The eutrophication process of Nador's lagoon (Morocco) evaluated by the Life Cycle Impact Assessment method

Gaétana Quaranta, Mohammed Karim Bloundi, Norbert Clauer, Joelle Duplay

► To cite this version:

Gaétana Quaranta, Mohammed Karim Bloundi, Norbert Clauer, Joelle Duplay. The eutrophication process of Nador's lagoon (Morocco) evaluated by the Life Cycle Impact Assessment method. *Arabian Journal of Geosciences*, 2021, 14 (5), 10.1007/s12517-021-06685-4 . hal-03360543

HAL Id: hal-03360543

<https://hal.science/hal-03360543>

Submitted on 4 Oct 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

The eutrophication process of Nador's lagoon (Morocco) evaluated by the Life Cycle Impact Assessment method

Gaétana Quaranta¹ & Mohammed Karim Bloundi² & Joëlle Duplay³ & Norbert Clauer⁴

Received: 1 July 2020 / Accepted: 3 February 2021

#Saudi Society for Geosciences 2021

Abstract

The Nador lagoon system of northeastern Morocco represents the largest regional paralic hydro-system between the Mediterranean Sea and the African continent. Due to its importance, this lagoon is one of the five Sites of Biological and Ecological Interest (SIBE) and was classified in 2005 as a protected site by the international Ramsar treatise. The Nador lagoon is subjected to eutrophic impacts due to pollutant releases from a wastewater plant, three major cities, an agricultural site, and to varied inputs carried by rivers draining the lagoon watershed. The NO_3^- , NO_2^- , NH_4^+ , and PO_4^{3-} contents of nine water samples collected during summer and winter times at different places in the lagoon were measured and translated in terms of the Redfield ratio (N/P) and the Aquatic Eutrophication Potential. The analyses show that N/P is less than 16 in terms of the Redfield ratio, which designates N as the limiting factor for the algal growth over the entire lagoon. However, one of the higher N/P ratios was obtained next to the releases of the Beni-Ensar city and near the outlets of the wastewater plant and the nearby Bouaroug creek. The aquatic eutrophication potential of the phosphorus compounds (AEP (P)) is systematically greater than the aquatic eutrophication potential of the nitrogen compounds (AEP (N)), whether in winter or summer, which confirms that nitrogen is the limiting factor for the local algal growth.

Keywords Eutrophication · Nitrogen · Phosphorus · Nador lagoon · Life Cycle Impact Assessment

Introduction

Coastal environments around the Mediterranean Sea are subjected to increasing impacts that result from concomitant urban, industrial, and touristic developments. These impacts induce potential pollution and degradation, and therefore

concerns about the sustainable development. This new situation means also that more thoughts have to be given to sustainable environmental aspects including the protection of natural resources, the reduction of pollutant emissions, and the preservation of the fauna and the flora. Among all lagoons exposed to various sources of pollution along the southern shelf of the Mediterranean Sea, that of Nador has been examined in detail during a period of more than 10 years from 1982 to 1993 (Maanan et al., 2015; Lefebvre et al. 1997). For instance, eutrophication increased significantly with a significantly higher supply of organic matter and sediments over time, with a concomitant proliferation of algae called "harmful algal blooms" (Lapointe et al., 2015; Ruiz et al., 2006).

Responsible Editor: Amjad Kallel

* Gaétana Quaranta
quaranta@unistra.fr

¹ Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, 23 rue du Loess, 67037 Strasbourg-Cedex, France

² RSK BENELUX, Chaussée de Namur 119, 1400 Nivelles, Belgium

³ Ecole et Observatoire des Sciences de la Terre, Laboratoire d'Hydrologie et de Géochimie de Strasbourg, Université de Strasbourg, 1 rue Blessig, 67084 Strasbourg-Cedex, France

⁴ Ecole et Observatoire des Sciences de la Terre, Institut de Physique du Globe de Strasbourg, Université de Strasbourg, 5 rue Descartes, 67000 Strasbourg, France

Examination of this algal proliferation has been used to evaluate the sanity of different lagoons (Bencheikroun et al., 2013; Dokulil, 2003; Hédouin et al., 2008). As the global confinement of the Nador lagoon increased also slightly, this initial information incited us to examine again the varied inputs of the potential pollutants into the lagoon. As the Life Cycle Impact Assessment (LCIA) applied to evaluate lagoon ecosystems by measuring the nutritive elemental concentrations of another lagoon system has raised interesting applicable

54 conclusions (Hadj et al. 2008), this method was used again in
55 the frame of this study.

