Chapter

Study of Water and Sediment Quality in the Bay of Dakhla, Morocco: Physico-Chemical Quality and Metallic Contamination

Mimouna Anhichem and Samir Benbrahim

Abstract

The present study contributes to the evaluation of the impact of the various activities developed around the Bay of Dakhla in Morocco through the study of the physico-chemical quality of the waters and sediments of the Bay. For this purpose, a spatial and temporal monitoring of the physicochemical and metallic pollution indicator parameters was conducted between May 2014 and March 2015. The main physicochemical descriptors of water quality were monitored, namely: temperature, salinity, pH, dissolved O2, nutrients (ammonium, nitrites, nitrates, phosphates) and chlorophyll (a). A qualification of the waters of the Bay was drawn up based on water quality assessment grids. The quality of the sediments was assessed through the determination of granulometry, the total organic carbon content and the contents of the main metallic trace elements (cadmium, lead, mercury, chromium, copper and zinc). The results of the present study show the beginning of nutrient enrichment of the water bodies of the bay, especially the stations located near the urban area, where 1.83 mg l^{-1} of nitrates, 0.37 mg l^{-1} of phosphate and 7.42 µg l^{-1} of chlorophyll (a) were recorded. For the sediment, the maximum concentrations of metallic trace elements were recorded in the station near the harbour basin. These results allowed to establish a quality grid for the waters of the bay, generally qualified as "Good", except for the sites located near the urban area for which the quality is qualified as "Average". The sediment quality of the bay was assessed according to the criteria established by the Canadian Council of Ministers of the Environment. The levels of metallic trace elements remain below the toxicity thresholds, except for the sediments taken from the harbour basin.

Keywords: Dakhla Bay, sediments, contaminations, hydrological parameters, trace metals, toxicity

1. Introduction

Paralic environments constitute a transition space between continental and marine ecosystems. They are areas of exchange and transfer of energy and nutrients, very favorable to the development of biological abundance. These environments are therefore the most important marine areas, but also the most vulnerable areas. They present an extremely complex dynamic, influenced by the open ocean and the terrestrial environment. These environments are bodies of water that are often confined, poorly renewed and therefore naturally vulnerable and whose balance can be rapidly modified under the influence of natural or anthropogenic factors [1, 2]. The physico-chemical properties of water masses, as well as the phenomena of tides, swell, and various types of currents, modify the nature of the fauna and flora [3]. The preservation of these fragile environments, of major socio-economic interest, therefore requires knowledge of the processes controlling their evolution [4, 5].

Monitoring the physico-chemical parameters of water bodies and assessing the levels of sediment contamination can help reduce the constraints imposed on these ecosystems and predict possible scenarios to preserve these environments.

For the water bodies the parameters temperature, salinity, pH as well as dissolved oxygen condition the presence of the species according to their preference. Depending on the degree of disturbance of these parameters, the variations can have an influence on the movement of species (e.g. barrier to migration) or have more permanent impacts by disturbing the physiological evolution of organisms (e.g. problems of growth, reproduction, …) [6–8]. In addition, nutrients and chlorophyll (a), which are hydrological descriptors essential for the study or characterization of the water masses of a marine ecosystem, can have repercussions on human activities such as fishing and shellfish farming because their availability conditions the primary production on the basis of which the whole biological activity of the environment then develops [7].

The physico-chemistry of water is considered to be a supporting element for biology, i.e. the quality thresholds to be determined must transcribe the environmental conditions that allow or not the different biological compartments to be in good condition. Thus, it is necessary to know the requirements of the living in terms of temperature, salinity, dissolved oxygen and nutrients, which implies an analysis of the links between physico-chemical parameters and biology as well as their preferences. Threshold grids of a few physico-chemical parameters and a classification from “very good” to “poor condition” in relation to the needs and tolerances of the ichthyofauna have been defined by the European Water Framework Directive [9].

The nutrient indicator proposed by [10] includes only dissolved inorganic nitrogen (DIN) concentrations, which includes ammonium, nitrates and nitrites. ICES [11].

For phosphate ions, the grid for assessing water quality and its suitability for the natural functions of aquatic environments is described by [12].

For sediments, they are the memory of hydro-sedimentary events and constitute both a place of accumulation and emission of pollutants. Any change in the quantities or nature of inputs (terrigenous, industrial and urban) to the environment is recorded in sediments [13]. The Canadian Council of Ministers of the Environment has established two reference values for trace metal elements in marine sediments. These reference values are defined by an Effect Threshold Concentration (ETC) and a Probable Effect Concentration (PEC). These two reference values have been retained among the new sediment quality criteria, but are not sufficient to determine all the thresholds necessary for sediment management. Three other quality criteria were therefore defined later, namely the Rare Effect Concentration (REC), the Occasional Effect Concentration (OEC) and the Frequent Effect Concentration (FEC). Together, these criteria provide a screening tool to assess the degree of sediment contamination. These criteria can prevent the contamination of sites that are vulnerable to anthropogenic contaminant input [14].

The biological richness of the Moroccan coastline is linked to the presence of a large number of paralic zones, such as estuaries, lagoons and bays. The latter are coveted, despite their fragility requiring special management. Dakhla Bay is considered one of the most important in Morocco, both in terms of its surface area and its fish stocks. It represents an ecosystem with strong potential in terms of aquaculture, especially shellfish farming. Moreover, it is characterized by vast beaches and permanent winds, favorable to the development of water sports. This marine domain, so rich in fauna and flora, plays an important socio-economic role for Morocco and therefore imposes a commitment for its protection and the preservation of its resources for future generations. The bay is subject to numerous anthropic pressures, particularly since the opening of the port of Dakhla in 2001 and the extension of industrial activities related to fishing, aquaculture and tourism. These different activities invite questions as to their possible negative impacts on the ecosystem of the bay and its balance.

The objective of this study is to carry out a diagnosis of the state of "health" of Dakhla Bay. Contamination assessment has focused on water and sediment quality indicators. The main physicochemical descriptors of water quality, namely: temperature, salinity, pH, dissolved O2, nutrients (ammonium, nitrites, nitrates, phosphates) and chlorophyll (a) were monitored. The quality of the sediments was assessed through the determination of granulometry, total organic carbon content, the contents of the main metallic trace elements (cadmium, lead, mercury, chromium, copper and zinc). A qualification of the waters and sediments of the bay was drawn up based, successively, on the evaluation grids resulting from the European Water Framework Directive [9] and Marine Sediment Quality Criteria according to the Canadian Council of Ministers of the Environment [14].

2. Materials and methods

2.1 Study area

Dakhla Bay is located on the Atlantic coast of southern Morocco. 37 km long and about 13 km wide, the Bay is relatively narrow and open to the ocean to the south. Oriented NE–SW, it is bounded on the Atlantic Ocean side by the peninsula of Oued Ad Dahab, formed by sandy dunes (**Figure 1**). Dakhla Bay is classified as a Site of Biological and Ecological Interest (SBEI), an Area of International Importance for the Conservation of Birds (IBA) and a RAMSAR site (site recognized as a wetland of international importance) [15]. Unique in North Africa, it is both a migration relay and a wintering and nesting area for thousands of waterbirds [16].

2.2 Sampling points and sampling frequency

Sampling sites were selected to cover the entire bay, particularly areas influenced by human activities (e.g. fishing, aquaculture, tourism, urban planning). For the water compartment, eleven stations were selected. Sampling was carried out at seasonal intervals between May 2014 and March 2015. A total of four sampling and measurement campaigns were carried out. For sediments, five stations were sampled during the winter of 2015 (**Figure 1**).

