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

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## 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  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{NH}_4^+$ , and  $\text{PO}_4^{3-}$  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).

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Examination of this algal proliferation has been used to evaluate the sanity of different lagoons (Benchekroun et al., 2013; 45 Dokulil, 2003; Hédouin et al., 2008). As the global confinement of the Nador lagoon increased also slightly, this initial 46 information incited us to examine again the varied inputs of 47 the potential pollutants into the lagoon. As the Life Cycle 48 Impact Assessment (LCIA) applied to evaluate lagoon eco- 49 systems by measuring the nutritive elemental concentrations 50 of another lagoon system has raised interesting applicable 53

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

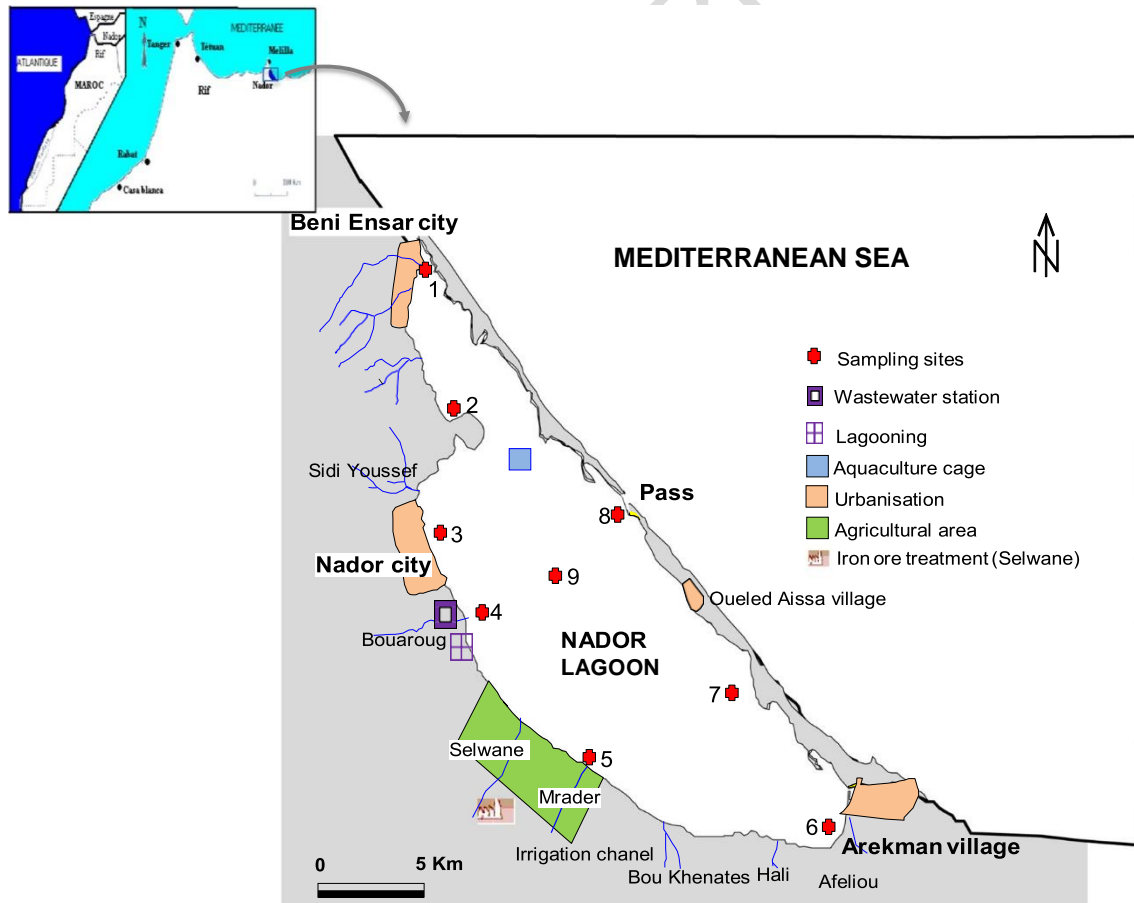
58 The lagoon of Nador is located on the eastern Mediterranean  
59 coast of Morocco (35° 10 N, 2° 55 to 2° 45W) near the  
60 Algerian border (Fig. 1). It is bound to the NW by the Cap  
61 des Trois Fourches and to the SE by the Cap de l'Eau. Of  
62 limited size with a surface of 115 km<sup>2</sup> (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  
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

