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The impact of industrial pollution on the ecosystem of Réghaia Lake (Algeria)

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ABSTRACT

This study lies within the framework of the anti-pollution action plan of Réghaia Lake. This lake, partially fed by the ground water of Mitidja, is regarded as an area of international importance because it is the last vestige of Mitidja. It is currently the only wetland in the biogeographic area of Algiers, thus making it a stopover for migratory birds after their crossing of the Mediterranean. The area is characterized by a great diversity of flora and fauna, and a large variety of ecosystems. Réghaia Lake has a considerable wealth of flora estimated at about 233 listed plant species: the equivalent of 13% of the North Algerian flora. The area is also home to four species of rare birds, three of which are classified as threatened on the red list of the IUCN. Because of this diversity, it was registered on the Ramsar list in November 2002 during the eighth meeting of the Conference of the Contracting Parties to the Ramsar Convention in Valencia, Spain. The lake, which has a surface area of 75 ha, is also variously polluted both by urban and industrial wastewater coming from the towns of Rouiba and Réghaia (heavily industrial areas), and by water traversing farmlands and causing the leaching of fertilizers and pesticides. The water pollution evaluation was carried out using physicochemical parameters to identify the nature of the pollutants and to measure the levels of pollution. The enrichment of nutrients in the lake water promotes changes such as increased production of algae, increased growth of macrophytes, and the degradation of water quality. This eutrophication causes the disappearance of susceptible species and the spectacular development of resistant species in their place. Pollution was thus detectable by measuring the levels of these resistant species, and the lake water appeared to be of very bad quality. Given the rate at which wastewater is discharged into the lake, the effect of dilution would not be enough to maintain the physico-chemical and biological pseudo-balance of the lake. The aim of this study is to determine the effects of this pollution on the ecosystem and to highlight the pollution bioindicators with a view to restoring the lake by ecobiological means.

Keywords: Environment; Water; Pollution; Biodiversity

1. Introduction

This study falls within the ''anti-pollution action framework'' of Réghaia Lake, which is partially fed by the ground water of Mitidja.

As a natural water resource, Réghaia Lake is used in various ways:

- There is a hunting center located on one of its shores.
- There is a water pumping station used for irrigation of agricultural land.

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- In addition, the lake is polluted both by urban and industrial wastewater coming from the towns of Rouiba and Réghaia (heavily industrial areas), and by water traversing farmlands and causing the leaching of fertilizers and pesticides.
- Many studies, mainly carried out in the upstream part of the lake, showed that the lake exceeded acceptable pollution levels. The strong pollutants cannot be solely attributed to the detergent factory. They are also due to the discharge of urban and industrial wastewater. The levels of phosphate measured in the lake exceed the usual standards and indicate a rapid decline of the ecosystem towards eutrophication [1].
- The objectives of this study are to determine the impact of pollution on the ecosystem, in particular the changes in the vegetation, and to draw attention to the bioindicators of pollution.

2. Framework

- The Réghaia Lake area, a natural reserve, registered on the Ramsar list in November 2002 during the eighth meeting of the Conference of the Contracting Parties to the Ramsar Convention in Valencia, Spain, is located approximately 30 km from Algiers on the east coast of Algeria [2].
- The area corresponds to the estuary of the Réghaia Wadi, the mouth of which is blocked by a sand ridge; this ridge is supplemented, some 600 m downstream, by an artificial dam which retains the permanent lake. The surface area of the lake is 75 ha [3].
- The reserve, covering an area of about 842 ha in total, is classified as being biogeographically comparable to the following areas of Algeria:
- The Mediterranean region
- The Maghreb–Mediterranean area
- The Algiers sector
- The coast sub-sector

The area not only contains a water reservoir, but is also a remarkable reservoir of biodiversity; it contains an array of fauna and flora, composed of more than 230 species of sedentary birds and 233 species of plants [4,5].

The lake, a direct receptacle of industrial and agricultural discharges, receives around 80,000 m^3 of water per day.

The concentrations of pollutants, as a result of the miscellaneous discharges (industrial, urban and agricultural), have exceeded international standards [6].