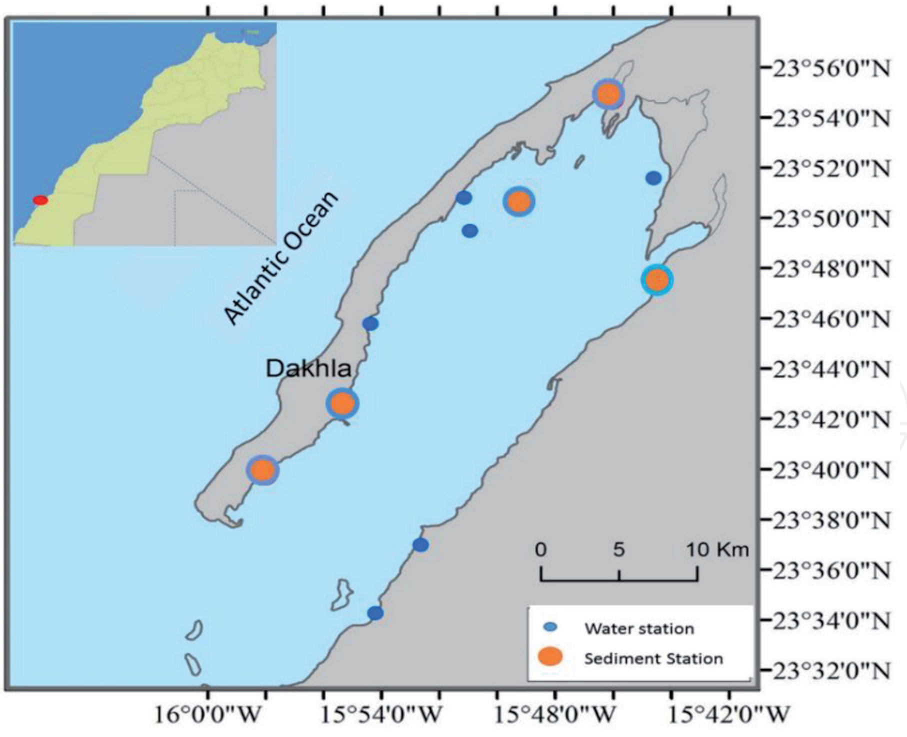

Figure 1.
Location of sampling stations in Dakhla Bay.

2.3 Sampling and analysis

2.3.1 Water compartment

- Physical parameters
  Temperature, salinity and pH were measured *in situ using* a portable multi-parameter probe WTW LF 197 (accuracy 0.1 units).

- Dissolved oxygen
  Dissolved oxygen was determined by Winkler's chemical method. Sampling was carried out in special glass vials with ground glass stoppers of known volume. Oxygen fixation is carried out on site by addition of the reagents. The method is designed to isolate the sample from air and fix the dissolved oxygen as quickly as possible by reaction with a precipitate of manganese hydroxide formed in the sample. Through a succession of reactions, an iodine solution is obtained which is easily and accurately quantified and has a concentration proportional to that of the oxygen initially present. The results are expressed in mg l^{-1} [7].

- Nutrient analysis
  Water samples for nutrient analysis (ammonium, nitrite, nitrate, phosphate) were taken sub-surface at a depth of about 0.5 m in clean polyethylene bottles previously rinsed with water to be analysed. The vials were then stored in a cooler at a temperature of approximately 4°C in the dark and transported to the laboratory for analysis. Nutrients were dosed by colorimetry according to the protocols described by [7].

- chlorophyll (a)
  For the determination of chlorophyll (a), one litre of water was filtered as soon as it arrived at the laboratory, under vacuum on a membrane (47 mm Whatman GF/C filter). The filters were then immersed in a solvent (90% acetone solution

10 ml volume) to dissolve the chlorophyll. The chlorophyll biomass (chlorophyll content (*a*) in µg l^{-1}) was estimated by spectrophotometry [7].

2.3.2 Sediment compartment

Sediment samples were taken from the surface layer using a hand corer. The contents of the corer were placed in a food-grade plastic bag, transported to the laboratory in coolers at approximately 4°C and then stored in the freezer at −20°C until analysis.

- Particle size analysis
  After drying at 40°C, the sediment samples were subjected to a conventional particle size analysis. A fraction of each sample was washed on 2 mm and 0.063 mm mesh sieves to separate the following three particle size classes [17]:
  - Class of "Rudites", with a particle diameter greater than 2 mm;
  - Class of "Arenites", with a particle diameter between 2 and 0.063 mm;
  - Class of "Lutites", with a particle diameter of less than 0.063 mm.
- Total organic carbon
  The determination of total organic carbon was carried out by indirect titration using the Walkley-Black method. This consists of oxidation of the organic carbon by a mixture of potassium dichromate and sulphuric acid. After the reaction, the concentration of total organic carbon is determined by measuring the excess dichromate. Titration is done by Mohr salt using diphenylamine as a colour indicator [18].
- Trace metals
  The extraction of metallic trace elements (cadmium, lead, mercury, chromium, copper and zinc) from the sediments was carried out by microwave mineralization using a mixture of strong acids: HNO3-HF and HCl [19]. The solutions obtained were analysed by Thermo iCAP Q Series Plasma Mass Spectrometry (ICP-MS). A certified reference material (IAEA-158) and a blank were analyzed with each mineralization series and are used for quality control and reliability of results.

2.4 Statistical processing of data

In order to highlight the relationships that can exist between the environmental factors studied (physico-chemical parameters and metal concentration) and the activities carried out at the bay, the obtained data were processed using XLSTAT 2016.06 software.

3. Results and discussions

3.1 Water compartment

3.1.1 Temperature

The surface water temperature values recorded *in situ* during this study allowed us to illustrate spatial and temporal variations in this parameter (**Figure 2**). The

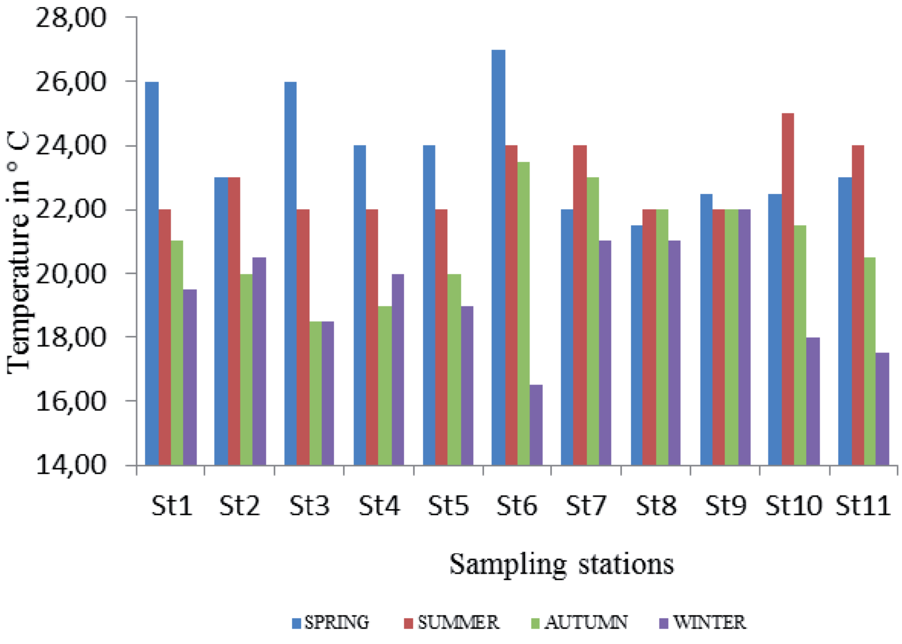

Figure 2.
Spatio-temporal evolution of the temperature at Dakhla Bay.

mean value recorded for the entire area was 21.8°C. The greatest thermal amplitude was observed at the Dunablanca station, with a minimum of 16.5°C recorded in winter 2015 and a maximum of 27.0°C recorded in spring 2014. This variation is quite normal given the shallow depth of the basin, which facilitates air-water exchanges.

