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RESEARCH ARTICLE

Spatio-temporal nutrients variability in the Oualidia lagoon (Atlantic Moroccan coast)

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Abstract

This work focuses on the water column biogeochemical cycle of the Oualidia lagoon (Moroccan Atlantic coast). The study of the biogeochemical cycle requires the evaluation of nutrients distribution, the factors controlling this process and their influence on different compartments of the lagoon environment. Water samples were collected fortnightly from March 2011 to August 2011, at six stations distributed throughout Oualidia lagoon. The physico-chemical parameters measured (temperature, salinity, dissolved oxygen) and nutrients (orthophosphate, nitrite and ammonium) showed seasonal and spatial variation with a gradient between upstream and downstream of the lagoon: diminution of the temperature, dissolved oxygen, nitrite, orthophosphate and ammonium and augmentation of the salinity throughout the lagoon. The highest nutrient values (NH_4^+ = 76.87 µmol.l^{-1} to station S4, PO_4^{3-} = 89.38 µmol.l^{-1} to station S4, NO_2^- = 17.74 µmol.l^{-1} to station S5) are generally from the middle to the upstream of the lagoon. Inversely the lowest values (NH_4^+ = 0.31 µmol.l^{-1} to station S1, PO_4^{3-} = 0.10 µmol.l^{-1} to station S1, NO_2^- = 0.03 µmol.l^{-1} to station S1) are located downstream, where the dilution of nutrient-rich originating in upstream (continental and vegetable crops inputs) are diluted by the high penetration of marine waters.

Introduction

The lagoons are ecosystems located between land and ocean. The hydrodynamics and water chemistry resulting from the confrontation between water masses of different origins and chemical compositions are an essential part of the ecology of the lagoon. They are directly intervening in the species composition, structure and spatio-temporal distribution of biodiversity but also on the dynamics of population (migration, rate of reproduction, growth).

Understanding how these productive but fragile ecosystems work, can help to reduce existing constraints on their living resources (Villanueva et al., 2004). Indeed, by their natural geomorphological features, lagoons are water bodies often confined, poorly renewed and therefore naturally vulnerable; their balance may be changing rapidly under the influence of natural and anthropogenic factors Kouassi et al. (2005).

Over three decades, the urban development and population growth are the most obvious features of the Moroccan cities along the Atlantic coast, included the development of the sea fronts for coastal cities.

Oualidia town is one of those cities, which attracts tourists and visitors. These strong interaction adverse effects on the marine environments were accompanied by solid and nonsolid wastes, which reach the lagoon. The most important of those, ground waters mixed with untreated sewage which find its way to the lagoon.

The exchange of water between the lagoon and the open ocean is very complex, which might be due to the waves break near the entrance. The lagoon was chosen because it is one of most vital sites in the Moroccan Atlantic coast, surrounded by many human recreational activities, and it also receives groundwater mixed with an incomplete treated sewage from the effluent discharge point on coastal waters of Oualidia.

The Oualidia lagoon is situated between El Jadida and Safi, this lagoon is one of the Moroccan sites where the oyster aquaculture has been developed in an artisanal way since 1950. Given the importance of the lagoon on the economy and tourism plans, a better understanding of how this ecosystem works is necessary to improve and streamline the management of aquatic resources of this site.

Several studies have been conducted in Oualidia lagoon, biology (Beaubrun, 1976; Chbicheb, 1996), hydrology (Orbi et al, 1998. Rharbi et al, 2001), Geology (Carruesco 1989; Fakir 2001), sedimentology Sarf, (1999), quality and safety (Bennouna, 1999; Shafik et al, 1996; El Attar, 1998) and currentology (Hilmi et al., 2005). However, the biogeochemical cycles of the lagoon have not been the subject direct studies. The results of this study are important to complete our knowledge about the richness of the nutrients in an unstudied area of the Moroccan Atlantic coast.

The objectives of this study were to define the distribution of biogeochemical parameters in a surface water of Oualidia lagoon subject to combined oceanic, terrigeneous and anthropogenic influences. To propose a simplified typology of lagoon waters and to assess the magnitude of temporal variability of water biogeochemical parameters at space and time-scales. This aspect has rarely been investigated despite the major constraints it exerts on the implementation of environmental surveys.

