	pH	TRB	SS	OD	D% O_2	BOD	COD	NO_3^-	NO_2-	NH_4^+	S_iO_2	PO_4^{-3}	P_{tot}	Chl.a
Min	15	7.5	18	8.1	4.7	45.3	13.5	43	2	0.01	0	0	0	0.04	0
Max	23	8.2	2446	1820	9	86.5	976	3904	18	0.5	1.58	7.1	6430	0.8	28
AVG	18.92	7.97	954.33	597.43	7.63	77.23	297.33	1250.75	8.88	0.21	0.45	2.20	1910.13	0.34	10.75
STD	2.57	0.17	938.56	663.11	1.27	14.16	297.90	1165.33	5.62	0.17	0.43	2.87	2877.80	0.22	8.48

Summary statistics raw data of Cheliff site (S2)

Var.	T	pH	TRB	SS	OD	D% O_2	BOD	COD	NO_3^-	NO_2-	NH_4^+	S_iO_2	PO_4^{-3}	P_{tot}	Chl.a
Min	14	7.01	20	8.1	3.7	40.3	6	30	4	0.1	0.05	0.05	0.02	0.15	0
Max	22	8.1	3036	2208	9.2	87.3	202	907	24	0.96	6.4	18.2	3300	0.64	23
AVG	17.92	7.88	899.25	512.43	7.59	76.78	92.00	344.58	10.96	0.44	2.06	6.13	690.71	0.41	9.08
STD	2.58	0.30	1023.07	647.53	1.36	13.40	64.10	266.17	7.71	0.31	2.47	6.74	1155.62	0.18	6.91

Summary statistics raw data: Sokhra site (S3)

Var.	T	pH	TRB	SS	OD	D% O_2	BOD	COD	NO_3^-	NO_2-	NH_4^+	S_iO_2	PO_4^{-3}	P_{tot}	Chl.a
Min	15	7.6	16	8.2	6.2	56.8	5	24	3	0	0	0	0	0.03	0
Max	23	8.3	2035	2337	8.4	87	430	1620	10	0.75	0.56	3	4225	0.6	45
AVG	18.92	8.07	627.00	414.77	7.88	80.38	125.63	497.83	5.20	0.21	0.24	1.14	602.58	0.26	19.67
STD	2.57	0.19	717.16	655.32	0.64	9.13	127.30	525.19	2.11	0.25	0.23	1.15	1430.94	0.24	16.14

Summary statistics raw data (Study area)

Var.	T	pH	TRB	SS	OD	D% O_2	BOD	COD	NO_3^-	NO_2-	NH_4^+	S_iO_2	PO_4^{-3}	P_{tot}	Chl.a
Min	14	7	16	8	4	40	5	24	2	0	0	0	0	0	0
Max	23	8.3	3036	2337	9.2	87.3	976	3904	24	0.96	6.4	18.2	6430	0.8	45
AVG	18.58	7.97	826.86	508.21	7.70	78.13	171.65	697.72	8.34	0.28	0.92	3.16	1067.81	0.33	13.17
STD	2.55	0.24	887.98	640.84	1.11	12.18	206.38	834.91	5.99	0.27	1.63	4.69	2008.06	0.22	11.90

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