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Evaluation of the Water Quality of Dakhla Bay (South Morocco): Qualification and Classification According to the European Methodology

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Abstract: Dakhla bay has become a center of socio-economic interest in southern Morocco due to its geographical location and its biological richness. During the last decade, several projects have been installed and the exploitation of this ecological niche has increased. Faced with this situation, it was necessary to assess the quality of the waters of Dakhla bay and determine its current ecological status. To do this, the European method established by the Water Framework Directive (2000) was adopted and adapted to Dakhla bay. The results of the evaluation showed that this bay has areas sensitive to chemical contamination and others affected by eutrophication. These ecological disturbances are due to Human activities and/or natural phenomena. The objective of this study is to contribute to the development of a methodology to evaluate the ecological status of a marine ecosystem and apply it to Dakhla bay. The results are presented in the form of a matrix of areas at Risk of Non-Respect of Environmental Objectives (RNREO) and measures that could mitigate these risks.

Keywords: Environmental Objectives, Marine Water, Assessment, Quality, European Methodology, Ecological Indicators

Introduction

The methods of qualification of marine waters applied at the level of the various countries are developed thanks to several scientific studies allowing to specify the effective tools and the necessary conditions for their application. These methods are sometimes subject to modification either due to improved scientific knowledge or to changes in environmental conditions such as climate change and anthropogenic pressure.

In Morocco, there are two marine water-monitoring networks:

– Network of Monitoring of the beaches quality conducted jointly by the Ministry of Equipment and Transport (MET) and the Ministry of Land Management, Water and Environment (MATEE)
– Network of Marine Environment and Coastal Health of the National Fisheries Research Institute (RSSL/INRH) which monitors the shellfish- farming areas of the national coast

These two networks are only responsible for the classification of bathing waters and shellfish areas using national and international standards. The objective is to protect summer residents and consumers of shellfish. However, no evaluation of the ecological status of the marine ecosystems has been used.

In this respect and after a thorough analysis of the different methods currently existing, we have adopted the one of the European Union (the closest geographically) described by the Water Framework Directive (DCE, 2000). This method constitutes the framework for a community policy in the field of water and imposes the preservation of non-degraded aquatic environments (reference areas) and the attainment of "good ecological status".

The good ecological status of a marine environment is defined as: "The ecological status of marine waters that maintains the ecological diversity and vitality of clean, healthy and productive oceans and seas within their intrinsic conditions and that ensures that the use of the marine environment is sustainable to safeguard its potential for uses and activities by present and future generations" (DCE, 2000).

All the responses of the indicators/criteria (parameters), aggregated into an ecological status, provide an image of the ecological status of the

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environment, which is established according to a five-class scale, from very good to poor status. If it is useful in a diagnostic approach, this image must be integrated into a dynamic perspective to constitute an effective tool.

This study presents the first and only exercise aimed at setting up a global assessment methodology, which did not previously exist in Morocco, for a marine ecosystem. Dakhla bay was chosen as an ecosystem considered less exploited and has a very socioeconomic interest. The study of the water quality of this ecosystem is conducted to highlight its current ecological status by applying the adopted and feasible methodology. The work was based on the data of the different compartments of the marine environment (physicochemical, biological, and chemical) of the study conducted (between 2011 and 2012) by Saad *et al*. (2015). It's to notice that there are no available data time series for this area. This last was virgin and it's partially exploitation started, almost, in 2003.

The objectives of this study are as follows:

- To carry out a detailed evaluation of the physicochemical, biological, and chemical aspects of each water mass (body)
- To define the potential sources that may have altered the quality of the water masses
- To identify the water masses at risk of not achieving the objectives set by the Framework Directive

The study was conducted in 3 phases:

- ⇨ Phase 1: Organization of data: It consisted in collecting and organizing the data of the different ecological parameters/criteria (physicochemical, biological, and chemical) of Dakhla bay to constitute the database necessary for the realization of the following phases of the study
- ⇨ Phase 2: Qualification of the water masses, conducted in three stages:
    - Definition of assessment tools by parameter
    - Adaptation of the assessment tools to the studied water masses
    - Evaluation by parameter and, then, global evaluation of the quality of the water masses
- ⇨ Phase 3: Exploitation of the qualification results

The qualification of the water masses allowed the final objectives assigned to this study to be met:

- Identification of water masses at Risk of Non-Respect of the Environmental Objectives (RNREO)
- Proposal for the evolution of the local monitoring network

Study Site

Geographic Location

The site chosen is Dakhla bay located in southern Morocco (Fig. 1). The choice of stations is made by referring to the sampling networks of previous studies initiated by INRH (Orbi *et al*., 1995; 1996; Dafir, 1997; Orbi and Berraho, 1999; INRH, 2002; Zidane *et al*., 2008; 2013; Zidane, 2009; Saad *et al*., 2013; 2015) and taking into consideration the exploited and non-exploited areas of the bay (Table 1).

Climate

The climate of Dakhla bay is determined by the desert character of the region (Orbi *et al*., 1995). This region is located in an area where the annual average solar radiation is very high (6090 $Wh/m^2/day$) (Ouammi *et al*., 2012). Rainfall data recorded between 1998 and 2005 show that rainfall is rare and the average value was around 30 mm (SRAT, 2011).

Wind

The main wind direction is NNE-SSW, with secondary directions of N-S and NE-SW. The average annual maximum wind speed is about 19.2 m/s (69 km/h) in Dakhla. These intense winds are the main vector creating the Upwelling phenomenon, which is at the origin of the biological richness of the Atlantic zone located in the south of Morocco.

Geomorphology, Bathymetry and Hydrodynamics

According to Karim *et al*. (2017), the marine circulation of Dakhla bay simulated by 2D hydrodynamic modeling over the period from 28 January to 09 February 2010 is governed by wind and tide (Fig. 2). The results of this study showed that during spring tides, the currents are very intense (between 1 and 2 $m.s^{-1}$) at the entrance of the bay and in its vicinity, less than 1 $m.s^{-1}$ in the central part of the bay and less than 0.5 $m.s^{-1}$ moving upstream in the bay. During neap tides, tidal current intensities are generally lower and less than 0.5 $m.s^{-1}$ in the bay.

The morphological evolution of the bay differs from one area to another. Indeed, the region of the "mouth (SW)" is mainly characterized by the transit of sedimentary material and thus shows a certain morphological constancy. The internal domains would be characterized mainly by a depositional phase. According to the work of Sogreah (1984), the bay is undergoing a fattening. This phenomenon is organized from north to south. The strong depths are located in the western part of the bay in the Lassarga zone, south of the main channel and south of the Boutalha channel, and lesser intensity in the northern zone of the bay. These areas correspond to strong water hydrodynamics related mainly to the effect of tidal currents and winds (Karim *et al*., 2017; Lakhdar *et al*., 2010).