3. Methodology

3.1. Taking monthly water samples from the lake (Table 1)

Our method focused on two forms of sampling:

Table 1
Sampling points

Stations	Location
Station I	– Located in the upstream part of the lake close to the wastewater discharges – 1 m of depth – Sample taken from surface
Station II	– Located at the center of the lake – 6 m of depth – 3 intake points: • On the surface • at depth of 3 m • at depth of 6 m
Station III	– Located in the downstream part of the lake near the dam. – 1 m of depth – Sample taken from surface

1. One with a gradient from the upstream to the downstream part of the lake.
2. The other follows a gradient of depth, with samples taken on the surface, the middle and the bottom of the lake.

Twice monthly during the festival (summer) period.

- The physical parameters measured are temperature, pH, conductivity, M.E.S. and turbidity.
- The chemical analyses related to bicarbonates, calcium, magnesium, sodium, potassium, chloride, sulphate, nitrate, phosphate, and ammonium.
- The criteria for organic pollution are determined as dissolved oxygen, organic matter and chemical oxygen demand (COD).
- The toxic metal elements analyzed are heavy metals (Fe, Mn, Cu, Zn, Cd) and toxic chemical substances contained in water.

3.2. Sampling of the vegetation of Réghaia Lake

The aim of this study is to show the impact of the pollution of the lake system on vegetation. We recorded the types of vegetation found every 200 m, along a gradient of pollution, from the upstream part of the lake to the dam, along the two banks of the lake. The points where these recordings were made correspond to the water sampling points.

At each station, two recordings were made: one carried out at water level at the edge of the lake, and the other further up the bank. For the recordings we adopted the design of GOUNOT [7], according to which ‘‘the site of the recording is subjectively selected, so that it is homogeneous and representative of a unit

Table 2
Results of the analyses of water in May

Analyzed elements	Station I (upstream)	Station II On the surface	(center of At a depth of 3m	lake) At a depth of 6m	Station III (downstream)
Water temp (°C)	24	24	22	23	24
Dissolved O_2 (mg/l)	2.00	2.60	1.90	2.20	2.00
pH	8.14	8.10	8.20	8.10	8.10
Cond (ms/cm)	1.95	1.96	1.94	1.96	1.94
Turbidity NTU	5.59	3.90	4.05	5.67	3.73
Raw water	3.63	3.27	3.50	4.44	3.24
Decanted water					
M.E.S. (mg/l)	349	353	349	353	349
Ca^{2+} (mg/l)	102	104	–	104	103
Mg^{2+} (mg/l)	53	55	–	53	52
Na^{+} (mg/l)	208	210	–	212	208
K^{+} (mg/l)	13.00	12.51	–	12.05	10.94
Cl^{-} (mg/l)	340	338	–	341	331
SO_4^{2-} (mg/l)	140	150	–	160	141
HCO_3^{-} (mg/l)	433	412	–	413	415
NO_3^{-} (mg/l)	0.00	0.00	–	0.00	0.00
NO_2^{-} (mg/l)	0.00	0.00	–	0.00	0.00
O. Matter (mg/l)	20.80	16.00	–	20.00	18.40
PO_4^{3-} (mg/l)	6.07	5.82	–	4.87	5.94
NH_4^{+} (mg/l)	1.94	1.95	–	1.94	1.96
COD (mg/l)	47	–	–	53	39.50
BOD_5 (mg/l)	5.50	4.50	–	2.50	5.50
N Kjeldahl (mg/l)	50.25	51.95	–	52.55	50.35
N NH_4 (mg/l)	48.05	49.65	–	47.10	42.10
Toxicity	N toxic	N toxic	N toxic	N toxic	N toxic
Fer (mg/l)	0.093	0.090	–	0.099	0.090
Mn (mg/l)	0.227	0.234	–	0.239	0.229
Zn (mg/l)	0.023	0.014	–	0.126	0.01
Cd (mg/l)	0.00	0.005	–	0.007	0.001
Cr (mg/l)	0.00	0.00	–	0.00	0.00

of vegetation''. Sampling was carried out in May. Samples of plant species were crushed, mineralized and analyzed to evaluate the accumulation of various elements in the leaves.

4. Results and discussion

4.1. Water analyses

Table 2 shows the results of the analyses of lake water samples taken in May 2005.