3.1.2 Salinity

Salinity (**Figure 3**) ranges from 33.0 to 40.5 PSU, with a mean value of 36.9 PSU. The results obtained are in perfect agreement with previous work [20] in which a mean salinity of 36.9 PSU was recorded for the entire area, with an increasing gradient from the ocean to the bottom of the bay. The maximum value of 40.5

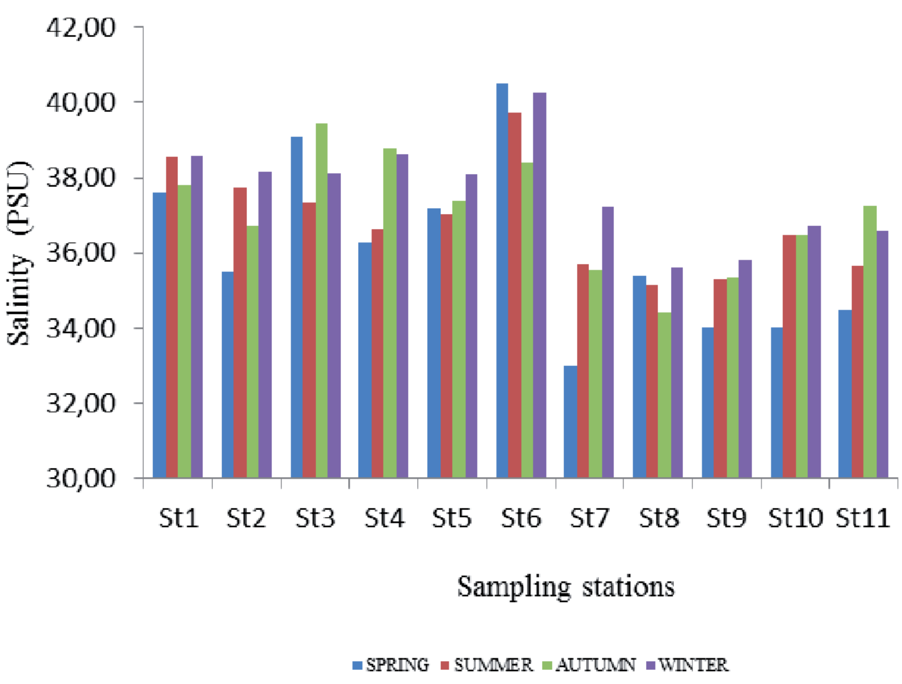

Figure 3.
Spatio-temporal evolution of salinity at Dakhla Bay.

PSU was recorded during spring 2014 at the Dunablanca site, where the highest temperature was recorded. This value would be explained by the location of the site at the bottom of the bay, characterized by slow renewal of marine waters [21] and a shallow depth favouring greater evaporation when the temperature increases. The value of 33.0 PSU was recorded during the spring of 2014 at the station in the urban area. Dilution of seawater by wastewater discharge would be the main source of the decrease in salinity at this sampling point.

3.1.3 pH

During the present study the values recorded for pH oscillate around 7.8 in the urban area near the discharges and 8.3 in the Lasargua station, with an average of 8.0 during the four seasons (**Figure 4**). These values are of the same order of magnitude as those reported in previous studies of the bay [22, 23].

3.1.4 Dissolved oxygen

The dissolved oxygen concentrations recorded range from 7.23 mg l^{-1} and 10.83 mg l^{-1}, with a mean value of 8.74 mg l^{-1} (**Figure 5**). This good oxygenation is mainly due, on the one hand, to the strong currents in the southern part of the bay where the strong exchanges with the ocean take place and, on the other hand, to the winds that stir the surface waters. The lowest levels were recorded at stations 7 and 8. However, oxygen levels remain above the required level despite the proximity of these urban discharge stations.

3.1.5 Ammonium

The maximum value recorded in the bay for the ammonium parameter is 0.31 mg l^{-1} and corresponds to the sample taken at the point in the urban area (city centre), and the minimum value is 0.00 mg l^{-1}, with an average of 0.06 mg l^{-1}. Ammonium is considered to be the hub of the nitrogen cycle in coastal ecosystems. Its concentrations in marine waters are often below 0,01 mg l^{-1} or even undetectable. Ammonium is mainly a tracer of urban and industrial discharges [24], the rise

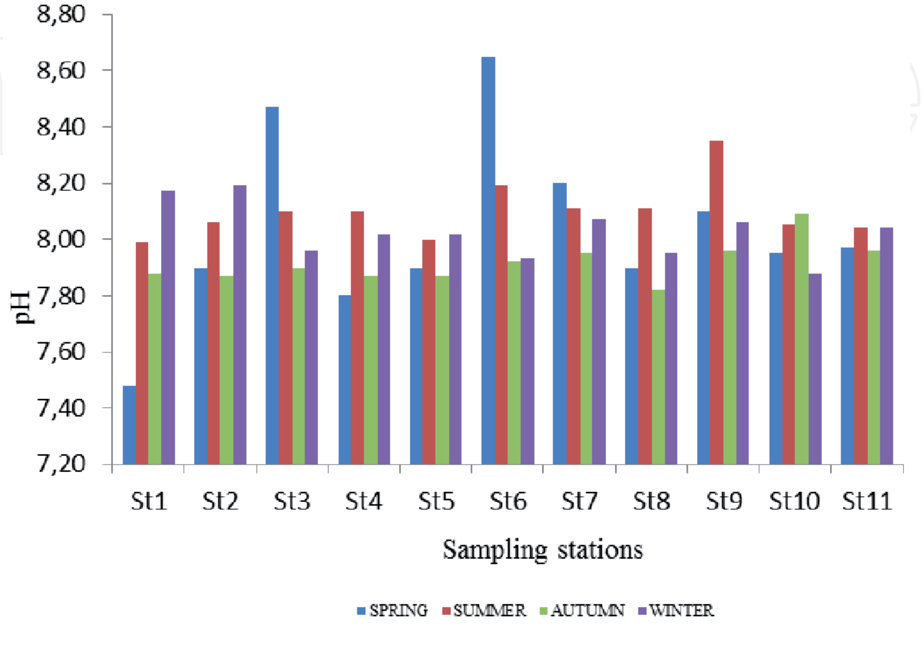

Figure 4.
Spatio-temporal evolution of the pH at Dakhla Bay.

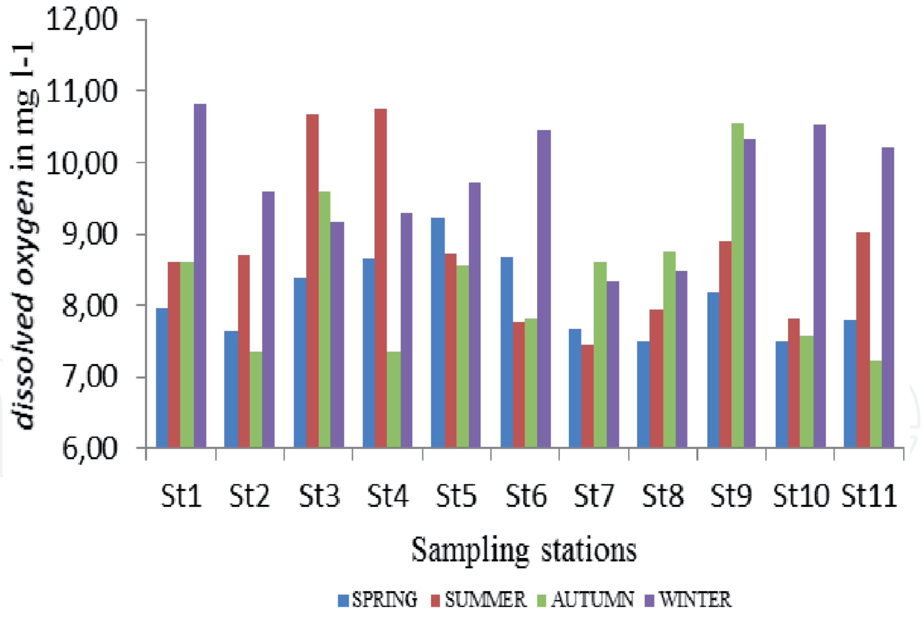

Figure 5.
Spatio-temporal evolution of dissolved oxygen at Dakhla Bay.

recorded during spring and summer (**Figure 6**) is mainly due to wastewater from the industrial area, port and some outfalls located in the urban area. On the other hand, the absence of ammonium in most stations during autumn and winter is related to the temperature drop that slows down biological activities and probably to the flow of urban and industrial discharges near the urban area. Another study on the characterization of these discharges is being carried out to identify their impacts on the bay.

