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Socio-ecological analysis of the Moulay Bousselham lagoon (Atlantic coast of Morocco): conditions, environmental impacts, and future management scenarios

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Abstract: Today, the Moulay Bousselham lagoon suffers from a growing containment problem due to the significant increase in the amount of sediment, especially in the inlet zone, which leads to the accumulation of sand and the creation of sandy areas called "sandpits." This situation presents a risk of the inlet's closure, leading to further environmental degradation and economic problems. Aware of the magnitude of this problem, the decision makers proposed a study to reduce sand deposits by suggesting the most practical options in terms of hydrodynamic improvements inside the lagoon. In this sense, this study focuses on the relationships between socio-economic factors and their impacts on the lagoon environment. To this end, a DPSIR approach is used, describing the causal links between "driving forces" (economic sectors, human activities), "pressures" (emissions, wastes), "states" (physical, chemical, and biological), and "impacts" on ecosystems, human health, and functions, ultimately leading to policy "responses" (prioritization, target setting, indicators). Likewise, some management proposals were discussed in this study, taking into account the current state of the lagoon as well as the ecological sustainability and well-being of the local population.

Keywords: DPSIR, Ecosystem Services, lagoon, Moulay Bousselham, Morocco.

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1. Introduction

Coastal lagoons are bodies of water, present on all continents, generally oriented parallel to the coast, isolated from the ocean by a barrier, and connected to the ocean by one or more restricted inlets that remain open at least intermittently and whose water depth rarely exceeds a few meters [1]. These environments are widely considered to be the most precious ecological environments worldwide [2, 3], sustaining significant environmental goods and services such as fisheries, aquaculture, and agriculture. Although of interest for sustainability, such environments still face many different types of challenges around the world owing to their socio-economic interests, which increase human pressure and, in turn, result in overutilization of natural resources and many forms of environmental degradation (eutrophication, pollution, urbanization, and various forms of change) [4–6].

This study focuses on the case of the Moualy Bousselham lagoon (Atlantic coast of Morocco). This lagoon is located in the northwest of the Kingdom of Morocco, on the Atlantic Ocean, and is the largest wetland in the country, serving as a stopover and wintering site for a large number of migratory birds. This Atlantic lagoon was designated as a "permanent biological reserve" by Ministerial Order No. 223-78 of 26 Rabia I 1398 (March 3, 1978) and listed among the sites of international biological and ecological interest to the biosphere when it joined the Ramsar Convention in 1980.

Depending on the ecological value of this lagoon, many studies have been carried out on it in order to contribute to the conservation of its resources [7–9]. Nevertheless, the

high influence of the local population on the natural resources of this site threatens the balance and long-term availability of these resources. Extensive growth of human activities (pollution, agricultural intensification, urban pressure, overgrazing, and overexploitation of water and plant resources) has reduced the area of natural habitats on the site and consequently its biological diversity [10] and impacted its ecological integrity. Furthermore, the overuse of fertilizers and phytosanitary products in adjacent agricultural areas and the discharge of wastewater from the highway into the lagoon contribute to eutrophication and contamination of the water and sediments (hydrocarbons, heavy metals) [11, 12].

Nowadays, this lagoon suffers from the problem of the sedimentation of large quantities of marine sediments, especially in the area of the lagoon's entrance (inlet), which causes the accumulation of sand. This poses the risk of closing the entrance inlet of the lagoon, which will lead to many other environmental problems and, consequently, the loss of the lagoon.

Taking into account all the pressures that impact the lagoon, this study focuses on the analysis of the causal chain between drivers, pressures, impacts, states, and responses based on the DPSIR framework in order to propose practical solutions and options that will contribute to decision-making for the sustainable management of this ecosystem to achieve blue growth.2. Methodological Approaches.

2. Materials and methods

2.1 Study procedures

We used the DPSIR model as an analytical framework to track the changes in different aspects of the Moulay Bousselham lagoon's structure and function over time, to look at the drivers of these changes, and to evaluate the impacts of these changes on the water quality and hydrodynamic balance in this ecosystem. Within this model, drivers are defined as the underlying factors causing or influencing a variety of pressures on the lagoon. The state is the measure of the physical, chemical, and biological conditions within the ecosystem. Impacts describe the effects of changes in the lagoon states on measures of ecosystem function. And finally, response is defined as the efforts of society (i.e., politicians, decision-makers) to solve the problems resulting from changes in hydrodynamics and water quality function. The DPSIR flow chart for the present study is shown in Figure 1 and has four major steps: (1) interpreting the drivers and the pressures; (2) describing the state changes; (3) describing the impacts; and (4) reviewing the human response [13, 14]. As one of the four Moroccan sites that were considered by the RAMSAR Convention for the conservation of wetlands of international interest, human population growth (tourism and urban development) and economic development (fisheries production and agriculture development) are undoubtedly the major drivers in the Moulay Bousselham lagoon.