56 **Setting of the lagoon and description**
57 **of the studied materials**

58 The lagoon of Nador is located on the eastern Mediterranean
59 coast of Morocco (35° 10 N, 2° 55 to 2° 45W) near the
60 Algerian border (Fig. 1). It is bound to the NW by the Cap
61 des Trois Fourches and to the SE by the Cap de l'Eau. Of
62 limited size with a surface of 115 km² (25 by 7.5 km) with a
63 depth never exceeding 8 m, it is open to the sea by a pass (Fig.
64 1b). Three agglomerations, namely Beni Ensar, Nador, and
65 Arekman Village from NW to SE, as well as a wastewater
66 plant and an ore treatment plant are located around the lagoon,
67 which is also used as a fish breeding place. The lagoon has
68 clearly a social and economic impact for the whole region and
69 has a major local socio-economic and ecological interest
Q3 70 (Giuliani et al., 2015; Orbi et al., 2008).

71 At each end of the lagoon, creeks (called oueds) carry tem-
72 porarily used surficial waters, which explains why any phys-
73 ical or chemical modification of the lagoon ecosystem may

have a significant impact, reducing or even stopping the fish 74
production and consequently causing unemployment. In fact, 75
modifying the environment of the lagoon is also an identified 76
risk due, for instance, to the construction of jetties that can 77
potentially silt up the coast and therefore plug the pass to the 78
sea. A progressive closing of the lagoon will potentially in- 79
crease the salinity of the water due to an increased evaporation 80
relative to a lowering of the water supply. The implication for 81
the Nador lagoon would be an increased organic and inorganic 82
contamination due to increasing urban releases generated by a 83
continuously increasing local and touristic population. 84

The Nador ecosystem

Studies in geomorphology, sedimentology, and geochemistry 86
were carried out on the ecosystem of Nador lagoon, which 87
helps to understand better how it functions (Tesson and 88
Gensous 1981; Guelorget and Perthuisot 1983; Inani 1995; 89
Elalami et al. 1998; Mahjoubi 2001; Irzi 2002; Mahjoubi 90
et al. 2003; Bloundi 2005). Also called Bou Areg Sebkh, 91
the Nador lagoon can be divided into three physiographic 92
domains (Fig. 1): the continental border, the lagoon itself, 93
and the barrier island. The continental border includes salt 94

Fig. 1 Locations of the water sampling places and of the main anthropogenic supplies around the Nador lagoon