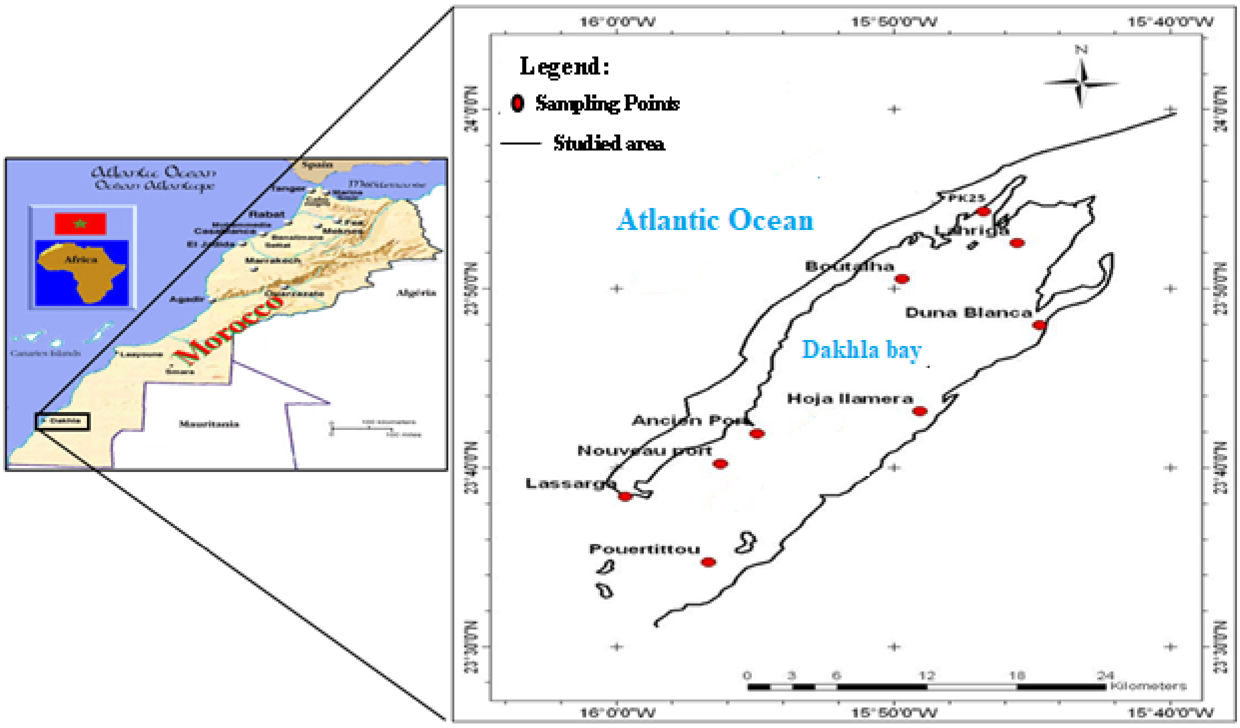

Fig. 1: Geographical location of the stations evaluated in Dakhla bay

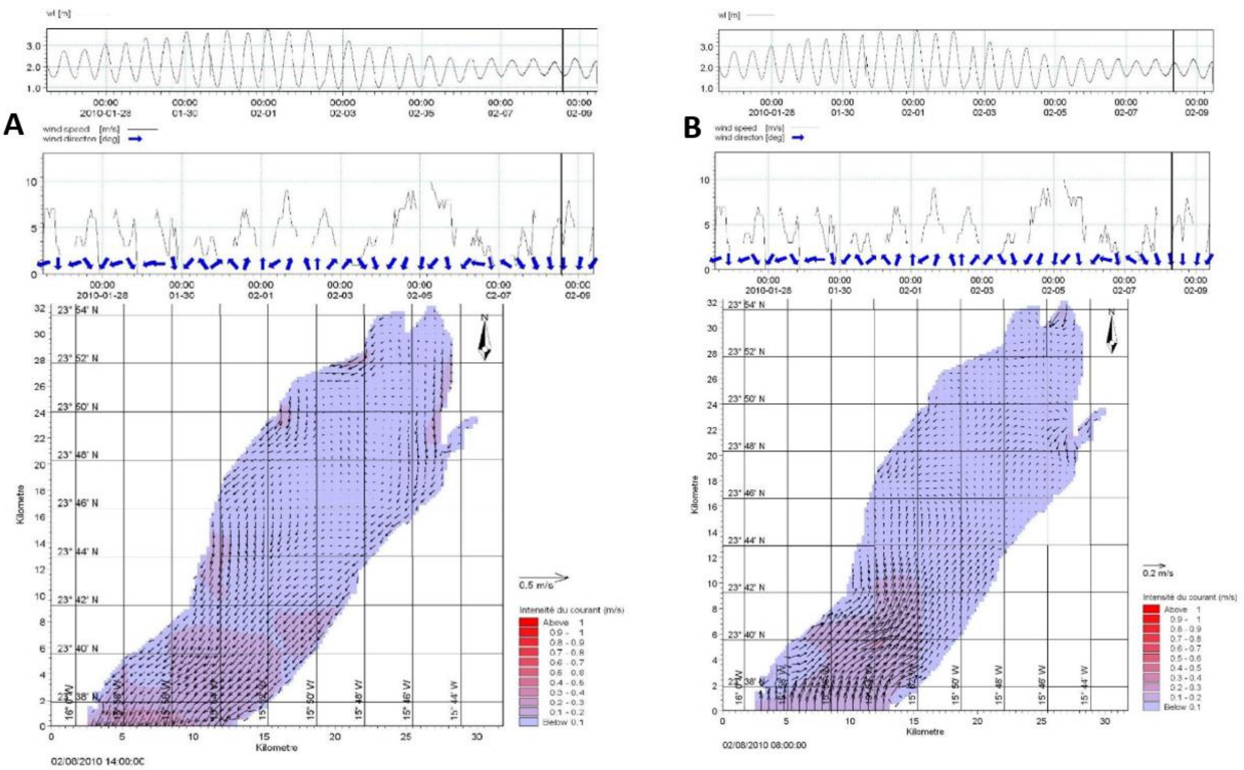

Fig. 2: Dakhla bay water circulation: (A) in neap period (coefficient 23) with the outgoing tide, (B) in neap period (coefficient 20) with the incoming tide (Karim *et al*., 2017)

Table 1: Geographical coordinates of the evaluated stations and type of activities carried out

	Geographical coordinates			
Site	N	W	Depth	Activity
PK25	23 52 929	015°46978	2 m	- Tourism (campsites, resorts, water sports...) - Collect of shellfish (*Solen marginatus* and *Cerastoderma edule*)
Lahrigua	23 52 828	015°46098	8-10 m	Collect of shellfish (*Solen marginatus* and *Cerastoderma edule*)
Boutalha	23 50 799	015°51458	1-2 m	Oyster-farming (hollow oyster)
Duna Blanca	23 47 795	015°44635	1-3 m	Oyster-farming (hollow oyster)
Hoja ILamera	23 41 639	015°49055	3-5 m	Collect of shellfish (mussel)
Old Port	23 41 993	015°55350	4-5 m	Reserved for the military (coasters, Royal Navy and coastal fishing)
New Port	23 39 854	015°56922	6-10 m	- Landings of fishery products - Traffic of hydrocarbons - Industrial activity (related to fishing)
Puertittou	23 34 717	015°54133	3-5 m	Collect of shellfish (mussel)
Lassarga	23 36 584	016°00217	15-20 m	Traditional Fishing village

Materials and Methods

The data used in this article are taken from the results of the study conducted between May 2011 and May 2012 by Saad (2015) in Dakhla bay. This study concerned the annual monitoring of parameters related to the biological and physicochemical compartments of the bay. The sampling frequency was monthly. The assessment of the chemical status of water was possible through the determination of chemical pollutants in bivalves. The collect of these bivalves was conducted in two periods: Summer and winter. These two periods are characterized by significant biological changes in bivalves (gonadal development, maturation period, etc.) and ecological fluctuations in the studied area (periods of upwelling, wind, temperature, etc.).

The data, used in the present paper, are in the form of an annual average for each parameter. Unfortunately, there are no time series data (for previous years) to include, because few studies (generally three) have been carried out in Dakhla bay and have not covered all chemical and biological indicators (DO, TTC, MO, pH, etc.) of the environment. Moreover, these studies were not regular and were sometimes carried out, only, in one or two seasons depending on the objective of the study.