This study focuses on two main drivers on the Moulay Bousselham Lagoon, which are urbanization growth and economic activities. These drivers lead to numerous pressures, including overexploitation of natural resources and heavy metal pollution. A number of changes in the physical, chemical, and biological conditions of the lagoon are being assessed, and these, in turn, are generating negative ecological and socio-economic impacts. The human response to these changes involved the control of pollutant discharges, conservation, and sustainable support to protect the natural resources of the Moulay Bousselham lagoon (Figure 1).

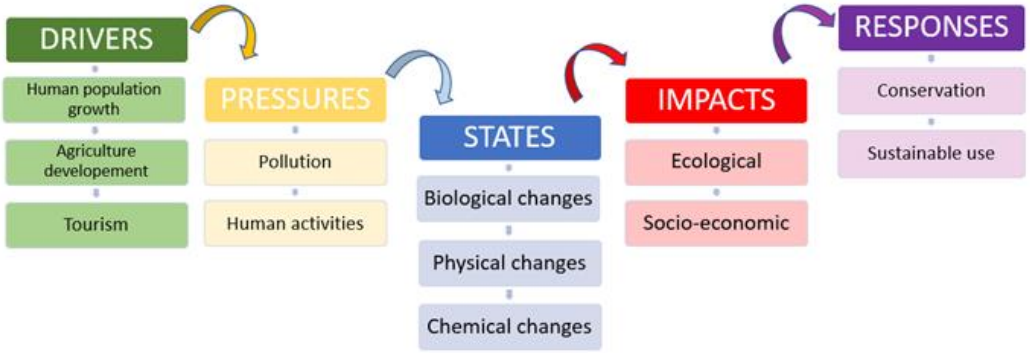

Figure 1. Flow chart of Environmental changes and their impacts on Moulay Bousselham Lagoon, Morocco.

2.2 Presentation of the site

The Moulay Bousselham lagoon, also named "Merja Zerga," is a coastal environment located on the Atlantic Ocean (34°470N, 6°130W, and 34°520N, 6°140W) (Figure 2). It is 9 km long, 5 km wide, and has an inlet (357 m wide) that allows water exchanges with the Atlantic Ocean and the renewal of the lagoon's water. The lagoon of Moulay Bousselham has been classified as a Ramsar site since 1980. The Convention on Wetlands of International Importance [1] and the Ministry of Water and Forests have identified Merja Zerga as a site of biological and ecological interest (SIBE). The lagoon has also been included in the coastal monitoring network of the National Fisheries Research Institute. This nature reserve is one of the most important lagoons in Morocco, with a high level of biodiversity and a remarkable habitat for birds.

Figure 2. Geographic location of the study area.

3. Findings and discussions

The outcome of the application of the DPSIR approach on the Moulay Bousselham lagoon is the result of a detailed analysis of data and information previously presented in the scientific literature (reports, studies, articles, theses, etc.), followed by the identification of the main issues of this area, the decomposition of these issues using the five components of DPSIR (driving forces, pressures, state, impact, and responses), and finally the mapping of these issues to facilitate decision-making.

The following section presents the decomposition of the environmental and socio-ecological issues of the Moulay Bousselham lagoon through the DPSIR model.

3.1. Driving forces and Pressures analysis

- **Population growth and Land use change**

Moulay Bousselham is an important urban pole on the Moroccan Atlantic coast. The user population of the lagoon comes under the province of Kenitra and is divided between the commune of Moulay Bousselham and that of Bahara Oulad Ayad. The demographic situation of the two municipalities studied over the past two decades reflects their evolution and provides information on their prospects. Thus, between the census of 2004 and that of 2014, the population of the two rural communes has evolved at a significantly different rate, with an average annual growth rate of 2.2% for the commune of Moulay Bousselham and 1.5% for the commune of Bahhara Oulad Ayad for the period 2004-2014.

- **Economic sectors**

Economic development has led to the expansion and increase of human activities and has been one of the main anthropogenic factors in resource use and land use/habitat. The main activities are agriculture and fishing (Table 1). However, other complementary activities are practiced, such as mat-making from rushes, livestock raising, and wage labor, which vary according to the resources available to them (Table 1).

Table1. Practiced economic activities in Moulay Bousselham Lagoon.