95	marshes and oued outlets, the most important being oued	world. It is a natural process by which waters become exces-	146
96	Selwane. The barrier island oriented NW-SE is about 25 km	sively enriched in nutrients, such as nitrogen and phosphorus.	147
97	long and has an average width of 300–400 m, becoming 2 km	It is a way along which water bodies, such as lakes, rivers, and	148
98	wide at its southeastern end, and containing an artificial pass	seas, change because their nutrients become progressively	149
99	called Bokhana. The lagoon itself is fed not only by natural	enriched, from scarce (oligotrophic) to rich (eutrophic).	150
100	oueds that have torrential flows from time to time but also by	Human activities often enhance the rate of change, or at least	151
101	several man-constructed outlets such as irrigation channels	modify it because of industrial and farming activity, road con-	152
102	and urban releases. Two water supplies by the Bou Areg and	structions, and building of waste treatment plants that all cause	153
103	Gareb oueds are in contact with the lagoon waters, which are	entrance of nutrients into the water cycle. This nutrient enrich-	154
104	also infiltrated by salt waters from sea waves breaking on the	ment often results in a blooming of algae and other aquatic	155
105	barrier island and by seawater flows into the inlet.	plants that lead to oxygen depletion and, therefore, to the	156
106	The human anthropogenic activities around the Nador lagoon	reduction and even the destruction of the fish population.	157
107	are diverse. They induce varied types of releases: (1) developing	Consequently, native fish species disappear and are replaced	158
108	infrastructures that include land transport and traffic, and recre-	by species that are more resistant to the new environmental	159
109	ational facilities that produce waste waters, municipal waste, and	conditions created by the supply of abnormal amounts of nu-	160
110	fuels; (2) the nearby airport activity; (3) local industrial activities	trients. Also, beaches and shorelines may be polluted by	161
111	including active and abandoned mining, excavation sites, indus-	masses of rotten algae. In order to assess the eutrophication	162
112	trial plants and storage sites, treatment of waste waters, harbour,	state of the Nador lagoon water, as for the Slimane-El Maleh	163
113	and port facilities; and (4) livestock, agriculture, aquaculture,	lagoon of Tunisia (Hadj et al. 2008), the LCIA method	164
114	and fisheries. The main vectors of the pollution issued from	adapted to a natural lagoon has been applied.	165
115	these activities are the oueds, which waters are used often as		
116	discharges of up-stream built-up sewers by irrigation canals,		
117	treated urban discharges of the city of Nador to the south, non-	The analytical methods and results	166
118	treated releases from Arekman Village to the southeast, from the		
119	city of Beni Ensar to the northwest, and streaming waters	The experimental procedure	167
120	(Bloundi et al. 2008a). The amount of fresh water drained into		
121	the lagoon was estimated to average about 19,000 m ³ /year, but	To study the seasonal evolution of the contents in major nu-	168
122	this contribution is decreasing since the construction of a dam	trients, surface waters were sampled during a winter and a	169
123	upstream the oued Selwane.	summer campaign at different sites in the lagoon (Fig. 1),	170
124	Mabrouk (1988) showed that untreated wastewaters induce	and were analysed for their P and N contents. To make the	171
125	bacteriological contamination around the releasing zones. In	comparisons with the Slimane-El Maleh lagoon even more	172
126	fact, the only facility for domestic waste collection around the	accurate, sampling was made here at places in the lagoon that	173
127	lagoon is located near the city of Nador. It is dedicated to the	were similar to those collected in the other lagoon: near the	174
128	downtown population and that of some suburban districts. It	entrance of the lagoon, near the outlet of creeks, and near the	175
129	cleans only 70% of the city domestic waters, the remaining	water treatment plant, as well as in more preserved places.	176
130	30% being evacuated into individual wells. Treating about	Physical parameters such as pH, temperature, conductivity,	177
131	10,000 m ³ of water per day that are subjected to biological	salinity, and Eh were measured on site right after sample col-	178
132	treatments, the nearby wastewater station is based on the princi-	lection (Bloundi 2005; Mostarih et al. 2016).	179
133	ple of the activated sludge. Although visible, the pollution de-	The waters were filtered on site right after collection by	180
134	crease may not be effective enough because of varied systematic	pressure using 0.45-µm filters and were stored in polypropyl-	181
135	failures in the physical, chemical, or micro-biological controls of	ene bottles at 4°C. The analyses were performed by atomic	182
136	the treated waters, lacking of the necessarily periodic disinfec-	absorption spectrometry (Hitachi Z8200) for NO ⁻ , NO ⁻ , and	183
137	tion operations of the treatment equipment, as well as cuts of the	PO ₄ ³⁻ and colorimetry (Technicon) for NH ⁴⁺ .	184
138	electrical power and defects of the electro-mechanical system,		
139	which altogether alter the quality, and also the reliability of the	The available data	185
140	water treatment. Other towns and villages around the lagoon,		
141	such as Beni Ensar and Arkmane Village, evacuate directly their	Concerning the organic-related contamination, the surface	186
142	faecal waters into the lagoon without any treatment.	sediments show variable rates in total organic carbon and sul-	187
143	The lagoon eutrophication	fur that are especially high in the centre of the lagoon at 7.5	188
144	Eutrophication is presently a major form of controlling the	and 1.8%, respectively. The n-alkanes distribution reveals a	189
145	water pollution that affects aquatic ecosystems around the	zone of “marine” influence and a zone of “continental” influ-	190
		ence in the lagoon, while pentacyclic tri-terpanes point to-	191
		wards a contamination by petroleum products in the entire	192

lagoon except in the centre. In turn, the organic petroleum by-products and the wastewater effluents are especially high near the cities, whereas the littoral and central parts of the lagoon remain less polluted by these contaminations (Bloundi et al. 2008b).

The eutrophication factors

The determined P and N concentrations show that the main contributors to eutrophication are N compounds for the nine water samples during both the summer and winter sampling campaigns (Table 1; Fig. 2). In summer, the sample at the output of the wastewater plant of Bouaroug (location 4) yields the higher contents at 0.78 mg/L for the N compounds followed at 0.35 mg/L by that near the city of Beni Ensar at the northern end of the lagoon (location 1). These two contents are ten times higher than those of the winter sampling. The water sample of location 4 contains also two times more P compounds in summer than in winter. In summer, the wastewater treatment plant discharges directly into the lagoon part of the wastewater loaded with N and P. Indeed, during this season, the population triples and the undersized plant is unable to treat all of the wastewaters. The values of the N

compounds at the sampling place next to the city of Beni Ensar (location 1) can be due to inputs of the oueds draining the local watershed. Conversely, the water samples of the barrier island (location 7) and next to the pass (location 8) yield two times more N compounds in winter than in summer. The samples of the locations 2, 6, and 8 yield very similar P contents for the summer and the winter, suggesting that the average P contents of the lagoon waters are close of those of these samples. The sample collected in the middle of the lagoon (location 9) is systematically the lowest for both the N and P contents, suggesting the lowest pollution probably due a better oxygenation by marine currents.