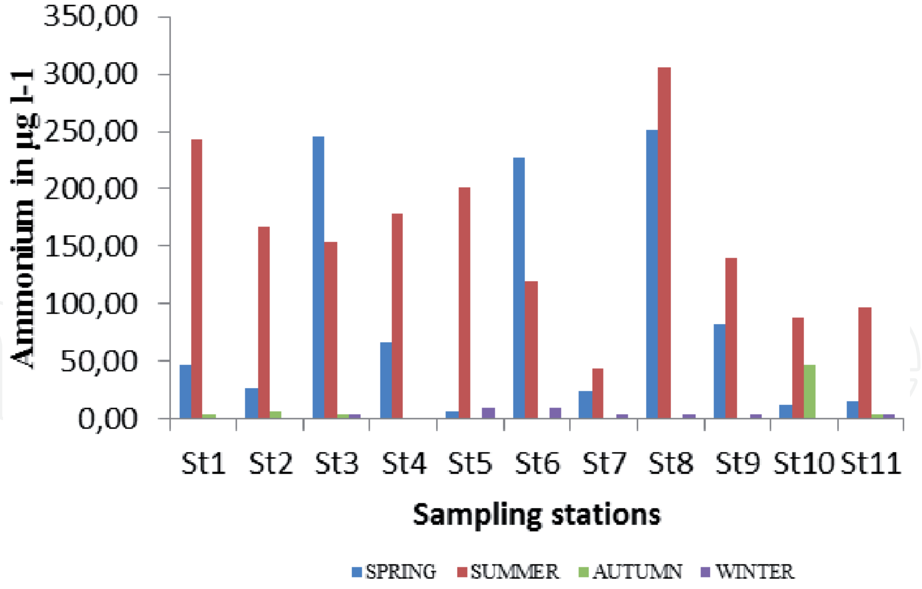

Figure 6.
Spatio-temporal evolution of ammonium at Dakhla Bay.

3.1.6 Nitrites

Nitrite concentrations in the study area range from a maximum of 0.04 mg l^{-1} to a minimum of 0.00 mg l^{-1}. The mean value of this parameter is 0.01 mg l^{-1} (**Figure 7**). The spatial distribution of nitrite is dependent on the proximity of the stations studied to sources of enrichment of the environment by this element.

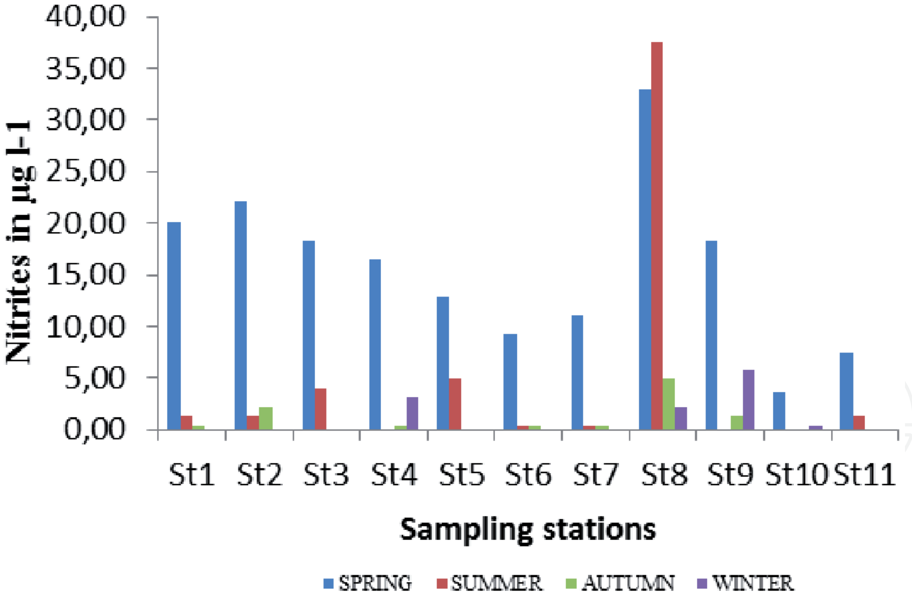

Figure 7.
Spatio-temporal evolution of nitrites at Dakhla Bay.

The dominance is observed during spring and summer at the point in the urban area (downtown) subject to urban and industrial discharges.

3.1.7 Nitrates

The values recorded for nitrates range from a maximum of 1.83 mg l^{-1} in the urban area, with a minimum of 0.00 mg l^{-1} recorded at most stations, especially during autumn and winter, with an average of 0.12 mg l^{-1} (**Figure 8**). The absence of nitrate ions at most sites in the bay during most of the year is only a strong signal of the significant biological activity within the bay. For the "urban area" station that recorded the maximum value, the increase in this element during most of the year means an enrichment of the environment by organic matter which, in the presence of nitrifying bacteria and oxygen, is transformed into nitrite and then into nitrate. This increase is certainly due to inputs from discharges that are close to the area.

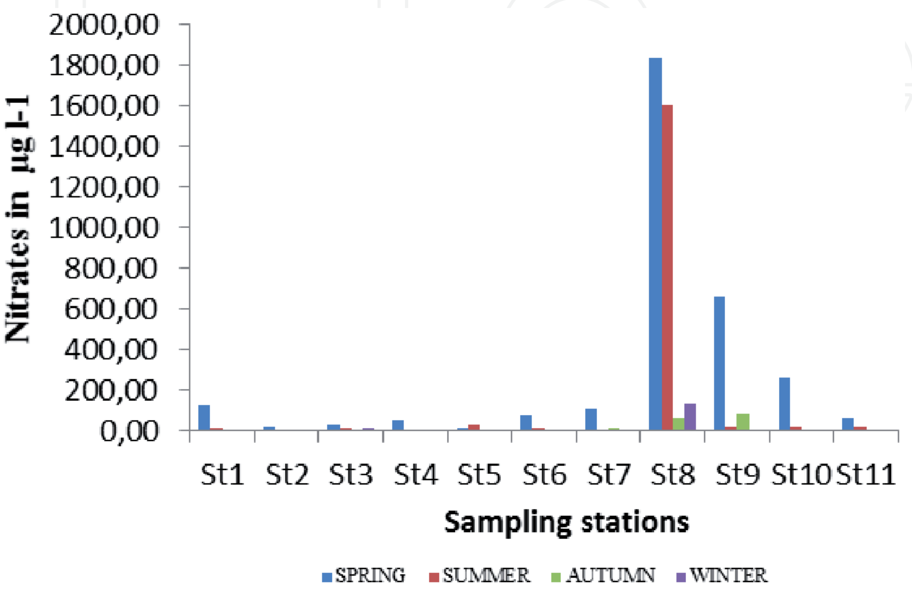

Figure 8.
Spatio-temporal evolution of nitrates at Dakhla Bay.

3.1.8 Phosphates

For the phosphate parameter, the values show a maximum of 0.37 mg l^{-1}, a minimum of 0.00 mg l^{-1} and an average of 0.14 mg l^{-1} (**Figure 9**). The results of previous studies have shown that phosphate levels in surface water have been in the range of 0.00 to 0.01 mg l^{-1} [25]. A clear trend toward increasing phosphate levels in the waters of the Bay of Dakhla has been noticed. This increase may be due, on the one hand, to the activities related to the processing industry of fishery products and domestic discards and, on the other hand, to the upwelling phenomenon that characterizes the Dakhla area [26].