Materials and methods

a. Study site

Covering an area of $4km^2$, with a length of 7km, (32 ° 46'N, 09 ° 01'W) Oualidia Lagoon is located on the Atlantic Ocean, between El Jadida and Safi north south (Fig. 1). The lagoon opens to the Atlantic Ocean by two passes (first field). A main (150 m wide), permanent and active throughout the year, and active secondary pass (50 m wide), only tidal period of spring tides Carruesco, (1989). It is subdivided in several part, all connected by a main channel with a maximum depth not exceed 5-6 m and secondary channels with a maximum depth between 1.0 to 1.5 m. An artificial dike in the north separates the lagoon of the salt marshes Carruesco, (1989).

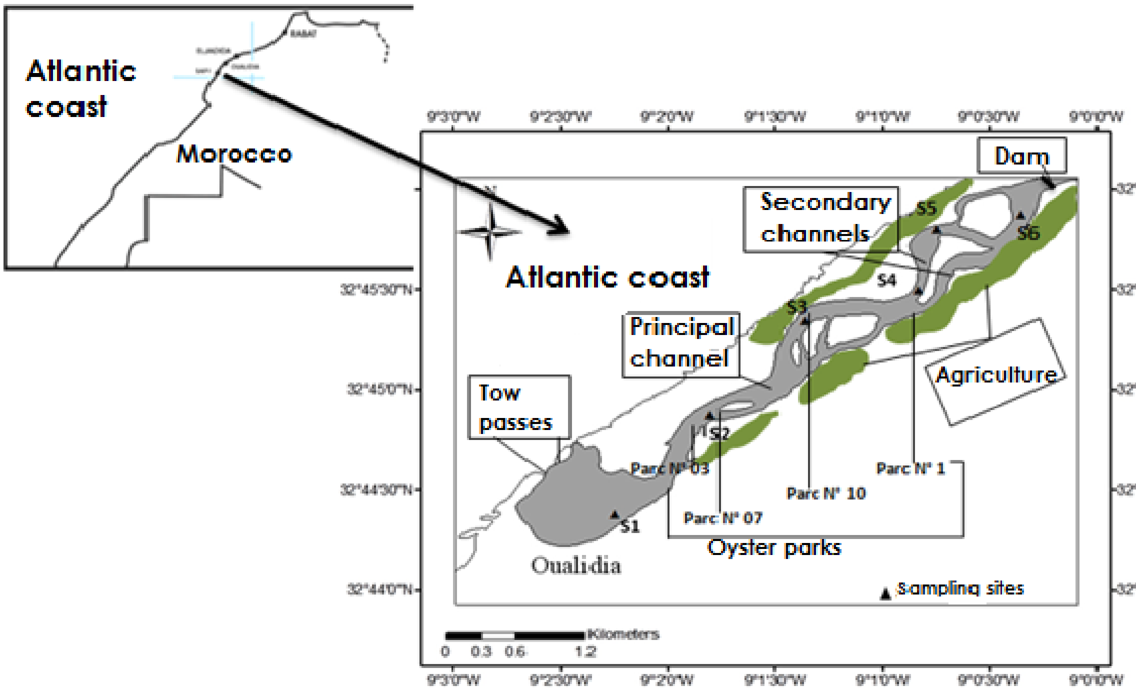


Figure 1: The geographical location of the Oualidia lagoon and sampling sites.

b. Sampling

Surface water samples were fortnightly collected from six stations (S1, S6) (Fig. 1) (Table-1), The sampling stations were selected to enable us to meet the objective of our study, taking into account a number of elements including: accessibility, representativeness, variability of the distances to the pass (reference station (S1)) and the determination of the influence of different activities (oyster zone [(S2) (S3)], agriculture area [(S4), (S5), (S6)]). In-situ measurements and water samplings were carried out on the surface at high tide. Campaigns were carried out fortnightly, from March 2011 to August 2011.

Table 1: Geographical coordinates of samples mission from March to August 2011.