Activity Practiced	Significance (%)
Agriculture and livestock	85
Fishing	5
Salaried work	6
Commerce	4

Human activities, including resource exploitation and agriculture, deliver several pollutants, such as fertilizers, insecticides, pesticides, and fertilizers used in vegetable crops around the lagoon and in the lagoon [12]. Consequently, this lagoon is threatened by three main environmental problems: (i) the sediment imbalance (flow velocity in the channels higher than the reflux velocity), which remains the main factor in the degradation of the water and the ecosystem of the lagoon; (ii) the overexploitation of natural resources (fishing, agriculture, etc.); and (iii) water pollution.

- **Silting and coastal erosion**

Over time, the dune cordon has undergone many changes (silting and erosion), particularly in its position of communication with the sea. Indeed, the periods of communication alternate more or less regularly with the periods of total closure of the lagoon.

- **Pollution**

The management of the "Merja" space appears to be a common and conflicting issue between the various activities. The risks of degradation and pollution of resources are all-pervasive and constitute a real threat to the ecological balance and hydrological functioning of the lagoon area of the MZ. Indeed, water pollution, especially from agricultural activities (contamination of water by pesticides and fertilizers), remains critical, and its impacts are greatest on the health of the lagoon area of the MZ in general and on the bird population in particular.

3.2. Analysis of states

- **Physical and sedimentological state**

Current velocities in the Moulay Bouselham lagoon are controlled by two hydrodynamical regimes: (i) during the flood: when the sea water pushes in, the force of the currents is concentrated on the shoals and the passes (1 m/s) as well as on the gently sloping banks; (ii) during the ebb tide: depending on the volume of water entering the Merja at the time of the flood, the current is more important in the deep areas than on the superficial parts (0.1 to 0.3 m/s) [15].

Moreover, the strength of the northeastern current remains constant (0.55 m/s) throughout the year, whereas the spring tides are more powerful in the summer (0.9 m/s) than in the winter (0.75 m/s) [15].

- **Biological State Changes**

Merja Zerga is a RAMSAR area; it is characterized by a particular hydrological regime (tidal and continental influences) and by the great diversity of its habitats. This lagoon is one of the largest coastal wetlands in Morocco. Mainly in relation to its ornithological importance, this site has been classified as a site of biological and ecological interest (SIBE) [16].

The Merja Zerga presents a large variety of wetland habitats characterized by the presence of important floristic diversity.

3.3 Analysis of impacts

Wetlands, especially those threatened by the intensification of human activities, as is the case with the Merja Zerga lagoon, are undergoing enormous negative impacts in all countries. Hydrology plays a fundamental role in the maintenance and creation of these environments, but the lack of specific measures relating to the hydrological aspects of wetlands means that there is little knowledge and few established models of operation.

Thus, the management of the space "Merja" is considered a common and conflicting issue among the various activities. The risks of degradation and pollution of resources are pervasive and constitute a real threat to the ecological balance and hydrological functioning of the lagoon space of the MZ.

In effect, water pollution, especially that caused by agricultural activities (contamination of water by pesticides and fertilizers), remains the most critical, and its repercussions are heavier on the health of the lagoon of the MZ in general and on the avifauna in particular [17].

Globally, the hydrological and essentially chemical problem evident in this lagoon is linked to the pressure generated by the upstream inputs, which are highly charged with chemical substances linked to agricultural practices using fertilizers and phytosanitary products, on the natural environment. Thus, the site remains sensitive to the developments and to the different speculations, in particular the different agricultural practices bordering it, which represent a perennial nuisance.

3.4. Analysis of responses

Environmental quality is a key factor in the development of different vital sectors and can limit the sustainability of natural resources if it is damaged. The absence of an integrated sustainable development strategy, which reconsiders the environmental parameter and socio-economic programs and actions, will increase the process of deterioration of the natural resources and compromise the concept of sustainability.

One of the most important sustainable options for lagoon protection is the establishment of a wastewater treatment plant to provide pre-treatment, biological treatment, and advanced tertiary treatment of wastewater, including low-pressure closed-loop ultraviolet disinfection.

According to Biwater's Country Manager for Morocco, the objective of this project is to protect the Merja Zerga lagoon reserve (one of the most important bird habitats in Morocco, attracting birdwatchers from all over the world) and the Moulay Bousselham beach from the discharge of wastewater, which can cause biological disturbances, leading to reproductive, growth, or immune system disorders in aquatic organisms.

The treated wastewater will be used for irrigation of the region, known for its agricultural activities, including the production of strawberries exported worldwide.