The lake water has very low levels of dissolved oxygen, which must have adverse effects on the functioning of the lake's ecosystem. These results are also characteristic of a large consumption of dissolved oxygen, and are therefore indicative of the presence of organic pollution in the waters of the lake.

According to the results, the water temperature of Réghaia Lake is highly variable; it is less than 16°C in winter, reaches 19°C in the spring and rises to 24°C in May. A temperature higher than 15°C promotes the development of microorganisms and may also intensify odors and taste [8]. This phenomenon is indeed encountered at Réghaia Lake in May.

We note that the pH of the water is close to neutral, indicating that the lake is an enabling environment for the development of living organisms.

The maximum values of conductivity are observed in the month of May; this is due to the increase in temperature which fosters the mobilization of ions.

The suspended solids from the effluent are driven by the flow of water into the depths of the lake. This is what is happening at station II, located at the center of the lake, where the level of suspended solids at a depth of 6 m reached 353 mg/l, and this is verified by the turbidity levels.

The results show that there is a significant accumulation of bicarbonates at the sampling stations (412–433 mg/l), with slightly higher levels at increased depth. The high values can be explained by the dissolution of limestone soil during heavy rains.

The waters of the lake are rich in calcium and magnesium (104 and 13 mg/l) because of the geological nature of land crossed by rivers and also due to waste from industrial sources.

The levels of sodium and potassium (212 and 13 mg/l) in the waters of Réghaia Lake are high. The sodium comes from the leaching of geological formations containing sodium chloride, the decomposition of minerals such as sodium silicate and aluminium, and the seepage of salt water into groundwater, but also from various industrial processes (soda industry). Potassium pollution is from the extractive industries of potash salt nearby.

The high levels of chloride (331–341 mg/l) are due to a combination of leaching during heavy rains, and domestic and industrial wastewater.

Sulphate is also present in substantial quantities (140–160 mg/l), and this comes from detergent factories, and from tanning and metal workshops.

We note that the quantity of organic matter is greater at depth than at the surface, because the organic matter from the effluent is conveyed by deep drainage. There is a high COD. The COD/BOD5 ratio provides information on the biodegradability of organic matter, and the increased ratio reflects the increase in the proportion of non-biodegradable organic matter [9].

The gap between COD and BOD allows us to assess pollutants that are not biodegradable due to their structure or because of an inhibitory effect.

COD/BOD5 < 2: indicates domestic wastewater which is easily degradable.

COD/BOD5 > 2: indicates industrial wastewater which is not easily degradable.

In Réghaia Lake, the results showed that the COD/BOD ratio is very high, and this confirms the presence of a large proportion of non-biodegradable organic matter.

There is an absence of nitrite during the warm period. A lack of dissolved oxygen causes the deoxygenation of nitrate; however, we note also the lack of nitrate during the warm period.

In the upstream part of the lake, ammonium is found in especially high quantities during the hot period, due to the organic matter present in the wastewater discharges. The level of nitrogen is very high at all the stations and for all the samples taken. This is due to the lack of dissolved oxygen at the center of the lake.

There is an ongoing accumulation of phosphate as a result of its presence in urban wastewater discharges and in discharges from the industrial detergent plant.

These results may have adverse effects on the lake ecosystem. Phosphate, which is a nutrient, encourages the overproduction of algae, and later breaks down using oxygen from the center of the lake and is responsible for bad smells and the eutrophication of lakes [10].

Table 3
ANRH matrix of water quality parameters

Classes of water quality	Good	Average	Poor	Very bad
Mineral matter				
Calcium (mg/l)	<100	100–200	200–300	>300
Magnesium (mg/l)	<30	30–100	100–150	>150
Sodium (mg/l)	<100	100–200	200–500	>500
Chloride (mg/l)	<150	150–300	300–500	>500
Sulphate (mg/l)	<200	200–00	300–400	>400
Organic matter and oxidizable matter				
Dissolved oxygen (mg/l)	>07	07–05	05–03	≤03
Chemical oxygen demand (mg/l)	<20	20–40	40–50	>50
Organic matter (mg/l)	<05	05–10	10–15	>15
Nitrogen and phosphate				
Ammonium (mg/l)	<0,01	0.01–0.1	0.1–03	>03
Nitrite (mg/l)	<0,01	0.01–0.1	0.1–03	>03
Nitrate (mg/l)	<10	10—20	20–40	>40
Phosphate (mg/l)	<0,01	0.01—0.1	0.1–03	>03
N Kjeldahl (mg/l)	<02	02–03	03–10	>10

The analyses showed the absence of heavy metals and toxic elements at the various sampling stations.