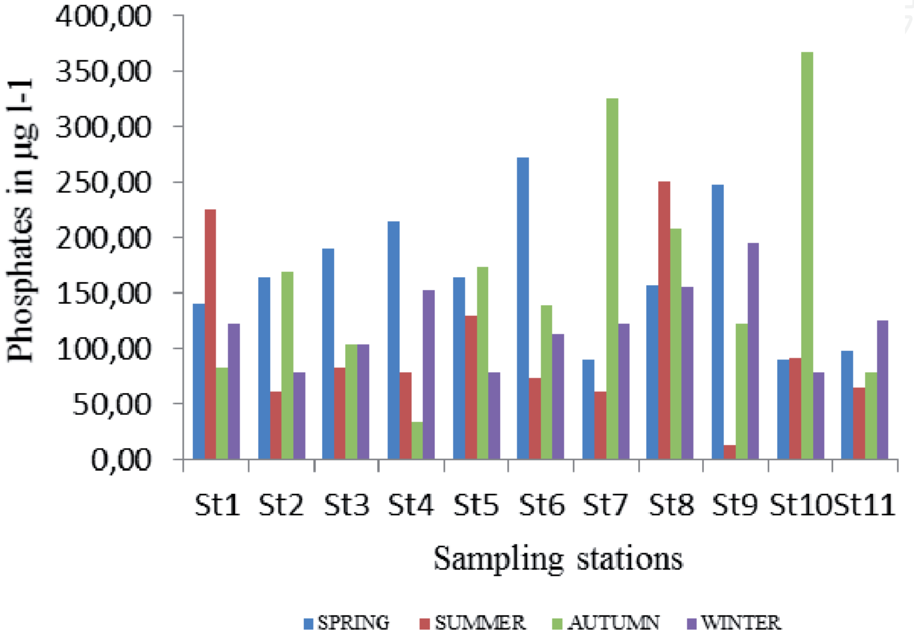

Figure 9.
Spatio-temporal evolution of phosphates at Dakhla Bay.

3.1.9 Chlorophyll (a)

Figure 10 shows the evolution of the chlorophyll (a) concentration during the study period, the mean value obtained was 2.74 µg l^{-1}, with a minimum of 0.00 µg l^{-1}

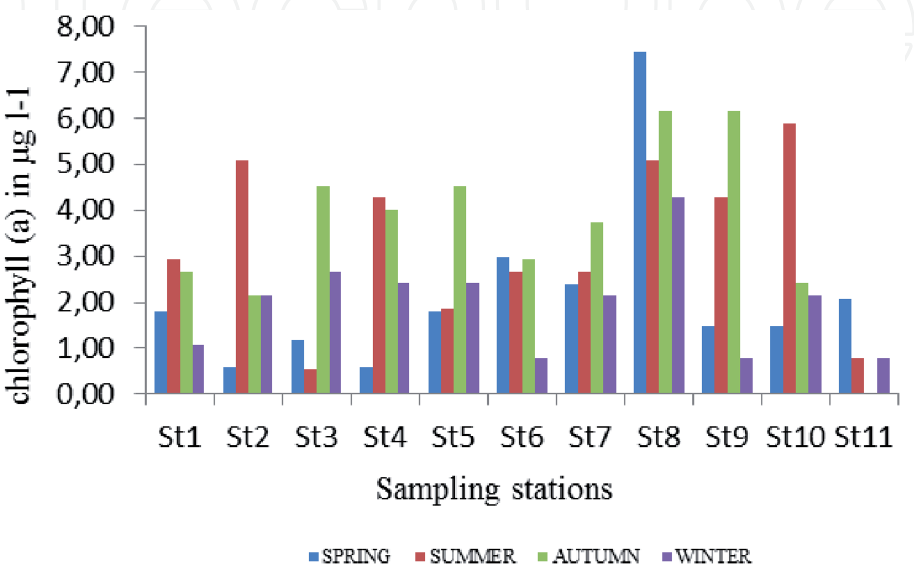

Figure 10.
Spati-temporal evolution of chlorophyll (a) at Dakhla Bay.

at "Puertitou" and a maximum value of 7.42 µg l^{-1} recorded in the urban area. These results indicate that the waters of Dakhla Bay have higher chlorophyll (a) levels than those reported in previous studies of the same ecosystem, which have showed that this concentration did not exceed 2.60 µg l^{-1} in 1991 and 5.00 µg l^{-1} in 1994 [25]. The high concentration recorded in this study corresponds to the site that is close to the urban area, which is undergoing essential nutrient enrichment for chlorophyll proliferation.

3.1.10 Water quality

Diffuse or punctual anthropogenic inputs have been responsible for significant nutrient enrichment (phosphates and nitrates in this case). These inputs come from various sources: agricultural, industrial or urban. Their "evacuation" or "elimination" is linked to the dilution capacity of the system, the hydrodynamics and the efficiency of the degradation processes of these elements by bacteria [24].

The implementation of the WFD has been a driving force forcing Member States to define environmental quality indicators associated with quality thresholds. These indicators concern dissolved oxygen, nutrients and phytoplankton, qualified among others through the chlorophyll concentration (a) [27]. Ifremer also defined in 2010 a quality indicator for coastal and transition masses, the nutrient indicator proposed by [10] integrates the dissolved inorganic nitrogen (NID) concentrations which include ammonium, nitrates and nitrites. Quality grids proposed by the European Water Framework Directive [9], enabled us to classify the waters of Dakhla bay as good quality for all the physico-chemical parameters studied, except for the sites located near urban discharges which have an average quality (**Table 1**).

REF	T	pH	O2	NID	PO4	Chlo
St1	Good	Good	Very good	Good	Good	Very good
St2	Good	Good	Very good	Good	Good	Very good
St3	Good	Good	Very good	Good	Good	Very good
St4	Good	Good	Very good	Good	Good	Very good
St5	Good	Good	Very good	Good	Good	Very good
St6	Good	Good	Very good	Good	Good	Very good
St7	Good	Good	Very good	Good	Good	Very good
St8	Good	Good	Very good	Average	Good	Good
St9	Good	Good	Very good	Average	Good	Very good
St10	Good	Good	Very good	Good	Good	Very good
St11	Good	Good	Very good	Good	Very good	Very good

Table 1.
Dakhla Bay Water Quality Grid

3.2 Sediment compartment

3.2.1 Grain size

In Dakhla Bay, Rudites are variable in the sediments. They range from 0.60% to 3.94% of the total dry sample weight. These Rudites mainly come from the biogenic fraction consisting of lamellibranch and gastropod shells [28]. The particle size distribution of the sediments collected at the Dakhla, shows an abundance of Arenites with percentages ranging from 75.60% to 98.28% respectively for the Port Basin and

Boutalha sites. This result informs about the hydrodynamic aspect of the bay and shows that the currents in the downstream part are stronger than in the upstream part. For the Lutites fraction, the sediments contain 1.56% for Boutalha and 22.01% for the harbour basin. The sediment in Dakhla Bay therefore has a predominantly sandy and sandy-muddy particle size texture (**Figure 11**).