The relationship between the seasonal development cycle of the phytoplankton and the N and P nutritional cycles in the Slimane-El Maleh lagoon where the N concentrations are more important than those of P in winter, the opposite occurring in summer (SETAC 2002), is not reproduced here: the N contents are always higher than the P ones in summer. No general law can be drawn for the winter data as the concentrations of the N compounds are either lower than those of the P compounds in the confined areas of N and S of the lagoon, or higher in the centre of the lagoon, near the barrier island, the treatment plant, and the irrigation channel (Table 1).

Table 1 P and N concentrations in mg/L of waters of Nador lagoon in summer and winter times

		Sample ID Location	1 Beni Ensar City	2 N Sidi Youssef Oued	3 Nador City	4 Step Bouaroug	5 Irrigation Channel	6 Arekman Village	7 Barrier Island	8 Pass	9 Centre of lagoon
Summer		NH_4^+ (mmol/l)	0.001	0.001	0.001	0.048	0.001	0.001	0.001	0.001	0.001
		NH_4^+ (mg/l)	0.018	0.018	0.018	0.864	0.018	0.018	0.018	0.018	0.018
		N (mg/l)	0.014	0.014	0.014	0.672	0.014	0.014	0.014	0.014	0.014
		NO_3^- (mmol/l)	0.024	0.004	0.004	0.008	0.003	0.003	0.003	0.004	0.003
		NO_3^- (mg/l)	1.488	0.248	0.248	0.496	0.186	0.186	0.186	0.248	0.186
		N (mg/l)	0.335	0.056	0.056	0.116	0.042	0.042	0.042	0.056	0.042
		ΣN (mg/l)	0.349	0.070	0.07	0.788	0.056	0.056	0.056	0.070	0.056
		PO_4^{3-} (mmol/l)	0.001	0.002	0.002	0.004	0.002	0.001	0.001	0.002	0.001
		PO_4^{3-} (mg/l)	0.095	0.190	0.190	0.380	0.190	0.095	0.095	0.19	0.095
		P mg/l	0.031	0.062	0.062	0.124	0.062	0.031	0.031	0.062	0.031
Winter		NH_4^+ (mmol/l)	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.006	0.001
		NH_4^+ (mg/l)	0.018	0.018	0.018	0.018	0.018	0.018	0.036	0.018	0.018
		N (mg/l)	0.014	0.014	0.014	0.014	0.014	0.014	0.028	0.084	0.014
		NO_3^- (mmol/l)	0.002	0.001	0.005	0.004	0.003	0.004	0.008	0.006	0.002
		NO_3^- (mg/l)	0.124	0.062	0.31	0.248	0.186	0.248	0.496	0.372	0.124
		N (mg/l)	0.028	0.014	0.070	0.060	0.042	0.056	0.011	0.084	0.028
		ΣN (mg/l)	0.042	0.028	0.084	0.074	0.056	0.070	0.039	0.168	0.042
		PO_4^{3-} (mmol/l)	0.002	0.002	0.001	0.002	0.001	0.002	0.002	0.002	0.001
		PO_4^{3-} (mg/l)	0.190	0.190	0.095	0.190	0.095	0.190	0.190	0.190	0.095
		P (mg/l)	0.062	0.062	0.031	0.062	0.031	0.062	0.062	0.062	0.031

The NO_2 molecules were counted with the NO_3 molecules. Compounds in mmol/l were converted to mg/l, and then, this concentration in mg/l was multiplied by the molar mass of the compound. Then, the percentage of nitrogen for nitrogen compounds and phosphorus for phosphorus compounds was calculated within the concentrations of the corresponding compounds

Fig. 2 Concentrations in mg/l of the analysed nutrients and the related N/P ratio into the waters of the Nador lagoon