The means and methods used, in the study conducted by Saad (2015), for sampling, measuring, and assaying the various physicochemical and biological parameters are those described by Aminot and Chaussepied (1983).

The determination of chemical pollutants in bivalves was carried out according to the method described by Essedaoui and Sif (2001).

The qualification of water masses, the objective of this article, is conducted according to the method required by the DCE (2000). The principle and detailed steps of this method are given in the following part. To notice, the major limitations of the European methodology are: The previous ecological parameters data and the grids of national standards specific to marine areas.

Qualification of Water Masses

The method consists in qualifying the water mass with respect to physicochemical and biological parameters and the chemical status of the studied area. To do that, we need to choose the parameters indicated as elements recommended by the DCE, collect available data, search the grid standards, and adapt them to our area conditions. The qualification/classification of the water mass, then, is possible by retaining the value of the most downgrading element among the different biological and physicochemical quality elements for the ecological status or among the priority substances for the chemical status.

Choice of Parameters

The choice of the parameters (criteria) analyzed was made with respect to the quality elements mentioned in Annex V of the DCE (2000) and synthesized in Table 2.

Synthesis of Available Data

The parameters measured for each of the studied stations in Dakhla bay (Fig. 1) are: Dissolved Oxygen (DO), nutrients (NO_3^-, NO_2^-, NH_4^+ and PO_4^{3-}), Total Suspended Solids (TSS), Organic Matter (OM), Temperature (T), Salinity (S), pH, phytoplankton, pheopigment, Chlorophyll a (Chl a.) and trace elements. These biological and physico-chemical parameters recommended by the DCE were monitored for an annual cycle. However, the monitoring of the ichthyofauna (composition, abundance and age structure), as well as the benthic fauna and flora, was not possible with the available human and logistical means. Moreover, these biological parameters are not tracked by any other network, which means that there are no data series available. For these reasons, they will therefore not be included in this assessment.

The evaluation, then, will only cover a part of the criteria retained by the DCE. The evaluation was based exclusively on the following parameters:

- Biological parameters: Chlorophyll a
- General parameters: Dissolved oxygen, Dissolved Inorganic Nitrogen (NID = NO_3^- + NO_2^- + NH_4^+), PO_4^{3-}, TSS, temperature and pH
- Contaminants: Metallic trace elements

The quality element "Salinity" was excluded following its declaration as not relevant for the assessment of coastal and transitional water masses (Daniel and Soudant, 2011).

It should be noted that the choice of all the parameters retained in this present work was based essentially on the relevance of these parameters and their interest for aquatic life as well as on the availability of the tools necessary for their evaluation.

Evaluation Tools

Inventory of Evaluation Grids

To evaluate the quality of the water masses in Dakhla bay, a search was made for existing evaluation systems and guide values that could serve as a reference for the parameters selected in the previous phase.

General Parameters

The grids used for the evaluation were developed from:

- The grid proposed by the Réseau Hydrologique du Littoral Normand (Daniel, 2004) for coastal waters
- The SEQ-Littoral grid (IFREMER, 2003) "biological potential component"
- The thresholds taken from the publications of the International Council for Exploration of the Sea (ICES, 2004)
- The SEQ-Eau grid (ADLAP, 2009)
- The thresholds grid proposed by Taverny *et al*. (2009) "fish compartment"

Contaminants

For chemical contaminants, 33 hazardous chemical substances among pesticides, volatile substances, aromatic hydrocarbons, chlorobenzenes, biocides, and metals have been determined as "priority substances" by the DCE (2000). However, the studied area is belonging to an arid zone that is not subject to rainfall, which means no impact of pesticides (in general there is almost no agricultural activity) and no other land inputs carried by rain. Moreover, the Dakhla region is not a mining industry zone and doesn't know any other hard industrial activities such as plastic, cement, foundries, chemical products, etc. In general, the major socio-economic activities practiced around the bay are those mentioned in Table 1, plus the daily activities such as the incineration of garbage in the open air, car traffic (fuel combustion), vehicle corrosion, brake, and tire abrasion, etc. Also, it's to be signaled that the observed risk, generated by the industry related to fishing and the discharge coming from some points of districts not controlled, is the wastewater (Saad *et al*., 2015). The synthesis of the type of activities around the bay allowed us to choose just the trace elements that can be produced by this type of activities (Chiffoleau *et al*., 2001; Sarkar, 2002; Rodier, 1996; Pichard *et al*., 2005; INERIS, 2000). As a result, the main elements to be studied, at that time, are Cadmium, Lead, Zinc, and Copper. They have, also, been a priority in assessments of chemical contamination in foodstuffs.

In the application of the DCE (2000), the Normes de Qualité Environnementale (NQE-Ifremer, 2004c) and reference levels have been established for these priority substances.

The proposals for environmental quality standards concern only the "water" compartment. However, the evaluation of the status of chemical contamination of Dakhla bay was only possible through the "shellfish" compartment.

Thus, we referred to the only evaluation grid taken from the water quality evaluation study carried out by the Biological Integrators Network (RINBIO) in 2009 (Andral and Tomasino, 2010) using the "mussels" as bioindicator. Furthermore, this shellfish species populates only five of the nine studied sites. Therefore, the water masses of these sites will be evaluated using the assay results obtained for mussels.

The other sites are populated by oyster and razor clam. However, there are no available grids to evaluate the chemical contaminants in these two types of bivalves. Therefore, the evaluation of their waters will be done, only for cadmium and lead who's the maximum levels of these contaminants in foodstuffs are fixed by the European regulations n°466/2001 and n°221/2002.

Adaptation of the Evaluation Grids

Dakhla bay is considered a part of the coastal area, given the very important exchanges with the Atlantic Ocean and the almost total absence of continental inputs. Therefore, the qualification of the bay waters will be carried out by adopting the evaluation grids, described previously, for coastal areas. These grids contain specific standards for the evaluation of each parameter and, thus make it possible to evaluate the water masse with respect to this parameter and then assign it an ecological status.

Summary: Parameters and Grids used for the Assessment

The global evaluation of each water masse will be based on the parameters/indicators/criteria that have been monitored and have an evaluation grid, i.e.:

- Dissolved oxygen
- Chlorophyll a
- Nutrients (NO^-_3, NO^-_2, NH_4^+, PO_4^{3-})
- Temperature
- TSS
- pH
- Contaminants: Metallic trace elements (cadmium, lead, zinc, and copper)

The grids selected and used for the evaluation are described for each parameter as follows:

⇨ For the biological criteria "biomass":

The chlorophyll "a" is an indicator of the enrichment of the area: Grid 1 proposed by Ifremer (RHLN, Ifremer, 2004) for coastal waters

⇨ For the physicochemical criteria:

Dissolved oxygen being a parameter in its own right and unique, the calculated metric alone constitutes a quality indicator: Grid 2 SEQ-Littoral (IFREMER, 2003).