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

## 85 The Nador ecosystem

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



Q5=Q4 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-	<b>The analytical methods and results</b>	166
118	treated releases from Arekman Village to the southeast, from the		
119	city of Beni Ensar to the northwest, and streaming waters	<b>The experimental procedure</b>	167
120	(Bloundi et al. 2008a). The amount of fresh water drained into		
121	the lagoon was estimated to average about 19,000 m <sup>3</sup> /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 <sup>3</sup> 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 <sup>-</sup> , NO <sup>-</sup> , and	183
137	tion operations of the treatment equipment, as well as cuts of the	PO <sub>4</sub> <sup>3-</sup> and colorimetry (Technicon) for NH <sup>4+</sup> .	184
138	electrical power and defects of the electro-mechanical system,		
139	which altogether alter the quality, and also the reliability of the	<b>The available data</b>	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	<b>The lagoon eutrophication</b>	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

193 lagoon except in the centre. In turn, the organic petroleum by-  
 194 products and the wastewater effluents are especially high near  
 195 the cities, whereas the littoral and central parts of the lagoon  
 196 remain less polluted by these contaminations (Bloundi et al.  
 197 2008b).

## 198 The eutrophication factors

199 The determined P and N concentrations show that the main  
 200 contributors to eutrophication are N compounds for the nine  
 201 water samples during both the summer and winter sampling  
 202 campaigns (Table 1; Fig. 2). In summer, the sample at the  
 203 output of the wastewater plant of Bouaroug (location 4) yields  
 204 the higher contents at 0.78 mg/L for the N compounds follow-  
 205 ed at 0.35 mg/L by that near the city of Beni Ensar at the  
 206 northern end of the lagoon (location 1). These two contents  
 207 are ten times higher than those of the winter sampling. The  
 208 water sample of location 4 contains also two times more P  
 209 compounds in summer than in winter. In summer, the waste-  
 210 water treatment plant discharges directly into the lagoon part  
 211 of the wastewater loaded with N and P. Indeed, during this  
 212 season, the population triples and the undersized plant is un-  
 213 able to treat all of the wastewaters. The values of the N

compounds at the sampling place next to the city of Beni 214  
 Ensar (location 1) can be due to inputs of the oueds draining 215  
 the local watershed. Conversely, the water samples of the 216  
 barrier island (location 7) and next to the pass (location 8) 217  
 yield two times more N compounds in winter than in summer. 218  
 The samples of the locations 2, 6, and 8 yield very similar P 219  
 contents for the summer and the winter, suggesting that the 220  
 average P contents of the lagoon waters are close of those of 221  
 these samples. The sample collected in the middle of the la- 222  
 goon (location 9) is systematically the lowest for both the N 223  
 and P contents, suggesting the lowest pollution probably due a 224  
 better oxygenation by marine currents. 225

The relationship between the seasonal development cycle 226  
 of the phytoplankton and the N and P nutritional cycles in the 227  
 Slimane-El Maleh lagoon where the N concentrations are 228  
 more important than those of P in winter, the opposite occur- 229  
 ring in summer (SETAC 2002), is not reproduced here: the N 230  
 contents are always higher than the P ones in summer. No 231  
 general law can be drawn for the winter data as the concen- 232  
 trations of the N compounds are either lower than those of the 233  
 P compounds in the confined areas of N and S of the lagoon, 234  
 or higher in the centre of the lagoon, near the barrier island, the 235  
 treatment plant, and the irrigation channel (Table 1). 236

t1:1 Table 1 P and N concentrations in mg/L of waters of Nador lagoon in summer and winter times