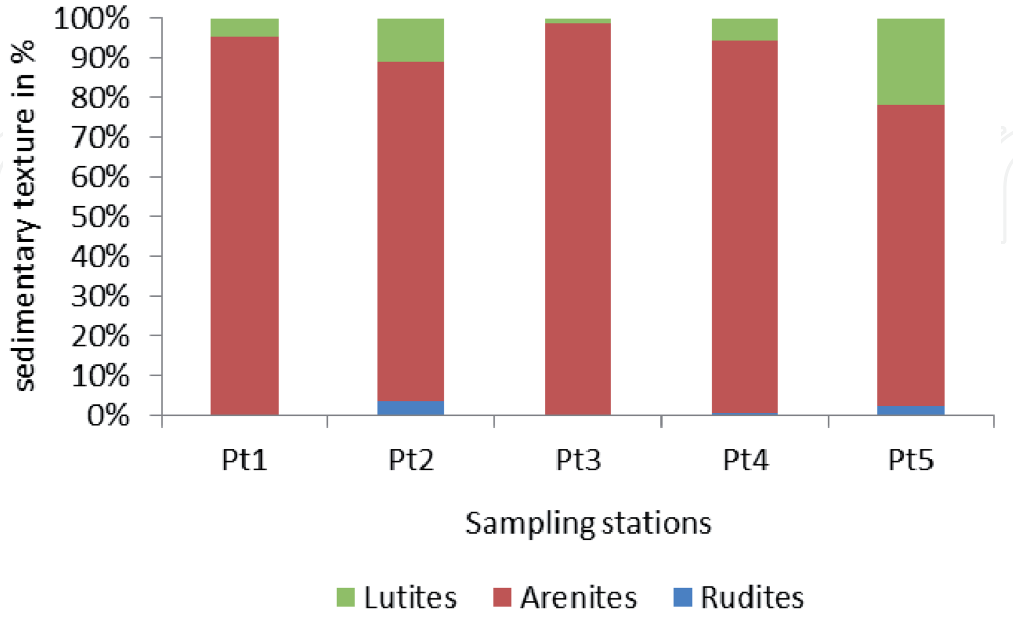

Figure 11.
Spatial evolution of the sedimentary texture of Dakhla Bay.

3.2.2 Organic carbon

During the present study, the percentages recorded for organic carbon oscillate around a minimum of 0.20% in Boutalha and a maximum of 2.85% in the port basin (**Figure 12**). Examination of the results of this study shows that the percentage of organic carbon gradually increases from the downstream to the upstream part. We find that the percentage of organic carbon follows the same evolution as the distribution of fine sediment fractions. The percentage of organic carbon in the harbour basin is ten times greater than in the bay, due to the confinement of the

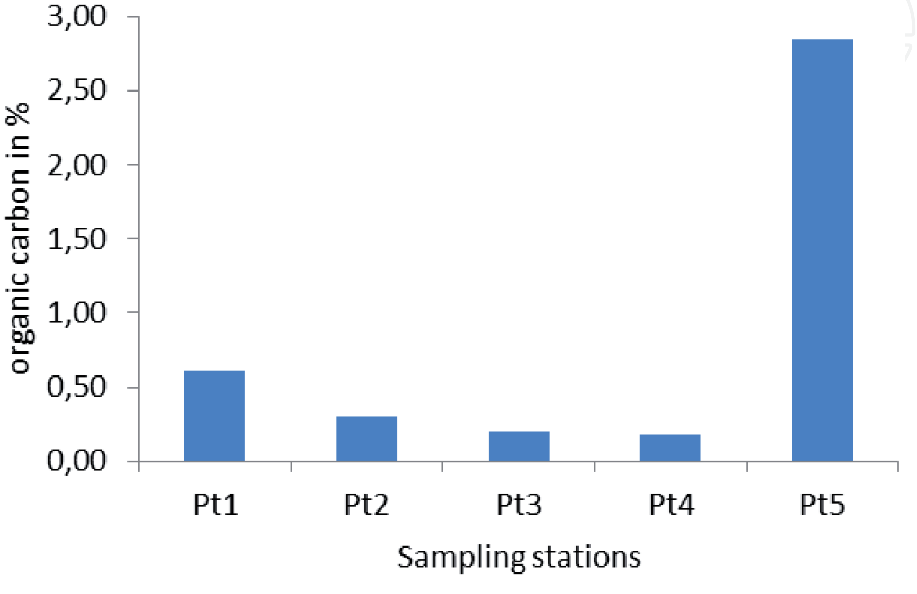

Figure 12.
Spatial distribution of organic carbon in the sediment of Dakhla Bay.

basin on the one hand, and on the other hand to the organic-laden discharges that could be dumped into the harbour.

3.2.3 Metal trace elements

The results for the majority of the metallic trace elements studied (cadmium, lead, chromium, copper and zinc) show a minimum at the Dunablanca station, except for mercury, for which a minimum was measured at the Boutalha station. On the other hand, the maximum was recorded, for all elements, at the Port Basin level. With regard to the three metals recognised as toxic (Cadmium, Lead, Mercury), the results recorded for Pb are of the order of 5.15 ± 0.12 and 16.69 ± 0.25 mg kg^{-1} successively in Dunablanca and Urban Area, while at the level of the port basin the concentration is 45.58 ± 0.61 mg kg^{-1}. For Cd concentrations are between 0.43 ± 0.01 and 0.62 ± 0.01 mg kg^{-1} respectively in Dunablanca and Boutalha, in the harbour basin the concentration is 1.3 ± 0.02 mg kg^{-1}. Mercury levels are below the detection limit for Boutalha and of the order of 0.0023 ± 0.0001 and 0.0145 ± 0.0021 mg kg^{-1} successively in the Urban Zone and the port basin (**Figure 13**).

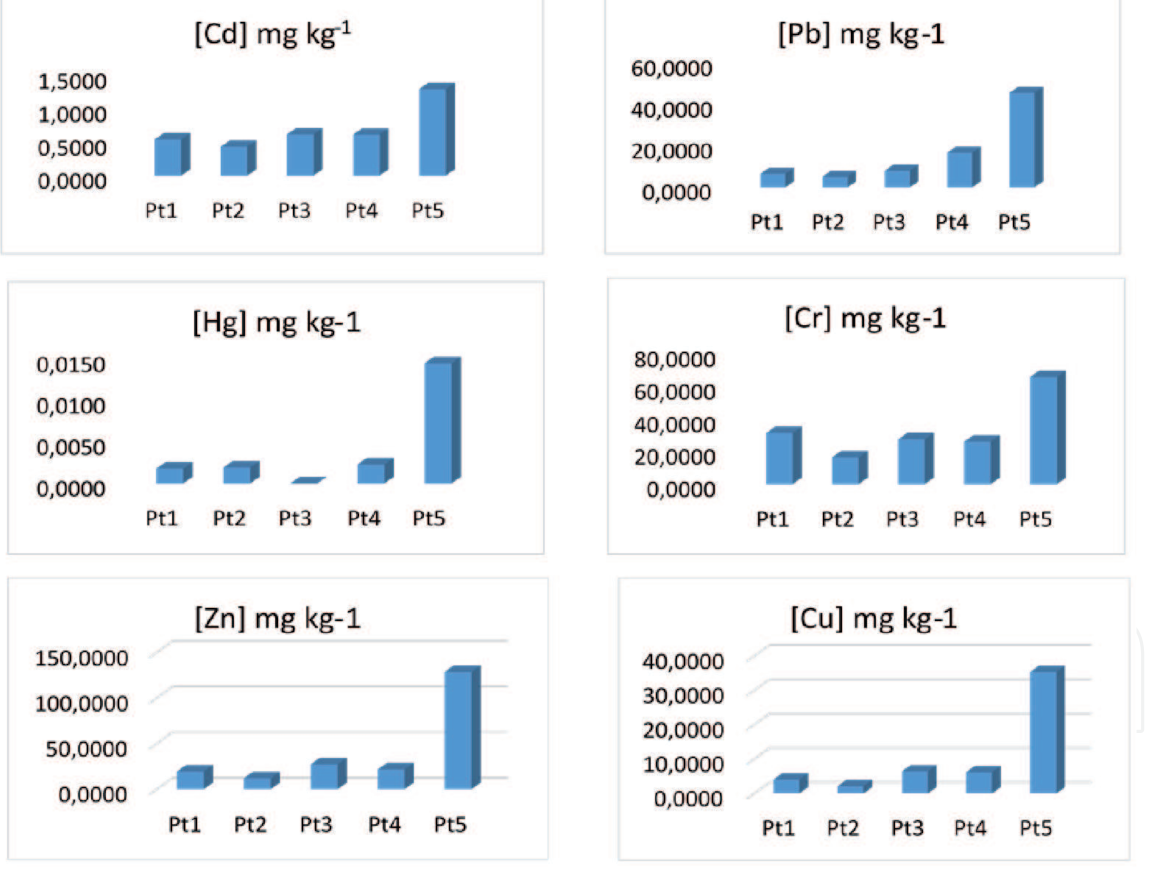

Figure 13.
Spatial evolution of trace metals in the sediment of Dakhla Bay. All values are in milligrams per kilogram (mg kg^{-1}) of dry sediment.