Geographic coordinates / **Study Area**	**Latitude (WGS)**	**Longitude (WGS)**
S1	32°44'22.282"N	9°2'14.907"W
S2	32°44'52.054"N	9°1'48.31"W
S3	32°45'20.162"N	9°1'21.526"W
S4	32°45'26.705"N	9°0'55.519"W
S5	32°45'47.65"N	9°0'44.863"W
S6	32°45'51.861"N	9°0'21.061"W

Temperature, dissolved oxygen and salinity were measured in-situ using calibrated multiparametric probes Multi340i (wtw82362 Weilheim). In all station triplicate water samples at the surface for nutrients were collected, with using a plastic bottles type PE-HD liter. All samples were then stored at 4°C, and were protected from light until arrival at the laboratory. Collected water was rapidly analyzed (not more than 48 h after the harvest).

c. Treatments of samples in the laboratory

In laboratory water samples were filtered using a Millipore system with fiberglass Whatman GF/C filters of 47 mm diameter. It is essential to eliminate any suspension matter susceptible to absorbing light in colorimetry and modify the chemical composition of the solution. The nutrient (ammonium, nitrite and orthophosphate) were determined by standard colorimetric approach using a spectrometer (BIOMATE 3) according to method (NF T90-013) (Afnor, 1983). Three replicate measurements were made for each nutrient.

d. Data analysis

Principal Component Analysis, PCA, (correlation-based transformed and normalized matrix) was performed using a set of environmental variables (all measurements taken throughout the study period) including: Water surface temperature (T°), dissolved oxygen (dis O_2), salinity (Sal), orthophosphate (PO_4), ammonium (NH_4) and nitrite (NO_2) concentrations. The factorial method of statistical analysis is used to summarize, describe and classify data. A correlation coefficient (r) is used to test and quantify the significance that unites the various parameters. This coefficient is considered insignificant when the value of the probability of significance (p) is greater than 0.05. All statistical analyzes were performed using SPSS (version 10 for Windows, SPSS, Chicago, IL, USA).

Results

The water surface temperature varied from 16 °C in S1 (downstream) in March and 25 °C in S6 (upstream) in May, with an average of 20.0 ± 2.4 °C (Fig. 2a). The decreased water temperature from upstream to downstream, following an 1.18 $°C.km^{-1}$ gradient. Salinity showed a seasonal trend varied from 22.5 $mg.l^{-1}$ in S6 in August and 35.9 $mg.l^{-1}$ in S1 in June (Fig. 2b); the average value was 33 $mg.l^{-1}$ (Table-2) and follows a decreasing gradient from downstream to upstream of the lagoon around 0.8 $mg.l^{-1}.km^{-1}$ (Tables-3).

The Oualidia lagoon waters is well oxygenated with a minimum in S4 (middle) (8.3 $mg.l^{-1}$ / 100.5%) during the summer, a maximum in S6 (upstream) (13.2 $mg.l^{-1}$ / 160.2%) in spring (Fig. 2c, Table-2); with 0.3 $mg.l^{-1}.km^{-1}$ gradient from downstream to upstream.