Nutrients (NO_3^-, NO_2^-, NH_4^+ and PO_4^{3-}): Being considered as a pressure on the ecosystem and not as having a direct effect on the environment, their normalized concentrations were relativized with respect to the proper functioning of each system via chlorophyll a, an indicator of eutrophication (Foussard and Etcheber, 2011). However, there is currently no grid for coastal waters defining thresholds for nutrient criteria. On the other hand, thresholds for DIN (dissolved inorganic nitrogen including NO_3^-, NO_2^-, NH_4^+) specific to coastal and transitional marine waters have been derived from the ICES results (ADLLB, 2005). For phosphate ions, the grid described by the SEQ-Eau relating solely to the evaluation of water quality according to its aptitude for the natural functions of aquatic environments will be used (ADLAP, 2009):

– Grid 3: ICES thresholds (2004)
– Grid 4: SEQ-Eau, Class of aptitude for biology (ADLAP, 2009)

TSS (turbidity): This criteria conditions the presence of certain species (e.g., for the benthos with suspension feeders) and can be harmful to organisms at a certain concentration level (e.g., fish, phytoplankton, and other aquatic plant species due to lack of light penetration). However, since this metric does not have a specific evaluation grid for coastal waters, we referred to the thresholds between 0.5 and 5 mg/L, already set by Aminot and Chaussepied (1983) for normal coastal water. The data selected for this parameter are those obtained outside the period of the dredging conducted at the bay during the Saad (2015) study whose normal concentrations did not exceed 12 mg/L. These thresholds and data were used to establish the following grid that should normally satisfy the conditions for good water quality: Grid 5 established based on thresholds set by Aminot and Chaussepied (1983) for normal coastal water and values measured in the waters of Dakhla bay during 2011-2012 (Saad, 2015).

pH (acidification): Is recognized for its indirect impact on aquatic life due to its ability to control the proportions of ammonia NH_3 and ammonium NH_4^+ in the marine environment (DIREN, 2002-2004). When the pH is between 6.5 and 8.5, most of the ammonia nitrogen is in its ionized form. This form is the least toxic. However, the same amount of ammonia nitrogen at high pH levels can be dangerous to aquatic animal life, and un-ionized ammonia is highly toxic (DIREN, 2002-2004). The data on the average pH values in Dakhla bay is compared to the thresholds specified by the SEQ-Eau grid related to the evaluation of the aquatic life suitability in water in general:

- Grid 6: SEQ-Eau, Class of aptitude for biology (ADLAP, 2009)

Temperature: Is considered to influence the movement of fish species (e.g., the barrier to migration) or more permanent impacts by disrupting the physiological developments of organisms (e.g., problems with growth, reproduction, etc.) (Foussard and Etcheber, 2011). Thresholds are defined according to the fish compartment and an assessment grid for waters concerning this compartment has been proposed by Taverny *et al*. (2009):

- Grid 7 Threshold grid proposed by Taverny *et al*. (2009) to qualify the physicochemical status of transitional water masses with respect to the fish compartment

⇨ For contaminants:

These substances are dangerous for marine organisms when they exceed certain thresholds and, therefore, represent a risk for human health. To assess the quality of the waters of Dakhla bay with respect to these contaminants, a grid proposed by the Réseau Intégrateurs Biologiques (RINBIO) (Andral and Tomasino, 2010) was adopted:

– Grid 8: proposed by RINBIO (campaign 2009) for contaminants in mussels from marine waters (Upper limits of quality classes)

As defined by Andral and Tomasino (2010) ‘’for each contaminant, class 0 includes all data below the background noise represented by the mean of the distribution. It corresponds to the reference range of data for each xenobiotic indicating at the network scale in the absence of significant area contamination":

Class 1: Corresponds to a safe range to avoid concluding that the environment is contaminated
Class 2: Corresponds to subnormal values compared to the background noise of the contamination. It thus testifies to certain but moderate pollution of the environment
Class 3: Corresponds to abnormal values of contamination compared to the background noise. It allows class 4 to characterize the degree of intensity of the contamination of the environment
Class 4: Corresponds to very high values of contamination. It includes the results higher than the upper limit of class 3

Other standards are also required by European regulations, concerning the two metals Cadmium and Lead in foodstuffs, to protect the consumer from chemical poisoning (Bulletin de la Surveillance de la Qualité du Milieu Marin Littoral, 2011):

- Grid 9: Standards in the European regulations n°466/2001 and n°221/2002 fixing the maximum levels of cadmium and lead in foodstuffs

Results and Discussion

The annual assessment of the water quality masses in Dakhla bay is carried out according to the following procedure:

- Data processing and evaluation of water quality by parameter for each station
- Evaluation of the quality per water mass and per parameter by retaining the most "downgrading" station
- Evaluation of the global quality of the water masse by retaining the result of the most downgrading parameter

The principle of the method described by the DCE (2000) consists in retaining the value of the most downgrading element among the different biological and physicochemical quality elements for the ecological status or among the priority substances for the chemical status. The classification of the status is done for the ecological status in 5 classes and the chemical status in two classes (good, not reaching good status) (Fig. 3). In this assessment, the most downgraded element can be a value, a station, or a parameter depending on the steps of this assessment.

Evaluation by Parameter

The result of the data processing (values, concentrations and means of each parameter studied) and the evaluation of the water quality by parameter have made it possible to establish Table 3 illustrates the class of each treated water mass.

Chlorophyll a

The simulation in Table 4 (based on the results in Table 3) gives a very positive assessment of the quality of the water masses with respect to chlorophyll a as long as no water masses in the bay are downgraded. Therefore, the quality of the water masses in the bay is better during the study period (May 2011-May 2012), indicating the absence of eutrophic disturbance.

Nutrients

The application of the CIEM grid (ICES, 2004) to Dakhla bay classifies eight water masses as having good ecological status and only one water mass is downgraded to average status (Table 5).

Thus, simulation 1 in Table 5 indicates that the quality of the water bodies with respect to the total nitrogen parameter (NID) is globally "Good". On the other hand, simulation 2 (Table 5), by applying the SEQ-Eau grid (class of aptitude for biology), classifies seven water bodies in very good ecological status and two others in good status. This evaluation, generally, allows the quality of the waters of the bay to be classified as "Very Good" with the respect to the phosphate parameter (PO_4^{3-}).

The analysis of the stations that "Downgraded" water masses refereed to Simulation 1 and 2, is as follow:

The only water mass in the bay downgraded to "Average" status during the study period is "Lassarga" (Table 3). This area (entrance to the bay) is subject to inputs of nutrient salts from incoming water (resulting from the upwelling) and outgoing water that is loaded with nutrients throughout the bay via wastewater discharge points installed upstream of the two ports. In this regard, it is proposed to install measuring and monitoring stations near the wastewater discharge points (currently not monitored) to evaluate the waters of the bay with respect to the NID parameter in this urban area.

The two water masses classified by simulation 2 in "Good" status are those of Boutalha and Lahrigua (Table 3). The small change in the normal concentration of phosphate ions that caused this downgrading (from "Very Good" to "Good" status) may be due to the input of nutrients from human activities upstream (tourism) and in-situ (aquaculture in the Boutalha site). It should be noted that phosphate ions are more dominant in these sites because phytoplankton assimilates nitrates much more (Saad, 2015).

Dissolved Oxygen

The quality of the bay's water masses with the respect to dissolved oxygen was evaluated using the SEQ-Littoral grid. Thus, the simulation in Table 6 gave a very satisfactory result by classifying all the water masses studied as having a "Very Good" ecological status. The quality of the water masses in the bay is then very good with respect to the oxygen parameter, which is in agreement with the results reported by Saad (2015).

However, despite this excellent result, Saad (2015) showed that oxygen saturation in Dakhla bay has been decreasing over the last two decades at some upstream sites. She attributed this to the increase in organic matter, especially that related to livestock activities (in Duna Blanca) and tourism (in Lahrigua and PK25), or to the discharge of wastewater and seafood waste that flows downstream next to the Old Port.

TSS

The northern part of Dakhla bay has overall higher turbidities than the southern part of the bay. The simulation in Table 7 shows relatively non-turbid water masses. It, therefore, gives a more optimistic assessment of the quality of the water masses, with only one downgraded water mass: Boutalha.