3.2.4 Sediment quality

Sediment quality in Dakhla Bay was assessed through the determination of particle size, total organic carbon content and the contents of the main metallic trace elements (cadmium, lead, mercury, chromium, copper and zinc).

The results of this study allowed us to assess the degree of contamination of the sediment in Dakhla Bay according to the criteria established by the Canadian

Council of Ministers of the Environment (**Table 2**). For the four stations Dunablanca, Pk25, Boutalha and the Urban Area, concentrations are below the CSE or even below the CER (**Class II**). On the other hand, for the Harbour Basin, the concentrations of Pb, Cd, Cu, Cr and Zn are between CSE and CEO (**Class III**), but for the Hg concentration they are still below CER (**Table 3**).

The study showed that, apart from the port basin, Dakhla bay remains less polluted, either compared to national or international ecosystems (**Table 4**). However, special attention must be paid to minimising, or even stopping, all kinds of pollution, in order to better protect the bay.

Sediment Quality Criteria	Pb	Cd	Hg
ERC	18	0.32	0.051
CSE	30	0.67	0.13
CEO	54	2.1	0.29
CEP	110	4.2	0.70
CEF	180	7.2	1.4

Rare Effect Concentration (REC), a Threshold Effect Concentration (TEC), an Occasional Effect Concentration (OEC), a Probable Effect Concentration (PEC) and a Frequent Effect Concentration (FEC) according to the Canadian Council of Ministers of the Environment.

Table 2.
Marine Sediment Quality Criteria [13].

Criteria for quality	Class	Impact on the environment	Prevention of sediment contamination from discharges	Evaluation of the quality of the sites studied
<CEF **<CEP** **= ou > CEO**	Class III	Frequently observed biological effects	The probability of measuring adverse effects increases with the concentrations measured. Examine the problem: continue investigations to identify the source(s) of contamination and intervene if necessary on these sources in order to avoid an increase in contamination or a new inflow of contaminants.	**- Port basin**
< ou = CSE	Class II	Biological efects semetimes observed	The likelihood of sediment having an impact on the environment is low. Monitoring can be put in place to verify the evolution of the situation.	**-Pk25** **-Dunablanca** **-Boutalha** **- Urban area**
< OU = CER	Class I	Rarely observed biological effects	Sediments are considered to have no impact. No action is required, except in cases where persistent, toxic and bioaccumulative substances (e.g., mercury) released into water bodies may accumulate in sediment and in the tissues of organisms	

Table 3.
Application of sediment quality criteria [13] of the sites studied.

Studies/Criteria	Pb (mg kg^{-1})	Cd (mg kg^{-1})	Hg (mg kg^{-1})	Reference
Dakhla Bay (min - max)	(5.15–16.69)	(0.43–0.62)	(< LD - 0.0023)	This study
New Port (Dakhla)	45.58 ± 0.61	1.3 ± 0.02	0.0145 ± 0.002	
Dunablanca	3.6 ± 1.8	< LD	n/a	[28]
Nador Lagoon (min - max)	(3–416)	(0–6.2)	—	[29]
Moulay Bou Selham Lagoon	22.4 ± 7.5	0.94 ± 0.32	—	[30]
Sidi Moussa Lagoon	33.0 ± 5.1	3.67 ± 0.64	—	[30]
Oualidia Lagoon (max)	2.5	0.7	0.08	[31]
Ebrie Lagoon	(7–250)	—	(0.0–2.2)	[32]
Oludeniz Lagoon	7	—	—	[33]
Piratininga Lagoon	66 ± 20	—	—	[34]
Bay of Bothnia	79	0.94		[35]

Table 4.
Comparison of Pb, Cd and Hg contents in sediments of Dakhla Bay with levels in other paralic environments.

3.3 Statistical analysis of results

More than 83% of the variation of all parameters studied is expressed by the two factorial axes F1 and F2 of the principal component analysis (PCA), with 58% for the F1 axis and 25% for the F2 axis. The principal component analysis shows that the parameters (Nitrates and chlorophyll (a)) are significantly correlated to the first factorial axis (F1 axis) in the urban area while the parameters (Total organic carbon, phosphates and trace metal elements) are significantly correlated to the second factorial axis (F2 axis) in the port area.

The analysis enabled us to highlight that the areas containing urban agglomerations and the port are the most impacted (**Figure 14**).

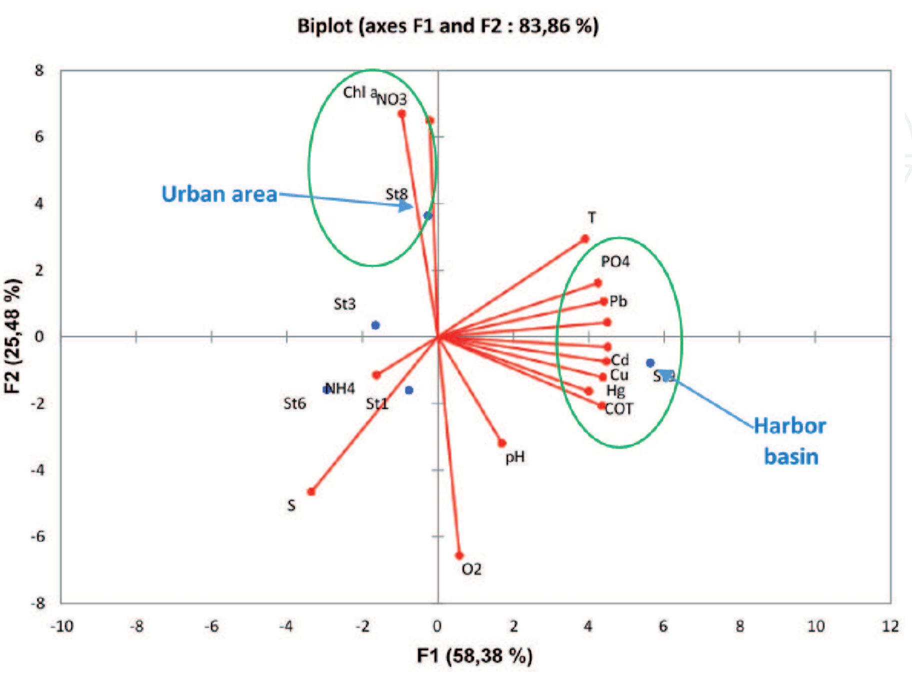

Figure 14.
PCA results for the variables studied for water and sediment of Dakhla Bay.

4. Conclusion

This study shows that:

The monitoring of physico-chemical parameters revealed nutrient enrichment and a significant chlorophyll biomass, especially at sites close to wastewater discharges.

Based on the different quality grids proposed by the WFD, a qualification of the waters of Dakhla Bay was established, which is generally "Good", except for two stations located near urban discharges, for which the quality is "Average".

The granulometric study enabled us to identify the sedimentary structure of Dakhla Bay, which is of sandy to sandy-muddy type.

The evaluation of the levels of metallic trace elements (Cd, Pb, Hg, Cu, Cr and Zn) in the sediments shows that, apart from the port basin, Dakhla Bay is less polluted, both in comparison with national and international ecosystems.

In conclusion, Dakhla Bay remains a site little impacted by human activities. However, particular attention must be paid to minimising, or even stopping, all kinds of pollution, to better protect the bay.