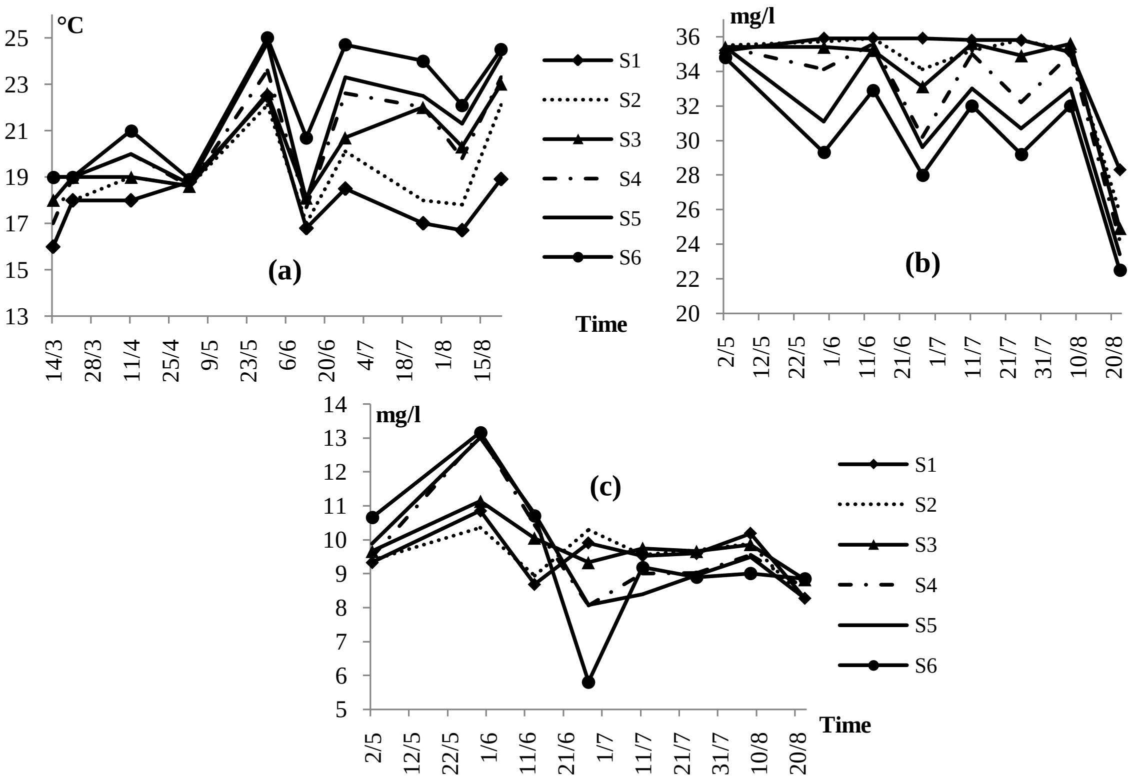
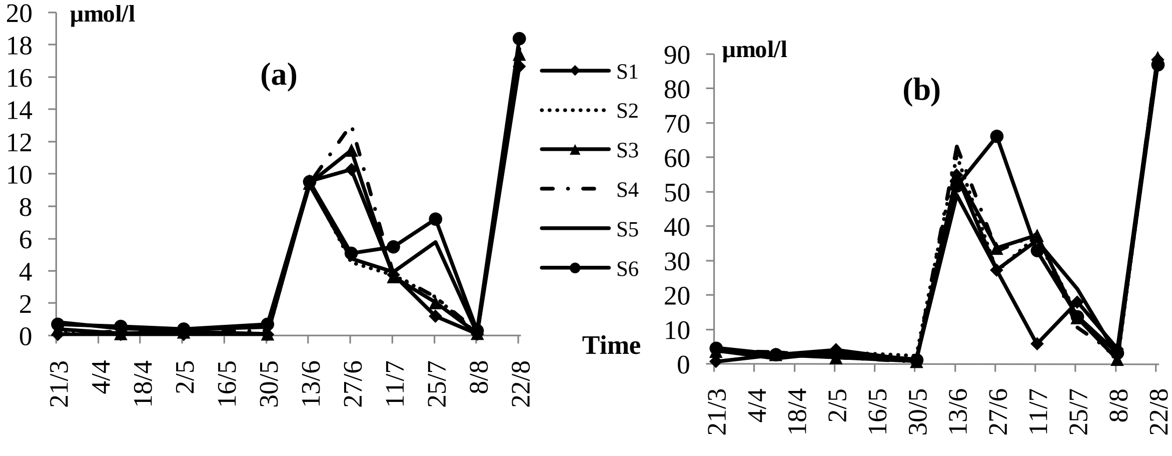


Figure 2: Fortnightly evolution of temperature (a), Salinity (b) and dissolved O2 (c), in the water column Oualidia lagoon at six sampling points (March-August 2011).

The nutrients variations have depending to the season and to the studied station (Table-2). Our results showed a significant increase in nitrite from June with a maximum in S6 (upstream) (18.3 µmol.l^{-1}) in August and a minimum in S1 (downstream) (0.02 µmol.l^{-1}) in March (Fig. 3a); the average was estimated at 5.52 µmol.l^{-1} (Table-2). A decreasing gradient from upstream to downstream (0.3 µmol.l^{-1}.km^{-1}) (Table-3).