Eutrophication is commonly visualized by the N/P ratio called the Redfield ratio. It describes the overall composition of C, N, and P at respective concentrations of 106:16:1 in phytoplankton (Finnveden and Potting 1999). In other words, 106 moles of C and 16 moles of N are consumed while 172 atoms of O are produced for 1 mole of used P in the photosynthesis. According to this ratio, 1 mole of N emitted produces 6.6 moles organic C in the biomass, whereas the corresponding amount is as much as 106 moles in the case of P. If algae growth is optimal in an aquatic environment, the N/P ratio is equal to 16, while P is the limiting factor of the algae growth for an N/P ratio above 16 and, alternatively, nitrogen is the limiting factor for an N/P ratio below 16. Here, the N/P ratio is systematically lower than 16 wherever the sampling site, which indicates that N is the systematic limiting factor and is the higher contributor to the eutrophication (Fig. 3). Especially, NO_3^- has a high rate in winter due to its leaching from catchment area and some releases from lagoon sediments. (Mostari et al. 2016). The N/P ratio is higher in summer, in the confined area of the Beni-Ensar city and near the outlet of the wastewater plant of Bouaroug due to urban releases and N fertilizers used in the

nearby agricultural plain, and also to storage of the waste mud from water treatment plant. The highest N/P values were obtained in winter for the sample collected at the pass with the open sea (location 8; Table 2).

In comparing the results obtained here with those of water samples collected at similar places in the Slimane-El Maleh lagoon in Tunisia, the N/P ratio is not systematically higher in the summer relative to the winter. However, even if this ratio is systematically below the reference value of 16 in the Nador lagoon and often in the Slimane-El Maleh lagoon, the high ratios in summer time are from near the wastewater treatment plants. In turn, the model suggested for the functioning of the Slimane-El Maleh lagoon (Hadj et al. 2008) is applicable here, the Nador lagoon appearing, however, to be less eutrophic than that of Slimane-El Maleh.

It also looks like that the load in organic matter and nutritive salts of the domestic wastewaters entering the Nador lagoon, the limited efficiency of the wastewater treatment by the plant, and probably the hydrodynamic functioning of the lagoon can generate seasonal periods of eutrophication that might be critical in some places. The water circulation in the lagoon favours the formation of a water mass rich in nutritive elements, as seems to be the case for the sample at the outlet to the sea (location 8) in wintertime, which might also be depleted in oxygen at the contact with the sediment. Conversely, the border currents seem to carry away the nutritive elements brought by the effluents, at least often. In summary, slow currents, weak salinity gradient, and low density facilitate somehow the diffusion of the N and P elements.

Calculation of the aquatic eutrophication potential by the Life Cycle Impact Assessment method

The LCIA method is routinely used in the industry for the study of environmental impacts during a production cycle—from cradle to grave (ISO 14040, ISO 14044, 2006). It is based on the calculation of impact category indicators like acidification, global warming, and eutrophication, by using equivalent factors that indicate how much a substance contributes to a problem compared to a reference substance (Jensen et al., 1997; Guinée, 2001; Rebitzer et al., 2004). In an original application to natural environments, such as lagoons, Hadj et al. (2008) have shown that the lagoon waters are variably polluted by releases of water treatment plants, creeks, solid waste deposits, and agricultural activities. Seppälä et al. (2004) evaluated the eutrophication impact caused by an anthropogenic system A within a region as:

$$I_{EU} = \sum_{j=1}^n C_{ji} \cdot E_j$$

where I_{EU} (A) is the impact value of aquatic eutrophication linked to the system A, C_{ji} (A) is the characterization factor

Q8 t2:1 Table 2 Aquatic eutrophication potentials (AEP) of waters of Nador lagoon

t2:2	Location	Sample ID	AEP (N) (summer)	AEP (N) (winter)	AEP (P) (summer)	AEP (P)(winter)
t2:3	Beni Ensar city	1	1.981	0.238	1.271	2.541
t2:4	N Sidi Youssef oued	2	0.396	0.159	2.541	2.541
t2:5	Nador city	3	0.396	0.476	2.541	1.271
t2:6	STEP Bouaroug	4	4.450	0.396	5.080	2.541
t2:7	Irrigation channel	5	0.317	0.317	2.541	1.271
t2:8	Arekman Village	6	0.317	0.238	2.541	2.541
t2:9	Barrier island	7	0.317	0.793	1.271	2.541
t2:10	Pass	8	0.396	0.952	2.541	2.541
t2:11	Centre of the lagoon	9	0.317	0.238	1.271	1.271

306 of the substance j caused by the system A that will reach a
307 given water area i , and $E_j(A)$ is the emitted amount of sub-
308 stance j due to the system A . The characterization factor
309 adapted from Seppälä et al. (2004) can then be expressed by
310 transport and effect factors:
311

$$C_{j,i} = \frac{1}{4} \eta_{j,i} \mu_{j,i} E_{q,j}$$

312 where $\eta_{j,i}(A)$ is the transport factor for the substance j , also

314 indicating the portion of the emitted substance j that will reach
315 a given water area i ; $\mu_{j,i}(A)$ is the effect factor of the substance
316 j , indicating the portion of the transported substance j that
317 causes an increased production of biomass in a given water
318 area i ; and $E_{q,j}$ is the equivalency factor of the substance j that
319 is usually expressed as kilogram PO_4^{3-} equivalent per kilo-
320 gram of emitted substance j .