Author details

Mimouna Anhichem* and Samir Benbrahim
National Institute for Fisheries Research (INRH), Casablanca, Morocco

*Address all correspondence to: anhichemm@gmail.com

References

[1] CHABAUD, C. (2013) - What means and governance for sustainable ocean management? The opinion of the economic, social and environmental council Official Journals. http://www.lecese.fr/sites/default/files/pdf/Avis/2013/2013_15gouvernanceoceans.pdf.

[2] Kouassi, Aka Marcel. (2005) - Hydrochimie and water quality in two tropical lagoons of Cote d'Ivoire (Ebrie, Grand Lahou).≫ These from Doctorate, University of Cocody,. Abidjan, 147 p.

[3] Ifremer (2008) DCE-MEFM - Taking into account the impact of shellfish farming activities on the biological quality element "Benthic invertebrate fauna" in the assessment of ecological potential - Case of the MEC "FRFC02". and " FRGC01 " Final Report.

[4] Maanan M. Sedimentological study of the filling of the sidi moussa lagoon (Moroccan Atlantic coast) granulometric, mineralogical and geochemical characterization. PhD thesis, Chouaib Doukkali University, Eljadida Faculty of. Sciences. 2003;**131p**

[5] Villanueva, Maria Concepcion S. (2004) - Biodiversity and trophic relations in some estuarine and lagoon environments in West Africa: adaptations to environmental pressures, PhD thesis from the Institut National Polytechnique de Toulouse, 246 p.

[6] Aminot A. and Chaussepied M. (1983) - Manual of chemical analyses in the marine environment. Centre National pour l'Exploitation des Océans, 395 pp.

[7] Aminot A., Keroul R. (2004) - [Hydrology of Marine Ecosystems: Parameters and Analyses]. IFREMER edition, 336 pp.

[8] Taverny, C. & Pierre Elie. (2009) - [Review of biological knowledge and the state of lamprey habitats migratory migrants in the Gironde basin]. Proposals for priority actions. irstea., pp.110.

[9] WFD(2000/60 / EC). (2000) - The Water Framework Directive or European Directive of the European Parliament and of the Council adopted on October 23, 2000. Ifremer.

[10] DANIEL, A. & SOUDANT, D. (2010) - WFD Assessment April 2010 - Quality Element: Oxygen Balance. Ifremer Report, 73 p.

[11] Loire Bretagne Water Agency. (2005) - Qualification of coastal and transitional water bodies on the basis of environmental quality data. Result of the assessment. Progress report 4.

[12] SEQ-Water, Biology Aptitude Class (2003).

[13] BELIAEFF, B., BOUVET, G., FERNANDEZ, J.-M., DAVID, C. & LAUGIER, T. (2011) - Guide for the monitoring the quality of the marine environment in New Caledonia. ZONECO and programme CNRT the Nickel. 169 pages.

[14] CMEC (2007) - Environment Canada and the Department of Sustainable Development, Environment and des Parcs du Québec. Quebec Sediment Quality Assessment Criteria and Frameworks application: prevention, dredging and restoration, 39 p.

[15] RAMSAR. (2016).- The List of Wetlands of International Importance Published.

[16] QUINBA, A., RADI, M., BENHOUSSA, A., BAZAIRI, H. & MENIOUI, M. (2003) - Fact sheet on Ramsar Wetlands (RIS). Categories endorsed in Recommendation

4-7 (1990) as amended by Resolution VIII.13 of the Conference of the Contracting Parties, 9 p.

[17] BELLAIR, P. & POMEROL, C. (1977) - Elements of geology. Paris, Armand Colin.

[18] WALKLEY, A. & BLACK, I.-A, (1934).- An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. Soil Sci, 63, 251-263.

[19] OSPAR/JAMP, 2002.- Guidelines for Monitoring Contaminants in Sediment. Ref. No. 2002-16. htpp://www.ospar.org/documents?d=32743.

[20] CTAQUA-CETECIMA (2014) - Report on the identification of the characteristics of the physical environment. Plan for the planning and development of aquaculture in the Oued Eddahab region Lagouira - Morocco Lot 1 Phase 2.

[21] ORBI, A., GUÉLORGET, O. & LEFÈBVRE, A. (1996) - La baie de Dakhla, organisation biologique et operation. INRH, Dakhla, Morocco, 240 p.

[22] DAFIR, J. (1997) - Application of phosphorus dynamics to the study of organization and functioning. aquatic ecosystems (management and preservation). PhD Thesis, University Hassan II, Faculty of Science Ain Chock, Casablanca, 634 p.

[23] SAAD, Z. (2015) - Assessing the quality of coastal marine waters: a new methodological approach applied for the case of Dakhla Bay (South Morocco). [Thesis] Ecology and management Cadi Ayyad University, Faculty of Sciences, Semlalia, Marrakech.

[24] SOUCHU, P., LAUGIER, T., DUSSERRE, K. & MAROBIN, D. (2001) - Monitoring of trophic parameters. in the water of the Narbonnaise ponds. Final report, Ifremer DEL, Coastal Laboratory of Sete, February 2001.

[25] ORBI, A., DAFIR, J.M. & BERRAHO, A. (1995) - Multidisciplinary study of Dakhla Bay. Works and document n°86 from INRH, Morocco. Internal report, 26 p.

[26] MAKAOUI, A., ORBI, A., HILMI, K., ZIZAH, S., LARISSI, J. & TALBI, M. (2005) - L'upwelling de la Atlantic coast of Morocco between 1994 and 1998. C. R. Geoscience, 337, 1518-1524.

[27] FOUSSARD, V. & ETCHEBER, H., (2011) - Report. Proposal for a monitoring strategy for physico-chemical parameters for the Seine and Loire estuaries. BEEST project: towards a multi-criteria approach to the good ecological status of large estuaries. Univ. Bordeaux 1, UMR 5805 EPOC and CR1 CNRS.

[28] ZIDANE, H., ORBI, A., MOURADI, A., ZIDANE, F. & BLAIS, J.-F. (2008).- Hydrological structure and edaphic of an oyster-farming site: Dunablanca (The bay of Dakhla in southern Morocco). Environmental Technology, 29, 1031-1042.

[29] RUIZ, F., ABAD, M., OLIAS, M., GALAN, E., GONZALEZ, I., AGUILA, E., HAMOUMI, N., PULIDO, I. & CANTANO, M. (2006).- The present environmental scenario of the Nador lagoon (Morocco). Approximately. Res., 102, 215-229.

[30] CHEGGOUR, M., CHAFIK, A., LANGSTON, W.J., BURT, G.R., BENBRAHIM, S. & TEXIER, H. (2001).- Metals in sediments and the edible cockle *Cerastoderma edule* from two Moroccan Atlantic lagoons: Moulay Bou Selham and Sidi Moussa. Approximately. Pollut, 115, 149-160.

[31] INRH (2015) - Lagoon of Oualidia. Ecological status and environmental

health. Integrated rehabilitation programme for the lagoon of Oualidia. INRH, Casablanca, Morocco.

[32] KOUADIO, I. & TREFRY, H.H. (1987).- Sediment trace metal contamination in the Ivory Coast, West Africa. Water Air Soil Pollut. 32, 145-154.

[33] TUNCEL, S.G., TUGRUL, S. & TOPAL, T. (2007).- A case study on trace metals in surface sediments and dissolved inorganic nutrients in surface water of Ölüdeniz lagoon -Mediterranean, Turkey. Water Res., 41, 365-372.

[34] LACERDA, L.D., FERNANDEZ, M.A., CALAZANS, C.F. & TANIZAKI, K.F. (1992) – Bioavailability of heavy metals in sediments of two coastal lagoons in Rio de Janeiro, Brazil. Hydrobiologia, 228, 65-70.

[35] LEIVUORI, M. (1998).- Heavy metal contamination in surface sediments in the Gulf of Finland and comparison with the Gulf of Bothnia. Chemosphere, 36, 43-59.