The water orthophosphate concentration varied from a maximum (89.4 µmol.l^{-1}) in August in S4 (middle), and a minimum (0.1 µmol.l^{-1}) in May in S1 (downstream) (Fig. 3b); the average value was 26.8 µmol.l^{-1} (Table-2). A decreasing gradient from upstream to downstream following a 1.7 µmol.l^{-1}.km^{-1} (Table-3). The data revealed the highest ammonium level of (77 µmol.l^{-1}) was observed at S4 in August (Fig. 3c). The lowest value (0.125 µmol.l^{-1}) in S1 in May; with average was 18.32 µmol.l^{-1} (Table-2).



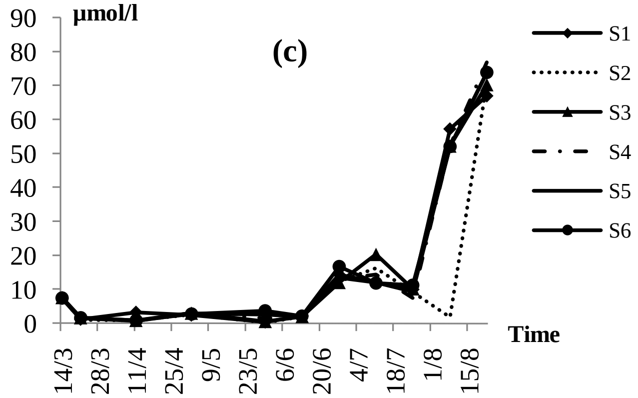
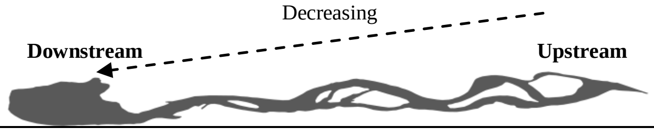
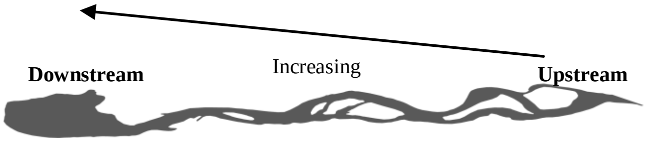


Figure 3: Evolution fortnightly evolution of nitrite (a), orthophosphate (b) and ammonium (c) from in the surface water of the Oualidia lagoon at six study sites (March-August 2011).

Table 2: Seasonal variation of physico-chemical parameters and nutrients characterizing the water surface of the Oualidia lagoon (Atlantic Coast, Morocco).

		Temperature (°C)	**Salinity (mg/l)**	**Dis O_2 (mg/l) (%)***	**PO_4 (µmol/l)**	**NO_2 (µmol/l)**	**NH_4 (µmol/l)**
Seasons	**Sites**	Mean ±C.I	Mean± C.I	Mean ±C.I	Mean ±C.I	Mean ±C.I	Mean ±C.I
Spring 2011	**S1**	**18.7±0.3**	**35.6±0.1**	**10.1±0.21 (105%)**	**2.166±0.171**	**0.065±nd**	**2.839±0.34**
	S2	**18.7±0.3**	**35.6±0.1**	**9.88±0.13 (109%)**	**2.865±0.125**	**0.13±0.018**	**2.725±0.342**
	S3	**19.4±0.2**	**35.4± nd**	**10.4±0.2 (116%)**	**2.604±0.156**	**0.215±0.01**	**3.063±0.328**
	S4	**19.6±0.3**	**34.8±0.2**	**11.3±0.5 (126%)**	**2.766±0.176**	**0.196±0.133**	**3.044±0.327**
	S5	**20.3±0.3**	**33.3±0.6**	**11.45±0.43 (130%)**	**2.903±0.159**	**0.518±0.297**	**2.756±0.343**
	S6	**20.6±0.3**	**32.1±0.8**	**11.92±0.35 (137%)**	**3.183±0.172**	**0.594±0.01**	**2.788±0.326**
Summer 2011	**S1**	**17.7±0.1**	**34.5±0.3**	**9.37±0.08 (100%)**	**33.187±3.684**	**6.927±0.716**	**27.146±3.108**
	S2	**18.9±0.2**	**33.7±0.4**	**9.44±0.08 (108%)**	**37.927±3.579**	**6.228±0.691**	**18.802±2.945**
	S3	**20.2±0.2**	**33.2±0.5**	**9.58±0.05 (104%)**	**38.318±3.505**	**7.361±0.74**	**27.566±3.093**
	S4	**20.8±0.2**	**32±0.5**	**9.11±0.09 (103%)**	**39.383±3.66**	**7.701±0.749**	**27.708±3.376**
	S5	**21.7±0.2**	**30.8±0.5**	**9±0.11 (104%)**	**37.211±3.228**	**6.938±0.683**	**26.93±3.293**
	S6	**23.1±0.2**	**29.4±0.4**	**8.75±0.18 (103%)**	**42.522±3.586**	**7.664±0.681**	**27.958±3.204**
Annual average		**19.7**	**33**	**9.24**	**26.8**	**5.52**	**18.32**