t1:2	Sample ID	1	2	3	4	5	6	7	8	9
t1:3	Location	Beni Ensar City	N Sidi Youssef Oued	Nador City	Step Bouaroug	Irrigation Channel	Arekman Village	Barrier Island	Pass	Centre of lagoon
t1:4	Summer	NH <sub>4</sub> <sup>+</sup> (mmol/l)	0.001	0.001	0.001	0.048	0.001	0.001	0.001	0.001
t1:5		NH <sub>4</sub> <sup>+</sup> (mg/l)	0.018	0.018	0.018	0.864	0.018	0.018	0.018	0.018
t1:6		N (mg/l)	0.014	0.014	0.014	0.672	0.014	0.014	0.014	0.014
t1:7		NO <sub>3</sub> <sup>-</sup> (mmol/l)	0.024	0.004	0.004	0.008	0.003	0.003	0.004	0.003
t1:8		NO <sub>3</sub> <sup>-</sup> (mg/l)	1.488	0.248	0.248	0.496	0.186	0.186	0.186	0.248
t1:9		N (mg/l)	0.335	0.056	0.056	0.116	0.042	0.042	0.056	0.042
Q6 t1:10		ΣN (mg/l)	0.349	0.070	0.07	0.788	0.056	0.056	0.070	0.056
t1:11		PO <sub>4</sub> <sup>3-</sup> (mmol/l)	0.001	0.002	0.002	0.004	0.002	0.001	0.001	0.001
t1:12		PO <sub>4</sub> <sup>3-</sup> (mg/l)	0.095	0.190	0.190	0.380	0.190	0.095	0.19	0.095
t1:13		P mg/l	0.031	0.062	0.062	0.124	0.062	0.031	0.062	0.031
t1:14	Winter	NH <sub>4</sub> <sup>+</sup> (mmol/l)	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001
t1:15		NH <sub>4</sub> <sup>+</sup> (mg/l)	0.018	0.018	0.018	0.018	0.018	0.018	0.036	0.018
t1:16		N (mg/l)	0.014	0.014	0.014	0.014	0.014	0.014	0.028	0.014
t1:17		NO <sub>3</sub> <sup>-</sup> (mmol/l)	0.002	0.001	0.005	0.004	0.003	0.004	0.008	0.006
t1:18		NO <sub>3</sub> <sup>-</sup> (mg/l)	0.124	0.062	0.31	0.248	0.186	0.248	0.496	0.372
t1:19		N (mg/l)	0.028	0.014	0.070	0.060	0.042	0.056	0.011	0.084
t1:20		ΣN (mg/l)	0.042	0.028	0.084	0.074	0.056	0.070	0.039	0.168
t1:21		PO <sub>4</sub> <sup>3-</sup> (mmol/l)	0.002	0.002	0.001	0.002	0.001	0.002	0.002	0.001
t1:22		PO <sub>4</sub> <sup>3-</sup> (mg/l)	0.190	0.190	0.095	0.190	0.095	0.190	0.190	0.095
t1:23		P (mg/l)	0.062	0.062	0.031	0.062	0.031	0.062	0.062	0.031

The NO<sub>2</sub> molecules were counted with the NO<sub>3</sub> 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

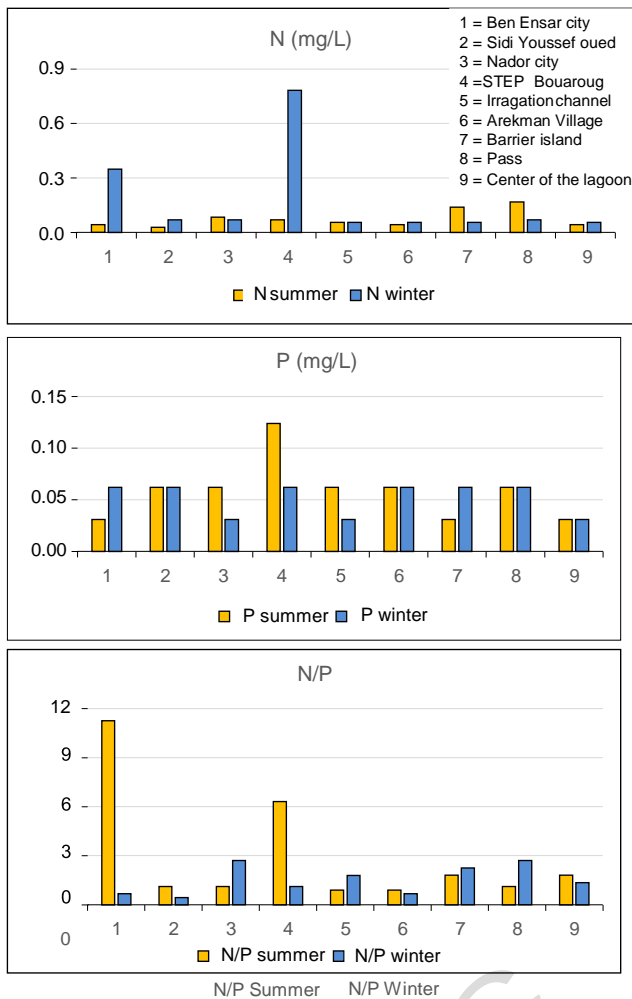


Fig. 2 Concentrations in mg/l of the analysed nutrients and the related N/P ratio into the waters of the Nador lagoon