Aware of the magnitude of the problem related to the pollution of the Moulay Bousselham lagoon and despite the substantial regression of agricultural activity, and in order to contribute to the safeguarding of the lagoon, the Ministry of Agriculture and Maritime Fishing has appointed a commission composed of representatives of the Directorate of Sectors, the Directorate of Irrigation and Development of the Agricultural Space, the Agency for Agricultural Development, and the ORMVAG to identify and evaluate an action plan in this regard. The main objectives of this action are to (i) eliminate all possible sources of contamination of microbial or chemical origin resulting from agricultural activities (grazing in the lagoon, leaching of nitrates, and pesticide residues); (ii) contribute to the environmental protection of the lagoon; and (iii) implement alternative solutions for the benefit of the farmers concerned.

3.5. DPSIR model of the Moulay Bousselham lagoon

The aim of managing water resources and quality is to safeguard human health while maintaining sustainable aquatic and associated terrestrial ecosystems. It is, therefore, important to quantify and identify the current state of ecosystems and evaluate their impacts on water environments.

For analyzing environmental conditions and vulnerabilities, especially lagoons as a socio-ecological system (SES), conceptual models are required to organize, visualize, understand, and clarify the issues concerning actual or predicted conditions and how they might be explained and solved. They can be considered as representing organizational schemas, which recapitulate information in a standard, logical, and hierarchical manner. As is the case for the following DPSIR analysis (Figure 3), it summarizes the different sources of degradation of the Moulay Bousselham lagoon, including pressures, states, impacts, and responses.

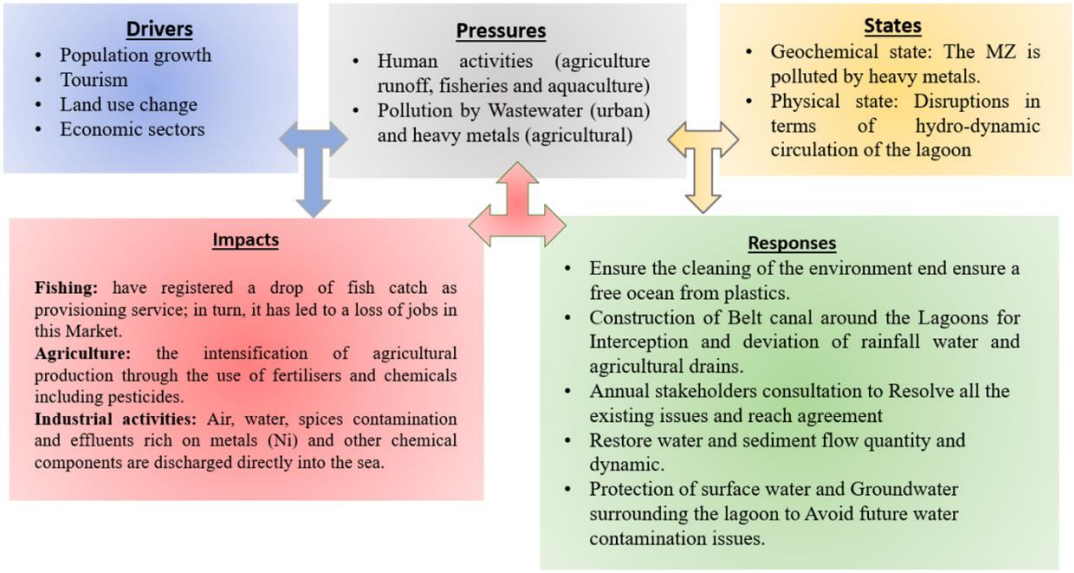

Figure 3. Scheme of the DPSIR model of the Moulay Bousselham lagoon.

4. Conclusion

Using "DPSIR" as a framework for study, this paper traced the recurrent changes in the Moulay Bousselham lagoon and their causes and impacts. Indicators of factors, pressures, states, impacts, and responses were used to assess the changes in Moulay Bousselham Lagoon. It can be concluded that pressures from human population growth and economic development have increased over the last half century in the Moulay Bousselham lagoon, Morocco. Overexploitation of natural resources, agriculture, selfish aquaculture, and water pollution have directly caused many physical, chemical, and biological degradations of the state of the Moulay Bousselham lagoon and have resulted in several negative ecological and socioeconomic impacts, including water pollution, sediment pollution by heavy metals, and disruption of hydrodynamic circulation. A human effort has been made to protect the Moulay Bousselham lagoon, such as the installation of a wastewater treatment station, environmental education and awareness (the creation of an information center), and scientific support capacity.

Finally, it can be noted that the DPSIR model has been a multi-disciplinary approach that has allowed us to trace the links between the socioeconomic activities, their impacts on the sustainability of the lagoon, and the human interventions to reduce them, with a strategic vision to improve the ecological productivity of the Moulay Bousselham, ensure the sustainability of its natural resources, and integrate the management of this ecosystem.

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