Table 3: Gradient variation of physico-chemical parameters and nutrients from the water surface of the Oualidia lagoon.

Parameters	**Gradient (upstream-downstream)** Oualidia lagoon
Temperature, Salinity, NO_2^-, NH_4^+, PO_4^{3-}, dissolved O_2 (in summer).	
Dissolved O_2 (in spring)	

Discussions

Our study defined the main features of the hydrological functioning of the Oualidia lagoon. The results of the correlation analysis showed an intra-station variability of hydrological parameters and nutrients is low.

The present study showed clearly that the lagoon dynamics mixed different water masses, preventing establishment of a vertical stratification and in the same way decreasing the upstream-downstream gradient. Unlike, the spatial variation, the measured parameters showed significant seasonal variation (Fig. 4), with the presence of two sub-groups; the first is the spring and the second represents in summer.

The Oualidia lagoon waters temperature values were relatively narrow with a seasonal average of about (15.3-24°C), these results are consistent with some previous studies (Natij et al., 2014; Bennouna, 1999; El Attar, 1998; Ouldessaib, 1997; Chbicheb, 1996). These values reflected the influence of the atmospheric temperature between 24 °C in summer and 12 °C in winter (Shafee et al. 1986), and the temperature of the ocean. This influence it was determined throughout the lagoon and especially at the passes that can be explained by an active hydrodynamics. Thus, at the Oualidia lagoon the renewal rate is 72% of the water column at each tidal cycle Carruesco, (1989). The temperature was negatively correlated significantly with salinity ($r = -0.721$, $p <0.01$) (Fig. 4). Indeed salinity variation at Oualidia lagoon can be explained by a homogeneous salinity rate during rising tides where the values are similar to those of the ocean. The freshwater input (28% of inputs of continental waters) permanently at the upstream zone clearly influenced the salinity general evolution. The salinity positively correlated with the dissolved oxygen ($r = 0.381$, $p <0.01$) (Fig. 4). The Oualidia lagoon waters salinity values were lower than those recorded in the Nador lagoon (Mediterranean), Damsiri et al. (2014) and (Table-4) which tends to sursalure its waters mainly due to a higher evaporation in some shallow areas (Bennouna, 1999). The analysis of dissolved oxygen at our study revealed a subdivision of the Oualidia lagoon into two distinct parts during spring, less oxygenated in downstream (S1, S2, S3) and a second part, more oxygenated in upstream (S4, S5, S6) (Fig. 2c) (Table-2). This distribution can be explained by the marine influence (downstream) where dissolved oxygen levels are similar to those found in the open ocean and a wealth of higher dissolved oxygen (upstream) resulting from the phytoplankton bloom (Bennouna, 1999) macroalgae in spring. The dissolved oxygen values are gradually decrease with increased respiration of organisms and the degradation of organic matter by aerobic heterotrophic bacteria during the summer. The agitation of the water surface, the freshwater supply (upstream) and bathymetry of Oualidia lagoon are the main factors of good oxygenation of the water (Table-3). The analysis results of this study clearly showed the richness of the Oualidia lagoon in nitrogen compared to coastal waters (Table-4) elements, but a relative scarcity of these elements in the lagoon passes area during the study period. The spatial variation of nitrite explained by an important sediment-water exchange in downstream and restrict the sedimentation of organic matter. This feature disadvantage the residence time of nitrifying bacteria and causes the inhibition of nitrification (Sarf, 1995), especially in the upstream by a continental inputs (fertilizers, mudflat ...) and low depth. The nitrite values were more important from May to August except July and decrease in March and April (Table-2); it explained by the phytoplankton bloom. Nitrite values were positively correlated significantly with ammonium ($r = 0.594$, $p <0.01$) and negatively with dissolved oxygen ($r = -0.413$, $p <0.01$) (Fig. 4). The seasonal variation showed that the highest orthophosphate values observed in summer can be explained by phytoplankton and zooplankton excretion, to coastal areas rich in phosphorus, leaching watershed and bacterial mineralization (Chbicheb, 1996).