To determine the water quality of Réghaia Lake, we tried to classify the results of the analyses by comparison with the grid proposed by the ANRH (National Agency of Water Resources) [11] (Table 3).

Classes of water quality:

- Class I: water of good quality used without special treatment.
- Class II: water of average quality used after a single treatment.
- Class III: poor quality water can be used only after a very thorough treatment.
- Class IV: very poor quality water, excessively polluted, can be used only after specific treatments.

Taking into account some criteria indicative of pollution: organic matter, dissolved oxygen, nitrogen and phosphate, we conclude that the waters of Réghaia Lake are of very poor quality and may be used only after a specific treatment.

4.2. Identification of the vegetation

Table 4 gives a description of the vegetation found on the left bank of the lake. Sampling carried out at water level at the edge of the lake showed the existence

Table 4
List of species found in the various vegetation formations

Place of sampling	Station 1	Station 2	Station 3
Description	Dense mixed formation of *Typha latifolia* and *Tamarix africana*	Dense artificial forest of *Casuarina* sp	Dense growth of *Juncus acutus* and *Typha angustifolia*
Samples taken at water level at the edge of the lake	*Typha latifolia* *Tamarix africana* *Polygonum salicifolium* *Ranunculus muricatus* *Plantago coronopus* *Phragmites communis* *Hirschfeldia incana* *Polypogon monspeliensis* *Rumex pulcher* *Lytrum junceum* *Ranunculus macrophyllus* *Bromus hordaceus* *Scrofularia canina* *Lolium multiflorum* *Poa trivialis* *Hordeum murinum* *Geranium dissectum*	*Casuarina* sp *Typha angustifolia* *Tamarix africana*	*Juncus acutus* *Typha angustifolia* *Plantago coronopus* *Polygonum salicifolium* *Ferula communis* *Trifolium palidum* *Cichorium intybus* *Melilotus infesta* *Bromus hordaceus* *Hordeum murinum* *Polypogon monspeliensis* *Anthemis maritima* *Lytrum junceum* *Rumex pulcher* *Centaurea calcitrapa* *Lolium multiflorum* *Trifolium resupinatum* *Eryngium campestre*
Description	Very dense matorral of *Olea europaea* and *Phragmites communis*	Dense mattoral of *Olea europaea* and *Phragmites communis*	Dense mattoral of *Pistacia lentiscus* and *Olea europaea*
	Olea europaea *Phragmites communis* *Scilla lingulata* *Galactites tomentosa* *Asphodelus microcarpus* *Chamaerops humilis* *Ferula communis* *Oxalis cernua* *Plantago coronopus* *Reichardia picroides* *Convolvulus althaeoides* *Ranunculus macrophillus* *Hedysarum flexuosum* *Lythrum junceum* *Anagallis arvensis* *Stachys ocymastrum* *Lavatera trimestris* *Bromus hordaceus* *Torilis nodosa*	*Olea europaea* *Phragmites communis* *Ferula communis* *Scilla lingulata* *Asparagus acutifolius* *Asphodelus microcarpus* *Trifolium compestre* *Borago officinalis* *Geranium robertianum* *Galactites tomentosa* *Echium confusum* *Solanum nigrum* *Eryngium campestre* *Stachys osymastrum* *Euphorbia terracina* *Ononis monophylla* *Sinapis arvensis* *Scolymus grandiflorus* *Bromus macrostachys*	*Pistacia lentiscus* *Olea europaea* *Chamaerops humilis* *Ferula communis* *Asphodelus microcarpus* *Rhamnus alaternus* *Smilax aspera* *Convolvulus althaeoides* *Galactites tomentosa* *Asparagus acutifolius* *Pallenis spinosa* *Plantago coronopus* *Dactylis glomerata* *Rubia peregrina* *Carthamus lanatus* *Trifolium campestre* *Torilis nodosa* *Euphorbia peplus* *Eryngium campestre*

of different communities of plants, some of which recur; also, the domination of one group of species that likewise recurs, *Phragmites communis*, *Iris pseudacorus* and *Tamarix africana*.