237 Eutrophication is commonly visualized by the N/P ratio  
 238 called the Redfield ratio. It describes the overall composition  
 239 of C, N, and P at respective concentrations of 106:16:1 in phy-  
 240 toplankton (Finnveden and Potting 1999). In other words, 106  
 241 moles of C and 16 moles of N are consumed while 172 atoms  
 242 of O are produced for 1 mole of used P in the photosynthesis.  
 243 According to this ratio, 1 mole of N emitted produces 6.6 moles  
 244 organic C in the biomass, whereas the corresponding amount is  
 245 as much as 106 moles in the case of P. If algae growth is  
 246 optimal in an aquatic environment, the N/P ratio is equal to  
 247 16, while P is the limiting factor of the algae growth for an  
 248 N/P ratio above 16 and, alternatively, nitrogen is the limiting  
 249 factor for an N/P ratio below 16. Here, the N/P ratio is system-  
 250 atically lower than 16 wherever the sampling site, which indi-  
 251 cates that N is the systematic limiting factor and is the higher  
 252 contributor to the eutrophication (Fig. 3). Especially, NO<sub>3</sub><sup>-</sup> has a  
 253 high rate in winter due to its leaching from catchment area and  
 254 some releases from lagoon sediments. (Mostarih et al. 2016).  
 255 The N/P ratio is higher in summer, in the confined area of the  
 256 Beni-Ensar city and near the outlet of the wastewater plant of  
 257 Bouaroug due to urban releases and N fertilizers used in the

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

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

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

### 287 Calculation of the aquatic eutrophication potential by 288 the Life Cycle Impact Assessment method

289 The LCIA method is routinely used in the industry for the  
 290 study of environmental impacts during a production cycle—  
 291 from cradle to grave (ISO 14040, ISO 14044, 2006). It is  
 292 based on the calculation of impact category indicators like  
 293 acidification, global warming, and eutrophication, by using  
 294 equivalent factors that indicate how much a substance contrib-  
 295 utes to a problem compared to a reference substance (Jensen  
 296 et al., 1997; Guinée, 2001; Rebitzer et al., 2004). In an original  
 297 application to natural environments, such as lagoons, Hadj  
 298 et al. (2008) have shown that the lagoon waters are variably  
 299 polluted by releases of water treatment plants, creeks, solid  
 300 waste deposits, and agricultural activities. Seppälä et al.  
 301 (2004) evaluated the eutrophication impact caused by an an-  
 302 thropogenic system A within a region as:

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

303 where  $I_{EU}$  (A) is the impact value of aquatic eutrophication  
 304 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

$$C_{j,i} = \eta_{j,i}(A) \cdot \mu_{j,i}(A) \cdot Eqv_j$$

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  $Eqv_j$  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)).

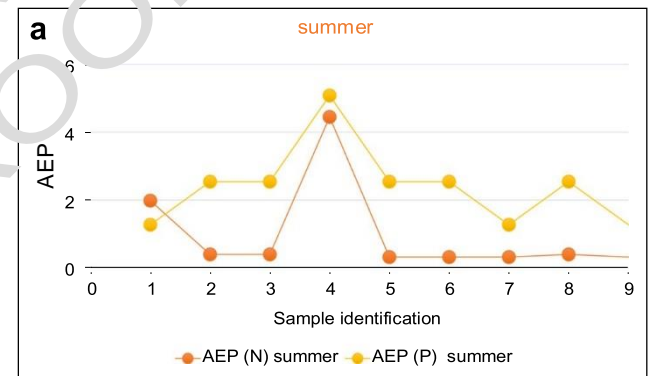
333 Concerning the eutrophication impact, the LCIA method  
 334 uses the Redfield ratio for the characterization factors of con-  
 335 taminant emissions. The basic approach to characterize differ-  
 336 ent emissions of pollutants or nutrients is:  
 337

$$AEP = \sum_i E P_i \times M_i$$

338 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  $E P_i$  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