Correlation analysis of orthophosphate showed a positive significant one with nitrite and ammonium ($r = 0.932$, $p < 0.01$) and ($r = 0.576$, $p < 0.01$) respectively, and a significant negative correlation with salinity ($r = -0.674$, $p < 0.01$) (Fig. 4). Values recorded during this study reflected the richness of the Oualidia lagoon of this biogenic element in the upstream. These values can be explained by shallow, the sediments influence on the water column, the muddy nature of the sediment (Barbantia et al., 1992), and by leaching agriculture areas that are rich in phosphate fertilizers and by the presence of phosphate mine between El jadida-Safi Kaimoussi et al. (2001). In comparison with other similar lagoon sites, the orthophosphates values recorded were strong enough and reflected the richness of the lagoon in this element (Table-4). The ammonium values showed that the Oualidia lagoon is rich in this element relative to other lagoon sites (Table-4). This wealth is explained by the presence of oyster Park, agricultural inputs, rainfall and runoff, degradation of organic matter and summer tourism. The highest values were observed in summer (Table-2). They are related to the mineralization of the organic matter (Chbicheb, 1996). The low values observed in the spring are explained by the phytoplankton bloom (Chbicheb, 1996). This element showed a significant negative correlation with salinity ($r = -0.694$, $p < 0.01$) and a significant positive correlation with temperature ($r = 0.322$, $p < 0.05$) (Fig. 4).

	T	**Sal**	**Dis O_2**	**NO_2**	**PO_4**	**NH_4**
T	1.000	-.721**	-.046	.308*	.250*	.322**
	.	.000	.715	.012	.043	.008
		66	66	66	66	66
Sal		1.000	.381**	-.721**	-.674**	-.694**
		.	.002	.000	.000	.000
			66	66	66	66
Dis O_2			1.000	-.455**	-.514**	-.413**
			.	.000	.000	.001
				66	66	66
NO_2				1.000	.932**	.594**
				.	.000	.000
					66	66
PO_4					1.000	.576**
					.	.000
						66
NH_4						1.000
						.

Figure 4: Correlation matrix between the physico-chemical parameters and nutrients from the water column.

Table 4: Physico-chemical parameters and nutrients comparison between water lagoons (Atlantic, Mediterranean).

Sites \ Parameters	**T** (°C)	**Dissolved O2** (mg/l)	**Salinity** (PSU)	**NH_4^+** (mg/l)	**P** (mg/l)	**NO_2^-** (mg/l)	**References**
Oualidia lagoon (Atlantic)	Min=16 ; Max= 25	Min=8.06 ; Max=13.17	Min=22.5; Max=35.9	Min=0.004; Max=1.085	Min=0.002; Max=2.207	Min=0.0001; Max=0.851	This study
Massa lagoon (Atlantic)	Min=16.1; Max=25	Min=3; max=6.356	Min=12.01; Max=24.6	4.08	Min=0.026; Max=0.188	nd	H. Badsi, 2010
Aghien lagoon (Atlantic)	Min=31,8 Max=33	Min=3,60 Max=6,70	Min=0 Max=0.1	Min=7,20 Max=50,40	Min=0 Max=0.43	Min=0.002 Max=0.006	A.Traore et al., 2012
Nador lagoon (Mediterranean)	Min=15; Max=29.22	nd	Min=37; Max= 40	Min=0.001; Max=0.004	Min=0.001; Max=0.004	Min=0.003; Max=0.024	F. Ruiz, 2006
El Meleh lagoon (Tunisia, Mediterranean)	Min=11.1; Max=27.6	nd	Min=26.6; Max=51.2	Min=0.0008; Max=0.18	Min=0.005; Max=0.07	Min=0.00004; Max=0.04	A. Dhib et al., 2013
Bizerte lagoon (Tunisia, Mediterranean)	Min=13.25 ; Max=26.9	Min=6.50 ; Max=7.70	Min=26.30 ; Max=37.10	Min=0.202 ; Max=0.404	Min=0.032 ; Max=0.07	nd	Mohamed Ali Chikhaoui, 2008