According to Saad (2015), all measurements of suspended matter were within the standards of the "Good" class except for the period when the dredging works for the construction of a tourist complex in the Boutalha area started. During this period, the water masses of most sites have known an abnormal increase in TSS concentrations. Nevertheless, this disturbance was limited in time and as soon as the work stopped, the environment gradually returned to its equilibrium, so we cannot accept this anthropization as a potential and continuous source of the disturbance.

pH (Acidification)

According to the result of the simulation in Table 8, based on the evaluation of the water masses with respect to the pH criterion (Table 3), the waters of the bay can be considered to be in "Very Good" condition overall, from the point of view of normal acidification for aquatic life.

Temperature

The thresholds proposed by Taverny *et al*. (2009) allowed the qualification of the physico-chemical status of the studied water masses with respect to the fish compartment, thus, the simulation showed good quality for the nine stations evaluated. This allows classifying the waters of the bay with respect to the temperature parameter in "Good" status (Table 9).

In conclusion, the water mass that may present worrying eutrophication shortly, if the sources of "pollution" are not controlled, is "Lassarga" (downgraded by simulation 1 (NID), Table 5).

The only water masses classified as "Good", among the nine studied water bodies (simulation 2 in Table 5 for PO_4^{3-} element), are "Boutalha" and "Lahrigua".

These two water masses, whose quality has gone from "Very Good" to "Good" status for the element PO_4^{3-}, should therefore be monitored as part of the operational surveillance, since this classification qualifies them as areas sensitive to eutrophication.

Contaminants

The comparison of the levels (shown in Table 10) detected in the mussel's flesh with the thresholds of the RINBIO 2009 (Andral and Tomasino, 2010) quality grid made it possible to synthesize the results of the assessment with a good vision of all the areas with the highest levels of chemical pollution (Table 10).

The classification synthesis result of the areas hosting a mussel deposit (Table 10) is as follow:

- ❖ Certain but moderate zinc pollution for the first three stations (class 2) and abnormal for the last two stations (by the order of Table 10)
- ❖ Certain but moderate cadmium pollution at only one station: Lassarga (the entrance to the bay)
- ❖ Certain but moderate pollution of the Hoja Ilamera and old port sites by copper
- ❖ Abnormal contamination by copper in the site new port and another very high at the sites of the entrance Lassarga and Puertittou

So, we can conclude that for the stations with a mussel deposit:

- ❖ Lassarga is downgraded by the most downgrading parameter which is copper, then zinc, and finally cadmium
- ❖ Puertittou is downgraded first by the parameter copper, then by zinc
- ❖ New Port is downgraded first by copper and then by zinc
- ❖ Hoja Ilamera and Old Port are downgraded by copper and zinc with the same degree

As for the sites hosting a deposit other than mussels, the result of the comparison between the thresholds, set by the European regulations for cadmium and lead, and the average levels calculated in the flesh of oysters and razor clams of Dakhla bay is presented in Table 11.

The comparison in Table 11 shows that the four stations do not show any risk related to the two metallic pollutants: Cadmium and Lead. Therefore, this result can be synthesized using the same colors of the RINBIO (2009) grid, indicating the different levels of contamination and considering that the water masses of the four stations (mentioned in Table 11) are classified at the "basic level" (reference class 0, whose blue color indicates the absence of contamination). The cases where the analysis could not be done due to lack of data are indicated in white, with the mention NDvs (no threshold value). Therefore, the synthesis of the results in Table 11 will be presented as shown in Table 12.

In conclusion, the assessment of the nine water masses (stations) studied in the bay of Dakhla with respect to the four contaminants showed a downgrading of five water masses (stations housing mussels) by zinc and/or by copper and cadmium. However, the classification of the four other stations (housing oysters and razor clams) is, actually, not possible because these stations are not evaluated in relation to zinc and copper (absence of thresholds specific to razor clams and oysters).

Global Evaluation

The global evaluation was carried out by integrating the evaluation results of all the parameters and by combining the different simulations. The only combination, of reference, obtained within the framework of the present study (the only evaluation study carried out for Dakhla bay) is the following:

Combination R: Nutrients/Chlorophyll a/Contaminants/Oxygen/TSS/pH/Temperature.

The result obtained for this combination is presented in the Table 13.

The analysis of the results of the global assessment, for the R combination, covered the nine water bodies studied. Of the nine water bodies evaluated, six were downgraded by the R-combination (Table 14).

A search for downgrading factors as a proportion of the water bodies assessed was conducted. The results are shown in Table 15. The "downgrading" factors are, in order of importance: Contaminants and Suspended matter.

The Exploitation of the Results of the Qualification of Water Masses

❖ Stages of qualification and identification of water masses at Risk of Non-Respect of the Environmental Objectives (RNREO)

According to the method adopted for the qualification of the waters of Dakhla bay, the identification of water masses at Risk of Non-Respect of Environmental Objectives must follow the following steps:

Step 1: In the case of several combinations, the two extremes should be retained: The most penalizing and the least downgrading. Thus, the raw results of the assessment allow the water masses to be classified into three categories: RISK, DOUBT, and RESPECT, according to the following principle:

- Water masses in Respect: Those classified as "very good" and "good" according to the two combinations
- Water masses at Risk: Those classified as "average", "poor" and "bad" according to the two combinations
- Water masses in Doubt: Those that are downgraded only by the combination relating to the most penalizing evaluation

For the case of Dakhla bay, however, only one combination is available, which is the one of the present studies (Combination R). In this respect, the following classification is proposed:

- Water masses in Respect: Those classified as "very good" and "good" according to the R combination
- Water masses at Risk: Those classified as "average", "poor" and "bad" according to the combination of R
- Water masses in Doubt: Those which are not assessed in relation to zinc and copper due to the lack of specific thresholds for these two chemical substances declared by the Directive Cadre sur l'Eau (2000) as "priority substances"

Thus, the results of step 1 will be as presented in column 4 "evaluation result" of Table 16:

Step 2: Based on the analysis of the downgrading parameters, the identification of the water masses at Risk of Non-Respect of the Environmental Objectives is reviewed and it is proposed:

=> to change from “Respect” to “Doubt” the water masses whose classification with respect to zinc and copper has not been carried out, except in the case where the water mass is already downgraded to Risk status by another parameter (as in the case of Boutalha).

❖ Final Classification

The final classification is presented in the last column of Table 16. The final assessment leads to the classification of:

- Six water masses in Dakhla bay in Risk: "Boutalha", "Hoja Ilamera.", "Old Port", "New Port", "Puertittou." and "Lassarga"
- Three water masses in doubt: "PK25", "Lahrigua" and "Duna Blanca"

Table 16 shows that Dakhla bay contains two types of areas at Risk. The first type is located near wastewater outfalls. The second type corresponds more to a very sensitive area, located mainly on the eastern shore of Dakhla bay, subject to the accumulation of metallic trace elements.