Q1 321 Gallego et al. (2010) and Barba-Brioso et al. (2010) intro-
322 duced transport factors into the calculation of aquatic eutro-
323 phication by the LCIA at a country scale, to evaluate if the
324 impact factor does allow an exhaustive assessment. Here the
325 LCIA is rather used to recognize variations of a limiting nu-
326 trient and of aquatic eutrophication potential that result from

327 inputs of variable concentrations of nutrients (N and P) due to
328 anthropogenic activities around and in the lagoon. It has been
329 adjusted here at the specific scale of the Nador lagoon. There
330 is then no reason to include a transport factor or an effect
331 factor into the calculation. Consequently, the characterization
332 factor is equal to the equivalency factor (see Eq. (2)).

333 Concerning the eutrophication impact, the LCIA method
334 uses the Redfield ratio for the characterization factors of con-
335 taminant emissions. The basic approach to characterize differ-
336 ent emissions of pollutants or nutrients is:
337

$$AEP = \frac{1}{4} EPI \times \sum_i Mi$$

339 where AEP is the aquatic eutrophication potential, M_i the
340 mass of the aquatic eutrophication emission, i the impact cat-
341 egory aquatic eutrophication (kg i), and EPI the

characterization factor of the emission i based on the
Redfield ratio (Redfield et al. 1993). The specific aspect to
address when applying the LCIA method to a lagoon is the
examination of the algae proliferation. Algae growth requires
favourable mineral species in the surrounding water, with C
being the dominant chemical element, followed by H and O.

Alternatively, P is the first element that is lacking in natural
conditions, before N and C. Therefore, P becomes normally

Fig. 3 a, b Comparison of AEP (N) vs. AEP (P) values for the waters of Nador lagoon. (1) Ben Ensar city. (2) Sidi Youssef oued. (3) Nador city. (4) STEP Bouaroug. (5) Irrigation channel. (6) Arekman village. (7) Barrier island. (8) Pass. (9) Centre of the lagoon

the “limiting factor” as an abnormally high anthropogenic input of P in waters induces a lack of N. In this case, the cyanobacteria proliferate in fixing atmospheric N to compensate this lack of N, which is recycled in the aquatic environment. On a limited scale of time and space, N may appear as the limiting factor and consequently it may hide the fact that P is the true limiting factor at a global scale (Barroin 2003). This is why the P and N compounds, which are the most important factors for limiting the growth rate of aquatic plants, are taken into account in the case of aquatic eutrophication (SETAC, 2002).

The aquatic eutrophication potential associated with P compounds (AEP (P)) has scores 2 to 16 times higher than AEP (N) in winter. In summer, the AEP (P) always dominates the AEP (N) but less significantly, the AEP (P) being 1 to 8 times higher than the AEP (N) according to the determined data. This means that the supply of P compounds to the lagoon is greater than that of N compounds, which confirms the results of the Redfield ratio showing that N is the limiting factor of algal growth in the Nador lagoon (Fig. 3a, 3b). In the detail, a focus on the release of wastewater treatment plant of Bouaroug (location 4) shows an AEP (P) of 5, which is twice the average score of the AEP (P) of the lagoon knowing that the lowest AEP value is that of the centre of the lagoon (location 9) with a score of 1.27. This last one is also found at the level of the barrier island (location 7) and the city of Beni Ensar (location 1).

In winter, no analysis outlines a high AEP (P) compared to an average score of 2.5, the lowest value being 1.27 in the centre of the lagoon (location 9). This score is obtained for the water sample collected at the exit of the irrigation canal (location 5) and near the city of Nador (location 3). No realistic explanation can be suggested as to the value of these three locations. The average AEP (N) in summer being 0.3, the results of three locations fall out: the wastewater treatment plant of Bouaroug (location 4) with a score of 4.4 and the city of Beni Ensar (location 1) with a score of 1.98. The first value relates to the discharge of urban water and the other to the local confined area. In winter, the AEP (N) scores are between 0.15 and 0.47, with only two results outside: the barrier island (location 7) and the pass (location 8) with scores of 0.79 and 0.95, respectively, that indicate a source of N compounds from marine waters or from re-suspension of the sediments of the barrier island.