1 = Ben Ensar city      4 = STEP Bouaroug      7 = Barrier island  
 2 = Sidi Youssef oued      5 = Irrigation channel      8 = Pass  
 3 = Nador city      6 = Khariat Arekman city      9 = Center of the lagoon

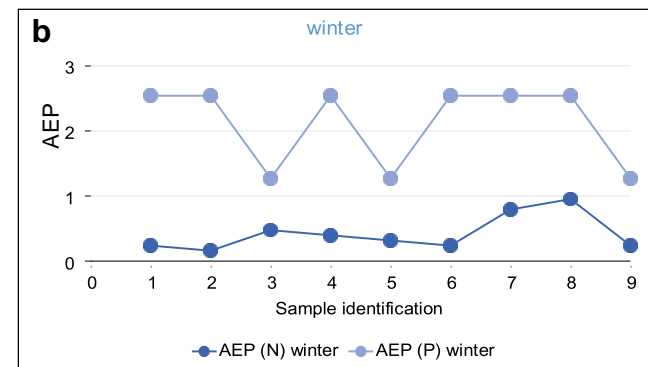


Fig. 3 a, b Comparison of AEP (N) vs. AEP (P) values for the waters of Nador lagoon. (1) Ben Ensar city. (2) Sidi Youssef oued. (3) Nador city. (4) STEP Bouaroug. (5) Irrigation channel. (6) Arekman village. (7) Barrier island. (8) Pass. (9) Centre of the lagoon

350 the “limiting factor” as an abnormally high anthropogenic  
 351 input of P in waters induces a lack of N. In this case, the  
 352 cyanobacteria proliferate in fixing atmospheric N to compen-  
 353 sate this lack of N, which is recycled in the aquatic environ-  
 354 ment. On a limited scale of time and space, N may appear as  
 355 the limiting factor and consequently it may hide the fact that P  
 356 is the true limiting factor at a global scale (Barroin 2003). This  
 357 is why the P and N compounds, which are the most important  
 358 factors for limiting the growth rate of aquatic plants, are taken  
 359 into account in the case of aquatic eutrophication (SETAC,  
 360 2002).

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

377 In winter, no analysis outlines a high AEP (P) compared to  
 378 an average score of 2.5, the lowest value being 1.27 in the  
 379 centre of the lagoon (location 9). This score is obtained for the  
 380 water sample collected at the exit of the irrigation canal (locat-  
 381 ion 5) and near the city of Nador (location 3). No realistic  
 382 explanation can be suggested as to the value of these three  
 383 locations. The average AEP (N) in summer being 0.3, the  
 384 results of three locations fall out: the wastewater treatment  
 385 plant of Bouaroug (location 4) with a score of 4.4 and the city  
 386 of Beni Ensar (location 1) with a score of 1.98. The first value  
 387 relates to the discharge of urban water and the other to the  
 388 local confined area. In winter, the AEP (N) scores are between  
 389 0.15 and 0.47, with only two results outside: the barrier island  
 390 (location 7) and the pass (location 8) with scores of 0.79 and  
 391 0.95, respectively, that indicate a source of N compounds  
 392 from marine waters or from re-suspension of the sediments  
 393 of the barrier island.

## 394 Conclusions

395 Waters from Nador lagoon, as well as waters from Slimane-El  
 396 Maleh lagoon in Tunisia, show the potential of using the Life  
 397 Cycle Impact Assessment in the case of an ecosystem under-  
 398 going eutrophic pressures. In the case of the Nador lagoon  
 399 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 var-  
 iations in concentrations of the nitrogen and phosphorus com-  
 pounds 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 concentra-  
 tions that are about 2 times higher than the average concen-  
 trations 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 ex-  
 cessive phosphorus inputs. Several options for reducing the  
 risk of eutrophication can be suggested: a systematic monitor-  
 ing of the urban discharges with the construction of a waste-  
 water plant for the population of the Beni Ensar city, phos-  
 phorus removal of the existing station or extension of its treat-  
 ment 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.

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