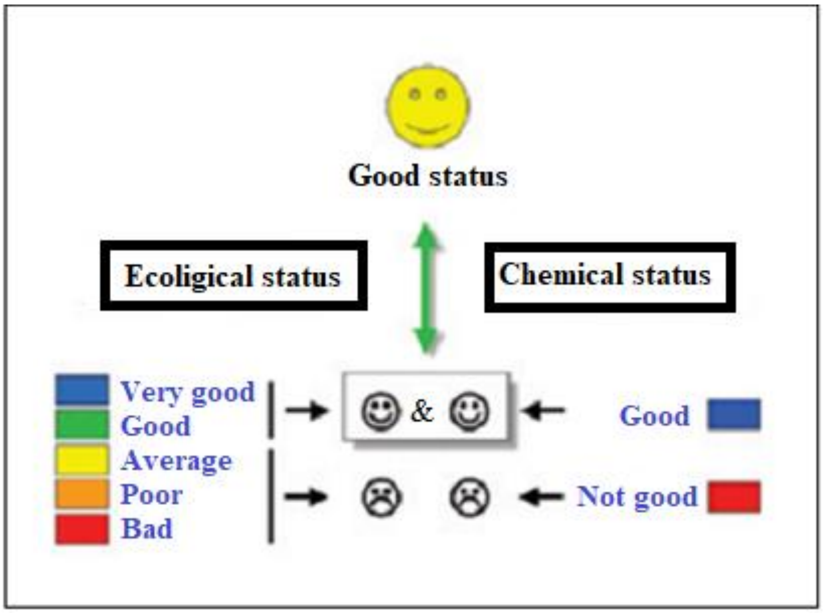

Fig. 3: Principle of the assessment of the good status of a surface water masse*.
*The different categories of surface water masses are rivers, water bodies, transitional waters (estuaries and lagoons), and coastal waters

Table 2: Quality elements recommended by the DCE (2000)

Biological parameters	Composition, abundance, and biomass of phytoplankton Composition and abundance of aquatic flora Composition and abundance of the benthic invertebrate fauna Composition, abundance, and the age structure of ichthyofauna
Physico-chemical parameters	General parameters (transparency, temperature, oxygen balance, salinity, nutrient concentrations) Chemical contaminants

Table 3: Evaluation results by parameter

Water mass	Chl. a	NID	PO_4^{3-}	O_2	TSS	Temp.	pH	Cd and Pb In mussels, oysters, and razor clams	Contaminants in mussels only
PK25	Very good	Good	Very good	Very good	Good	Good	Very good	Very good	No mussel deposit
Lahrigua	Very good	Good	Good	Very good	Good	Good	Very good	Very good	No mussel deposit
Boutalha	Very good	Good	Good	Very good	Average	Good	Very good	Very good	No mussel deposit
Duna Blanca	Very good	Good	Very good	Very good	Good	Good	very good	Very good	No mussel deposit
Hoja Ilamera	Very good	Good	Very good	Very good	Good	Good	Very good	Very good	Average *
Old Port	Very good	Good	Very good	Very good	Good	Good	Very good	Very good	Average *
New Port	Very good	Good	Very good	Very good	Good	Good	Very good	Very good	Poor **
Puertittou	Very good	Good	Very good	Very good	Good	Good	Very good	Very good	Bad **
Lassarga	Very good	Average	Very good	Very good	Good	Good	Very good	Very good	Bad **

*downgraded by Zn and Cu
**downgraded by Cu
- The color corresponds to the ecological status mentioned inside the box (e.g.: The blue color corresponds to Very Good Status).
- NID: Dissolved Inorganic Nitrogen
- TSS: Total Suspended Solids
- Chl. a: Chlorophyll a

Table 4: Simulation for the nine water masses studied in Dakhla bay with respect to the biological criterion

Ecological status	Simulation (Chlorophyl a)
Very good	9
Good	0
Average	0
Poor	0
Bad	0
Total WM downgraded	0

- WM: Downgraded water masses classified as "average", "poor" and "bad"

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Table 5: Simulation for the nine water masses studied in Dakhla bay with respect to the nutrient criterion

Ecological status	Simulation 1 (NID)	Simulation 2 (PO_4^{3-})
Very good	0	7
Good	8	2
Average	1	0
Poor	0	0
Bad	0	0
Total WM downgraded	1	0

Table 6: Simulation for the nine water masses studied in Dakhla bay with respect to the oxygen criterion

Ecological status	Simulation (O2)
Very good	9
Good	0
Average	0
Poor	0
Bad	0
Total WM downgraded	0

Table 7: Simulation for the nine water masses studied in Dakhla bay with respect to the TSS criterion

Ecological status	Simulation (TSS)
Very good	0
Good	8
Average	1
Poor	0
Bad	0
Total WM downgraded	1

Table 8: Simulation for the nine water masses studied in Dakhla bay with respect to the pH criterion

Ecological status	Simulation (pH)
Very good	9
Good	0
Average	0
Poor	0
Bad	0
Total WM downgraded	0

Table 9: Simulation for the nine water masses studied in Dakhla bay with respect to the temperature criterion

Ecological status	Simulation (T)
Very good	0
Good	9
Average	0
Poor	0
Bad	0
Total WM downgraded	0

Table 10: Synthesis of quality assessment results for stations with mussel beds with respect to the four contaminants

Name of the sampling site	Pb	Zn	Cd	Cu
Hoja Ilamera	<LD	250,90	0,62	7,35
Old port	<LD	251,28	0,28	7,63
New port	<LD	315,82	0,27	10,08
Puertittou	<LD	319,55	0,59	20,67
Lassarga	<LD	319,51	1,36	17,05

LD: Limit of detection
NB: The color indicates the status of the water quality (see RINBIO grid 8)

Table 11: Comparison of the averages of Cd and Pb calculated in the oysters and razor clams flesh of Dakhla bay with the thresholds set by the European regulations

Site name	Threshold value (Pb)	Calculated average value (Pb)	Threshold value (Cd)	Calculated average value (Cd)
Lahrigua (razor clams)	7,5	<LD	5	0,16
PK25 (razor clams)		<LD		0,15
Duna Blanca (oyster)		<LD		1,23
Boutalha (oyster)		<LD		1,86

LD: Limit of detection
Unite: mg/kg of dry weight

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Table 12: Synthesis of the analysis of the results in Table 11

Site name	Pb	Zn	Cd	Cu
Lahrigua	<LD	NDvs	0,16	NDvs
PK25	<LD	NDvs	0,15	NDvs
Duna Blanca	<LD	NDvs	1,23	NDvs
Boutalha	<LD	NDvs	1,86	NDvs

LD: Limit of detection
NDvs: No threshold value
Unite: mg/kg of dry weight

Table 13: Global assessment result (result per water mass)

Name of water mass	Combination R	Downgrading factors
PK25	Good	
Lahrigua	Good	
Boutalha	Average	TSS
Duna blanca	Good	
Hoja Ilamera	Average	Zn+Cu
Old port	Average	Zn+Cu
New port	Poor	Cu
Puertittou	Bad	Cu
Lassarga	Bad	Cu

Table 14: Analysis of the global evaluation result for combination R

Name of water mass	Combination R
Very good	0
Good	3
Average	3
Poor	1
Bad	2
Total WM* downgraded	6

*WM: Water mass

Table 15: Number of downgraded water masses compared to the number of assessed water masses

Quality criterion	Number of downgraded WMs	Number of assessed WMs
Nutrients	0	9
Chlorophyll a	0	9
Oxygen	0	9
Contaminants	5	9
TSS	1	9
Temperature	0	9
pH	0	9

Table 16: Identification of water masses at Risk of Non-Respect of Environmental Objectives

Name water masse	Degrading Parameter	Combination R	Evaluation result	Position of downgrading stations	Final classification
K25		Good	RESPECT		DOUBT
Lahrigua		Good	RESPECT		DOUBT
Boutalha	TSS	Average	RISK		RISK
Duna Blanca		Good	RESPECT		DOUBT
Hoja Ilamera	Zn+Cu	Average	RISK		RISK
Old port	Zn+Cu	Average	RISK	Close to wastewater	RISK
New port	Cu	Poor	RISK	Close to wastewater	RISK
Puertittou	Cu	Bad	RISK		RISK
Lassarga	Nutrients, Cu	Bad	RISK	In the south of wastewater	RISK