Conclusions

Waters from Nador lagoon, as well as waters from Slimane-El Maleh lagoon in Tunisia, show the potential of using the Life Cycle Impact Assessment in the case of an ecosystem undergoing eutrophic pressures. In the case of the Nador lagoon ecosystem, the environmental trophic state examined by the

nitrogen and phosphorus impact factors into the waters allows evaluation of their contribution to eutrophication. In contrast to previous studies of other lagoons, the role of seasonal variations in concentrations of the nitrogen and phosphorus compounds has not been demonstrated nor a clear predominance of nitrogen or phosphorus. However, there is clearly a direct relationship between releases of the Bouaroug wastewater plant and the nitrogen and phosphorous summer concentrations that are about 2 times higher than the average concentrations of the lagoon. There is also a direct relation in summer between nitrogen compounds and the confined area of the Beni Ensar city.

The assessment of the aquatic eutrophication potential of the waters of the Nador lagoon shows that AEP (P) is higher than AEP (N), which confirms an eutrophication due to excessive phosphorus inputs. Several options for reducing the risk of eutrophication can be suggested: a systematic monitoring of the urban discharges with the construction of a wastewater plant for the population of the Beni Ensar city, phosphorus removal of the existing station or extension of its treatment capacity, and reduction of the diffuse leaching of the agricultural site, which all would reduce the exportation of N and P loads into the confined lagoon.

Declaration

Conflict of Interest The authors declare that they have no competing interests.

References

- Barba-Brioso C, Quaranta G, Galàn E, Fernández-Caliani JC, Miras A (2010) the life cycle impact assessment applied to the Domingo Rubio tidal system by study of seasonal variations of the aquatic eutrophication potential. *Sci Total Environ.* <https://doi.org/10.1016/j.scitotenv.2010.08.002>
- Barroin G (2003) Santé et environnement : le cas des nitrates- phosphore, azote et prolifération des végétaux aquatiques. *Le courrier de l'environnement*, p 48. (in French)
- Bloundi MK (2005) Etude géochimique de la lagune de Nador (Maroc oriental): Impact des facteurs anthropiques. Thèse Doctorat es-Sciences, Université Louis Pasteur de Strasbourg (France) et Université Mohamed V – Agdal de Rabat (Maroc), p 238. (in French)
- Bloundi MK, Duplay J, Quaranta G (2008a) Heavy metal contamination of coastal lagoon sediments by anthropogenic activities: The case of Nador (East Morocco). *Environ Geol* 56:833–843
- Bloundi MK, Faure P, Duplay J (2008b) Organic contamination identification in sediments from a Mediterranean coastal ecosystem: The case of the Nador lagoon (eastern Morocco). *Compt Rendus Geosci* 340:840–849
- Boyauzan A, Irzi Z (2015) Impacts of man-made structures on sediment fluxes and water circulation around the barrier island of the Nador lagoon (north-east of Morocco, Oriental region). *J Mediterr Geogr* 125:85–94