Sampling carried out further up the bank showed the existence of several formations, matorral and maquis, which are frequently accessed. These formations have a dominant species such as *Olea europaea, Pistacia lentiscus* and *Phyllirea angustifolia.*

They present a predominance of species such *Olea europaea*, *Pistacia lentiscus* and *Phyllirea angustifolia*.

4.3. Results of the chemical analyses of the vegetation

By comparing the percentages of the nutritive elements in all the species on the banks with those of the maquis, one notices that the species *Typha latifolia*, *Iris pseudacorus*, *Juncus acutus*, *Phragmites communis* and

Arundo donax have a biocapacity for accumulation of certain nutritive elements, with the result that these macrophytes resist extreme organic pollution.

Indeed, we note that the percentages of chloride are very high in all the species, with higher values upstream as compared to downstream, and reaching 73.33% in *Iris pseudacorus* and 61.07% in *Arundo donax*. This confirms that the chloride comes not only from the infiltration of sea waters, but also from industrial waste.

The percentage of sulphate reaches 41.5% (*Iris pseudacorus*). It is usually of industrial origin (detergents), and also comes from the decomposition of organic matter.

By comparing the species, we note that *Iris pseudacorus* is the species which generally concentrates the most nutritive elements (73.33% chloride, 5.7% phosphate). Its presence along the upstream part of the lake, close to the wastewater discharges (station 1), proves its resistance to the strong concentrations of pollutants.

The percentage of nitrogen reaches 4.56% in the roots of *Juncus acutus* (station 1).

The percentage of sulphate reaches 50.5% in the roots of *Phragmites communis* (station1).

We can thus conclude that each species has a preference with respect to certain pollutants because of the specificity of the species.

5. Conclusion

Quantifying the water pollution of Réghaia Lake with physicochemical parameters enabled us to identify the nature of the pollutants and the intensity of pollution.

The lake water proved to be of very bad quality. The lake contains large quantities of suspended matter, which prevents the penetration of light.

The decomposition of organic matter will result in decreased levels of dissolved oxygen, and this allows for colonization by species demanding little oxygen.

The enrichment of the water with nutritive matters involves changes such as a higher production of algae and macrophytes, and the deterioration of the water quality.

This eutrophication caused the loss of vulnerable species and the spectacular development of species which are more resistant and which occupy the space left available. The macrophytes existing at water level at the edge of the lake (*Phragmites communis*, *Arundo donax*, *Typha latifolia*, *Juncus acutus* and *Iris pseudacorus*) play an important part in dealing with the excess of organic matter. They are able to absorb and concentrate large quantities of nutrients through having a preference with respect to certain elements.

These species are bioindicators and also serve to purify water; they are used in water treatment because they are tolerant of extreme chemical conditions.

The water of Réghaia Lake is of very bad quality and the degradation of the ecosystem is increasing. It requires a purification which can avoid the irreversible pollution of the water.

To resolve it, we propose the restoration of the lake using a water treatment. Firstly, we propose a primary purification in the upstream part of the lake which is regarded as a natural filtration of wastewater, thanks to the combined action of bacterial supports and watery plants.

As a secondary purification, we propose a biological treatment on bacterial beds which transform the polluting organic matter into stable mineral matter (nitrate, phosphate, carbonate), and also agitation and ventilation of the water, as the problems observed within the lake are related to a lack of oxygen.

A tertiary purification will relate to the fixing and accumulation of the nutritive elements using macrophytes; the most commonly used variety is the *Phragmites communis* because of its speed of growth, its root development and its resistance to conditions of ground saturation. The planting can be done using seeds, young plants or rhizomes. Regular checks of the water quality and the vegetation are essential in order to detect any developments, to check the effectiveness of this treatment, and to be able to take any measures necessary to the optimization of management.

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