Grid 1: Proposed by Ifremer (RHLN, Ifremer, 2004) for coastal waters

	Quality				
Parameter	Very Good	Good	Average	Poor	Bad
Chlorophyll a (µg/l)	<5	5-10	10-20	20-40	>40

Grid 2: SEQ-Littoral (IFREMER, 2003)

	Quality				
Parameter	Very good	Good	Average	Poor	Bad
Dissolved oxygen (mg/l)	>6	5-6	2-5	1-2	<1

Grid 3: ICES thresholds (2004)

	Quality				
Parameter	Very good	Good	Average	Poor	Bad
NID (mg/l)		<0.15	>0.15		

Grid 4: SEQ-Eau, Class of aptitude for biology (Agence de l'eau Artois-Picardie, 2009)

	Quality				
Parameter	Very good	Good	Average	Poor	Bad
PO_4^{3-} (mg/l)	0.1	0.5	1	2	

Grid 5: Established on the basis of thresholds set by Aminot and Chaussepied (1983) for normal coastal water and values measured in the waters of Dakhla bay during 2011-2012

	Quality				
Parameter	Very good	Good	Average	Poor	Bad
TSS (mg/l)	0.5-5	5-12	>12		

Grid 6: SEQ-Eau, Class of aptitude for biology (Agence de l'eau Artois-Picardie, 2009)

	Quality				
Parameter	Very good	Good	Average	Poor	Bad
pH min	6.5	6	5.5	4.5	
max	8.2	9	9.5	10	

Grid 7: Threshold grid proposed by Taverny et al (2009) to qualify the physicochemical status of transitional water masses in relation to the fish compartment

	Quality				
Parameter	Very good	Good	Average	Poor	Bad
Temperature (°C)	<20	<23 et ≥20	<28 et ≥23	≥28	

Grid 8: Proposed by RINBIO (2009) for contaminants in mussels of marine waters (Upper limits of quality classes)

Class	Pb	Zn	Cd	Cu
Basic level	1.03	141.93	0.84	4.67
Low level	2.16	229.08	1.26	6.9
Moderate level	3.29	316.22	1.68	9.13
High level	4.42	403.37	2.09	11.36
Very high level	Upp	Upp	Upp	Upp

- Units: In mg/Kg of dry weight

Grid 9: Standards in the European regulations n°466/2001 and n°221/2002 fixing the maximum levels of cadmium and lead in foodstuffs

Heavy metals	Regulatory thresholds: mg/kg wet weight (w.w.)	Equivalent in mg/kg dry weight (d.w.)
Cadmium	1.0	5.0
Lead	1.5	7.5

The Boutalha area does not present any permanent risk. However, the qualification of its waters in a status of risk is due to the development of land in this area for tourist complex and to the discharge of sediments into the water. This one-time event was identified by this classification method. This shows its relevance and robustness.

In general, to assign an ecological status to Dakhla bay, it is essential to rely on all the results obtained for the nine studied water masses.

Thus, concerning the physicochemical status, 77.8% of the water bodies are in "Good" ecological status and the rest are in average status. As for the biological status, 100% of the water bodies are in "Very Good" status. However, for the chemical status (contaminants) 22.2% (2 stations out of 9) of the water masses are in "Bad" status, 11.1% (1 station out of 9) in "Poor" status, 22.2 in "Average" status (2 stations out of 9) and the rest of the water masses indicated no risk to chemical pollution. This classification shows that Dakhla bay is a very sensitive area at risk of anthropogenic and/or natural chemical contamination (due to wastewater and marine sediment transport). In order not to accentuate anthropogenic contamination and its impact on this marine ecosystem, a great effort should be made to eradicate the sources of wastewater in the bay.

Conclusion

This study is the first attempt at the establishment of procedures for assessing the quality of water in Dakhla bay. It allows in particular:

- To illustrate the approach to assessing the quality of water masses
- To develop tools and methods
- To give a final classification of the studied water masses

To evaluate the ecological status of an ecosystem, at least two successive years of data covering a large number of stations are required. In the present case, only one year's results were used in addition to the available older data.

National standards for ecological parameters are also of great importance for the evaluation and qualification of the waters of a marine ecosystem. In the case of Dakhla bay, we referred to European standards since Morocco does not have any.

The study showed that to ensure full monitoring of all sensitive areas in the bay, areas at risk of contamination by chemical pollutants (such as ports and areas hosting outfalls inventoried in the study conducted by Saad, 2015) must be added to those already included in the regular monitoring program. The latter is maintained by the Laboratoire de la Surveillance et de la Salubrité du Littoral (LSSL) of the Institut National de Recherche Halieutique de Dakhla (INRH-Dakhla).

Once the network of water masses to be evaluated has been determined, the approach to evaluate the entire bay should be as follows:

- Choice of the parameters to be analyzed: Generally, this is done with respect to the quality elements mentioned in most of the international directives, such as that of the European Union. Three types of parameters are distinguished here:
  - Biological parameters: Chlorophyll a (other biological parameters are also recommended and are indicated in the DCE, 2000)
  - General parameters: Dissolved oxygen, dissolved inorganic nitrogen (DIN = NO_3^- +NO_2^-+NH_4^+), PO_4^{3-}, TSS (or preferably turbidity), temperature, and pH
  - Contaminants: Chemical pollutants are determined as "priority substances" by the Directive Cadre sur l'Eau (2000). Preferably in the water compartment for which the evaluation grid is already established.
- Search for existing evaluation systems and guide values that can serve as a reference in Morocco, or else those used by international directives
- Adaptation of the used grids to existing data
- Evaluation by parameter and global evaluation of the quality of the water masses
- Identification of water masses at Risk of Non-Respect of Environmental Objectives (RNREO)

The major limitations of applying the European methodology are the data time series of ecological parameters and the grids of standards specific to the studied area. Also, as the seasonality and the morphology (depth, structure, etc.) of the sites play a very important role in the fluctuations of concentrations (ecological parameters) and biological transformations (biological cycles, bioaccumulation, etc.), it's necessary to consider these two factors in such studies.

The objective of this study is to present to the public authorities a matrix of areas at Risk of Non-Respect of Environmental Objectives and measures that could mitigate these risks.

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Author's Contributions

Zohra Saad: Writing, production of graphs, interpretation of result.

Orbi Abdellatif: Production of the water circulation graph of Dakhla bay, correction of the totality of paper, assistance in the methodology choice, assistance in the adaptation of the methodology.

El Khattat Mahmoud: Responsible of sampling work, assistance in carrying out analyzes in the laboratory.

Oudra Brahim: Academic corrections, critic of the methodology, discussion of results, correction of the paragraphs succession and conclusion.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues are involved.

References

ADLAP. (2009). Annuaire de la qualité des eaux superficielles du bassin Artois-Picardie. Évaluation de l'état écologique des eaux de surface continentales sur la base des données 2007. 2ème Partie: Les différents systèmes d'évaluation de l'état des eaux, 41-60pp.

ADLLB. (2005). Qualification des masses d'eau du littoral Loire Bretagne sur la base de données de qualité du milieu (2005). Rapport d'étape 4, 159p.