452	Conley DJ, Markager S, Andersen J, Ellerman T, Svenden LM (2002)	493
453	Coastal Eutrophication and the Danish National Aquatic Monitoring	494
454	and Assessment Program. <i>Estuaries</i> 25(4b):848–861	495
455	Duplay J, Semhi K, Bloundi MK, Khediri S, Ben AR, Darragi F (2012)	496
456	Geochemical background and contamination level assessment in	497
457	Tunisian and Moroccan Mediterranean coastal lagoon sediments.	498
458	<i>Environ Earth Sci</i> 67:1201–1214	499
459	Elalami M, Mahjoubi R, Damnati B, Kamel S, Icole M, aeib M. (1998)	500
460	Sédimentologie et géochimie organique des sédiments superficiels	501
461	de la lagune de Nador (Maroc nord – oriental). <i>J Afr Earth Sci</i> 26(2):	502
462	249–259 (in French)	503
463	Finnveden G, Potting J (1999) Eutrophication as an impact category. <i>Int J</i>	504
464	<i>LCA</i> 4(6):311–314	505
465	Guelorget O and Perthuisot JP (1983) Le domaine paralique : Expressions	506
466	géologiques, biologiques et économiques du confinement. <i>Travaux</i>	507
467	du Laboratoire de Géologie, Ecole Normale Supérieure, Paris, série	508
468	156, n° 16, p 136 (in French).	509
469	Hadj AR, Quaranta G, Gueddari F, Million D, Clauer N (2008) The life	510
470	cycle impact assessment applied to a coastal lagoon: the case of the	511
471	Slimane lagoon (Tunisia) by the study of seasonal variations of the	512
472	Aquatic Eutrophication Potential. <i>Environ Geol</i> 54:1103–1110	513
473	Howarth RW, Sharpley A, Walker D (2002) Sources of Nutrient	514
474	Pollution to Coastal Waters in the United States: Implications for	515
475	Achieving Coastal Water Quality Goals. <i>Estuaries</i> 25(4b):656–676	516
476	Huijbregts MAJ, Seppälä J (2000) Towards Region-Specific, European	517
477	Fate Factors for Airborne Nitrogen Compounds Causing Aquatic	518
478	Eutrophication. <i>Int J LCA</i> 5(2):65–67	519
479	Inani I (1995) Dynamique Sédimentaire et Etat de Pollution dans la	520
480	lagune de Nador. Thèse de 3ème Cycle, Université Mohammed V,	521
481	Rabat p.186 (in French).	522
482	International Organization for Standardization ISO 14040, ISO 14044	523
483	(2006) Environmental Management – Life cycle assessment –	524
484	Principle and framework. AFNOR, Paris	525
485	Irzi Z (2002) Les environnements du littoral méditerranéen oriental du	526
486	Maroc compris entre l'Oued Kiss et le Cap des Trois Fourches,	527
487	Dynamique sédimentaire et évolution écologique des foraminifères	528
488	benthiques de la lagune de Nador, Thèse de Doctorat ès Sciences.	529
489	Université Mohamed I, Oujda, 279 p	530
490	Lefebvre A, Guelorget O, Perthuisot JP, Dafir JE (1997) Evolution	531
491	biogéologique de la lagune de Nador (Maroc) au cours de la	
492	période 1982-1993. <i>Oceanol Acta</i> 20:371–385	
493		
494	Mabrouk A (1988) Etude bactériologique de la lagune de Nador. Thèse	
495	Doctorat Vétérinaire, Université Hassan II, Rabat, 123 p + annexes	
496	(in French).	
497	Mahjoubi R (2001) Nature et origine du flux de matière particulaire et son	
498	enregistrement dans un milieu paralique microtidal : cas de la lagune	
499	de Nador (Maroc Nord Oriental), Thèse de Doctorat ès Sciences,	
500	Université Moulay Ismail, Meknes, p 231 (in French).	
501	Mahjoubi R, Kamel S, El Moumni B, Noack Y, Parron C (2003) Nature,	
502	origine et répartition de la phase argileuse de la lagune de Nador	
503	(Maroc Nord Oriental). <i>Geol Belg</i> 6(1-2):31–42	
504	Mostari M, El Madani F, Yahya HSA, El Hachemi O, Abdellaoui S,	
505	Chafi A (2016) Evaluation physico-chimique de la qualité de l'eau	
506	de la lagune de Nador- N du Maroc Oriental- après l'ouverture de la	
507	passé. <i>J Mater Environ Sci</i> 7:4795–4809	
508	Parinet B, Lhote A, Legube B (2004) Principal component analysis: an	
509	appropriate tool for water quality evaluation and management- ap-	
510	plication to a tropical lake system. <i>Ecol Model</i> 178(3–4):295–311	
511	Redfield AC, Ketchum FH and Richards FA (1963) The influence of	
512	organisms on the composition of sea water. <i>The sea</i> 2, (M.N. Hill,	
513	Editor), Wiley- Interscience, New York, 26-77.	
514	Redfield AC, Ketchum FH and Richards FA (1993) The influence of	
515	organisms on the composition of sea water. <i>Proceedings of the</i>	
516	2nd International Water Pollution Conference; Tokyo, Japan.	
517	Pergamon, Oxford, 215-243.	
518	Seppälä J, Knuuttila S, Silvo K (2004) Eutrophication of Aquatic	
519	Ecosystems. A new method for calculating the potential contribu-	
520	tions of Nitrogen and Phosphorus. <i>Int J LCA</i> 9(2):90–100	
521	Smil V (2000) Phosphorus in the Environment: Natural Flows and	
522	Human Interferences. <i>Annu Rev Energy Environ</i> 25:53–88	
523	Smith VH (2003) Eutrophication of Freshwater and Coastal Marine	
524	Ecosystem. A Global Problem. <i>Environ Sci Pollut Res</i> 10:126–139	
525	Society of Environmental Toxicology and Chemistry (2002) Life-Cycle	
526	Impact Assessment: Striving towards best practice. SETAC Press, p	
527	250.	
528	Tesson M and Gensous B (1981) Quelques caractères de la géochimie	
529	d'une lagune microtidal : la Sebkh Bou–Areg (Maroc). 106ème	
530	Congrès des Sociétés Savantes, Perpignan, Faculté des Sciences,	
531	Fasc. III, 183–194 (in French).	