The study of similarity (Fig. 5), clearly showed the existence of two distinct groups; the first is represented by (temperature, nitrite, orthophosphate and ammonium) and the second group (salinity, dissolved oxygen). This distinction can be explained by the existence of a seasonal variation of these elements and the existence of spatial homogeneity of the parameters of the same group, resulting from mixed different water masses (seawater in downstream) and (freshwater in upstream). This spatial homogeneity (intra-stations) of water masses can be explained by lagoon hydrodynamic.

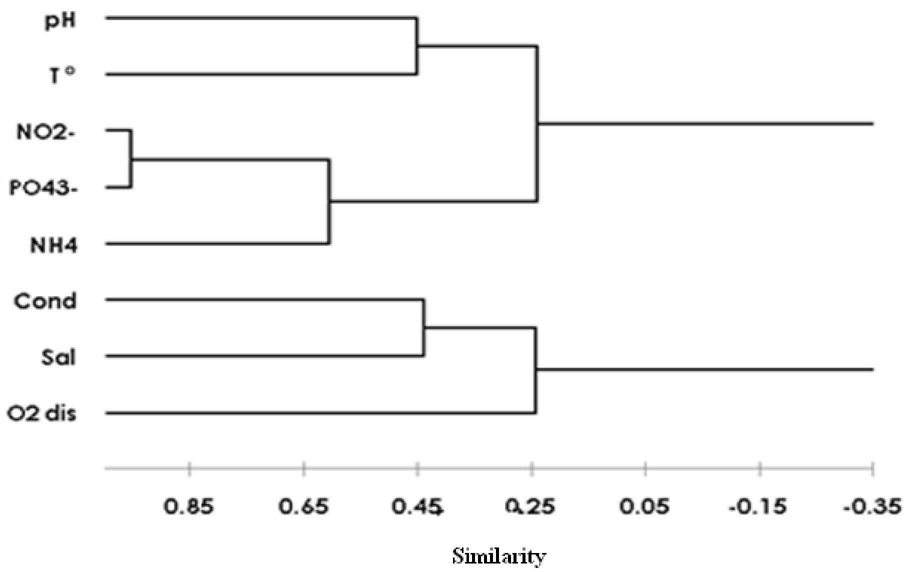


Figure 5: Dendrogram (hierarchical clustering) of physico-chemical parameters and nutrients from the water column of the Oualidia lagoon (Moroccan Atlantic coast).

Our study to prevent a drastic and potentially irreversible change to the ecological character of Oualidia lagoon, it is recommended that temporal trends in nutrient dynamics in the lagoon could be accurately and better interpreted by the use of continuous monitoring data rather than with bimonthly series of grab sample information. Continuous, high frequency data is a useful source of information for the understanding of seasonal chemical and biological changes in the lagoon. Integration of continuous nutrient monitoring to the our data monitoring system operating in the lagoon offers an improved monitoring design in order to facilitate comprehensive analyses of changes in trends, patterns in space and time. They are useful to estimate nutrient dynamics, primary and secondary production as well as to assess C, N, P fluxes associated with biogeochemical cycling and toxicant transport.

More and better water quality data is needed for to calculate Maximum Permissible Loading in Oualidia lagoon. We need better data to assess trends, to determine current status of waters and their impairments, and to test water quality models.

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