Aminot, A., & Chaussepied, M. (1983). Manuel des analyses chimiques en milieu marin. https://agris.fao.org/agris-search/search.do?recordID=XF2015043640

Andral, B., & Tomasino, C. (2010). RINBIO 2009-Evaluation de la qualité des eaux basée sur l'utilisation de stations artificielles de moules en Méditerranée: Résultats de la campagne 2009. https://archimer.ifremer.fr/doc/00028/13913/

Chiffoleau, J.F., Claisse, D., Cossa, D., Ficht, A., Gonzalez. JL., Guyot, T., Michel, P., Miramand, P., Oger, C., & Petit, F. (2001). La contamination métallique. Programme scientifique « Seine Aval ». Fascicule n°8. Editions IFREMER.

Dafir, J. M. (1997). Application de la dynamique du phosphore à l'étude de l'organisation et du fonctionnement des écosystèmes aquatiques (gestion et préservation). Thèse de Doctorat, Université Hassane II, Faculté des sciences Ain Chok, Casablanca, 634p.

Daniel, A. (2004). Réseau Hydrologique Littoral Normand (RHLN): Cycles annuels 2001-2003 et proposition d'indicateurs d'eutrophisation. https://archimer.ifremer.fr/doc/00020/13148/

Daniel, A. & Soudant, D. (2011). Evaluation DCE février 2011 – Elément de qualité: Salinité. Rapport Ifremer DYNECO/PELAGOS/11-02, 12 p. https://archimer.ifremer.fr/doc/00037/14779/

DCE. (2000). Directive n° 2000/60/CE du 23 octobre 2000 du Parlement européen et du Conseil, établissant un cadre pour une politique communautaire dans le domaine de l'eau. Directive Cadre pour l'Eau.

DIREN. (2002-2004). Réseau des estuaires bretons, Qualité des eaux: Présentation et analyse des résultats campagne 2002-2004. Ministre de l'écologie et du développement durable. Rapport, 211 p.

Essedaoui, A., & Sif, J. (2001). Bio-accumulation des métaux lourds et induction des métallo-protéines au niveau de la glande digestive de Mytilus galloprovincialis. *Revue Marocaine des Sciences Agronomiques et Vétérinaires*, 21(1), 17-25. https://www.agromaroc.com/index.php/Actes_IAVH2/article/view/138

Foussard, V., & Etcheber, H. (2011). Proposition d'une stratégie de surveillance des paramètres physico-chimiques pour les estuaires de la Seine, de la Loire et de la Gironde. Projet LITEAU-BEEST, 75.

ICES. (2004). In: Agence de l'Eau Loire Bretagne-Qualification des masses d'eau du littoral Loire Bretagne sur la base de données de qualité du milieu (2005). Rapport d'étape 4, 159 p.

IFREMER. (2003). Système de classification pour l'évaluation de la qualité des eaux littorales: Grilles d'aptitude aux usages et à la biologie. Rapport d'étude, Agence de l'eau Loire Bretagne, 26 p.

INERIS. (2000). Fiche de données écotoxicologiques et environnementales des substances chimiques. Le ZINC. Version l, Institut National de l'Environnement Industriel et des Risques, pp. 58.

INRH. (2002). Ressources littorales: Etat de nos connaissances. Institut National de Recherche Halieutique, Document du Ministère des Pêches Maritimes, Royaume du Maroc, 110 p.

Karim, H., Abdellatif, O., Ahmed, M., Hassan, B., Mohammed, I., Omar, E., & Mustapha, A. C. (2017). Circulation marine de la baie de Dakhla (Sud du Maroc) par modèle hydrodynamique 2D. *European Scientific Journal*, 13(9).

Lakhdar, I. J., Orbi, A., & Hilmi, K. (2010). Rapport relatif à l'étude bathymétrique de la baie de Dakhla.

Orbi, A., & Berraho, A. (1999). Potentialités de l'aquaculture marocaine. *Cahiers Options Méditerranéennes*, 43, 77-81. https://om.ciheam.org/om/pdf/c43/99600260.pdf

Orbi, A., Dafir, J. M., Berraho, A., & Sarf, F. (1995). Étude pluridisciplinaire de la baie de Dakhla. Rapport interne, Institut Scientifique des Pêches Maritimes, Royaume du Maroc, 86, 26.

Orbi, A., Guelorget, O., & Lefebvre, A. (1996). La baie de Dakhla: Organisation biologique et fonctionnement.

Ouammi, A., Zejli, D., Dagdougui, H., & Benchrifa, R. (2012). Artificial neural network analysis of Moroccan solar potential. *Renewable and Sustainable Energy Reviews*, 16(7), 4876-4889. doi.org/10.1016/j.rser.2012.03.071

Pichard, A. (2005). Le Cuivre et ses dérivés. Edit. INERIS-DRC-02-25590-02 DF54 version N°1-5.66p.

Rodier, J. (1996). L'analyse de l'eau. Eaux naturelles, eaux résiduaires, eau de mer. 8ème édition. Paris, Dunod.

Saad, Z. (2015). Evaluation de la qualité des eaux marines côtières: Application d'une approche méthodologique européenne à la baie de Dakhla. Thèse de Doctorat, Université Cadi Ayyad, Faculté des sciences Semlalia, Marrakech, 334pages.

Saad, Z., El-Gharmali, A., El-Khalloufic, F., Saad, A., Orbi, A., & Oudra, B. (2015). Metal contamination of the macrobenthic fauna of the Dakhla Bay (South of Morocco): An ecotoxicological diagnostic and environmental perspective. *South Asian Journal of Experimental Biology*, 5(2), 55-69. https://www.cabdirect.org/cabdirect/abstract/20153445816

Saad, Z., Orbi, A., Abouabdellah, R., Saad, A., & Oudra, B. (2013). Impact of economic development on the dynamics of phytoplankton and physic-chemical quality of Dakhla Bay (South of Morocco). *South Asian Journal of Experimental Biology*, 3(5), 274-287. https://www.cabdirect.org/cabdirect/abstract/20143058912

Sarkar, B. (2002). Heavy metals in the environment. Editions Marcel Dekker.

Sogreah. (1984). Etude Sédimentologique de la baie d'Ad Dakhla Direction des ports secondaires, Rabat, 31p.

SRAT. (2011). Etude des schémas régionaux des provinces du sud, Schéma Régional d'Aménagement du Territoire d'Oued Ed Dahab-Lgouira. Schéma Régional d'Aménagement du Territoire. Version définitive mars 2011, 165 p.

Taverny, C., Elie, P., & Boët, P. (2009). La vie piscicole dans les masse d'eau de transition: Proposition d'une grille qualité pour la température, l'oxygène dissous, la salinité et la transparence (Doctoral dissertation, irstea). https://hal.inrae.fr/hal-02592725

Zidane, H. (2009). Biologie et potentialités aquacoles de l'huitre creuse Crassostrea gigas (Thunberg, 1793) en élevage dans la baie de DAKHLA (Maroc). Thèse de Doctorat, Université IBN TOFAIL, Faculté des sciences, Kenitra, Maroc. 154p.

Zidane, H., Menioui, M., Mouradi, A., Orbi, A., Zidane, F., & Blais, J. F. (2013). Les métaux lourds dans le sédiment et leur impact sur le développement de la conchyliculture (Baie de Dakhla, Maroc). Rapp. Comm. int. Mer Médit., CIESM, 40, 766. https://ciesm.org/online/archives/abstracts/pdf/40/PG_0766.pdf

Zidane, H., Orbi, A., Mouradi, A., Zidane, F., & Blais, J. F. (2008). Structure hydrologique et edaphique d'un site ostreicole: Duna blanca (la baie de dakhla sud du maroc) hydrological and edaphic structure of an oyster-farming site: Duna blanca (bay of dakhla, south morocco). *Environmental Technology*, 29(9), 1031-1042. doi.org/10.1080/09593330802180328