



Seasonal characterization of the nutrients state in Oualidia Lagoon (Moroccan Atlantic coast)

Z. Damsiri^{1,*}, L. Natij¹, K. Khalil¹, M. Loudiki², R. Jonathan^{3,4}, H. El Himer⁵, K. Elkalay¹

¹Laboratory of Applied Sciences for the Environment and Sustainable Development, School of Technology Essaouira, Cadi Ayyad University. Essaouira Al Jadida, Route d'Agadir, BP 383, Essaouira, Morocco.

²Laboratory "Biology and Biotechnology of Microorganisms", Faculty of Sciences Semlalia of Marrakech. Cadi Ayyad University. Bd. Prince Mlly Abdellah, B.P. 511. Marrakech, Morocco.

³Numerical Ecology of Aquatic Systems, University of Mons, Pentagone 3D08, 6, Avenue du Champ de Mars, 7000 Mons, Belgium

⁴Laboratory of Oceanology - MARE Center University of Liege (ULg), Bât. B6C 4000 Sart Tilman-BELGIUM

⁵GEOHYD, Geology Department, Faculty of Sciences Semlalia, University Cadi Ayyad, P.O. Box 2390, Marrakech, Morocco.

Received 12 Jun 2016, Revised 05 Aug 2016, Accepted 25 Aug 2016

*Corresponding author. E-mail: zainab.damsiri@gmail.com, Phone: +212 6 11 76 19 71.

Abstract

The nutrient cycle in Oualidia lagoon, on the Atlantic Moroccan coast, was studied at both spatial and temporal scales, covering spring and summer conditions. Water samples were collected bimonthly at high tide from March to August during years 2011 and 2012 at six stations distributed throughout the lagoon. The physico-chemistry (temperature, salinity, dissolved O₂) and nutrient enrichment of the lagoon surface water were monitored. The average nutrient concentration of surface water were 14.4 μmol.l⁻¹ and 28.1 μmol.l⁻¹ for NH₄⁺, 20.4 μmol.l⁻¹ and 19.9 μmol.l⁻¹ for PO₄³⁻ and 3.7 μmol.l⁻¹ and 7.6 μmol.l⁻¹ for NO₂⁻ in 2011 and 2012, respectively. Strong seasonal differences of nutrient distribution at the different stations were noticed. Temperature, salinity and dissolved O₂ were correlated with nutrient concentrations, all parameters showing low spatial (inter-station) variability. Hydrological conditions exert a major control on the nutrient cycling in the lagoon. Results of this study are important to increase the richness on the scientific knowledge of nutrient dynamics along the Moroccan Atlantic coast, particularly in the semi-enclosed lagoons that are important transitional systems.

Keywords: Nutrients, physico-chemical parameters, seasonal variability, Oualidia lagoon, Atlantic, Morocco.

1. Introduction

Coastal lagoons constitute ecosystems of ecologic, economic and social value [1]. High biological productivity is a common characteristic they share [2] due to the coupling of several processes which include: (1) elevated inputs of nutrients due to land runoff; (2) shallowness, allowing light penetration in the whole water column and high exchanges of chemical variables (nutrients, oxygen etc) between sediments and the water column; and (3) partial isolation from the sea [3]. Factors affecting the nutrient cycling in coastal lagoons on a temporal scale have been extensively characterized for a number of different systems [4, 5], showing that nutrient regeneration in the water column and sediments is a key factor enhancing phytoplankton production [6, 7]. These studies generally rely on data obtained from surface water sampling at high tide.

Lagoons are highly dynamic environments, subject to frequent fluctuations under control of physical processes [8, 9] and especially sensitive to natural disturbances [1, 10]. In the context of the global change, the vulnerability of these systems is even greater and the sea-level rise, storm intensification, tidal regime alterations or freshwater input changes can significantly impact the functioning of coastal lagoons [11]. But these systems are further facing serious problems due to anthropogenic activities, such as intense agricultural,

fishing and tourism activities, changes in land use, destruction of mangroves, aquaculture effluents, overfishing, use of illegal fishing techniques (i.e., dynamite and cyanide), sedimentation, waste discharge and fertilizer and pesticide use[12].

Studying the spatio-temporal dynamics of nutrients in lagoons is necessary in the context of climate change and increasing human disturbances on these systems[13]. Thus, the aim of this work was to study a Moroccan lagoon representative of the Atlantic coast in order to (i) delineate a quantitative and qualitative physico-chemical description of its surface waters; (ii) to assess the spatio-temporal dynamic of nutrients of its surface waters; (iii) to highlight relationships between nutrient dynamics and the physico-chemical forcing parameters monitored.

2. Materials and methods

2.1. Study site

The Oualidia lagoon (32°46'N, 09°01'W; Fig. 1) is located on the Moroccan Atlantic coast between the cities of El Jadida and Safi. It is about 7 km long and 0.5 km wide, covers an area of 4 km² and has a mean depth of 1.5 m. Water is exchanged with the sea by two inlets: a main pass (150 m wide), permanent and active throughout the year, and a secondary one (50 m wide). The lagoon is subdivided in several parts that are connected by a main channel with a maximum depth not exceeding 5 to 6 m and a secondary channel with a maximum depth of 1.0 to 1.5 m. The lagoon is separated from the salt marshes by an artificial dike in the north.

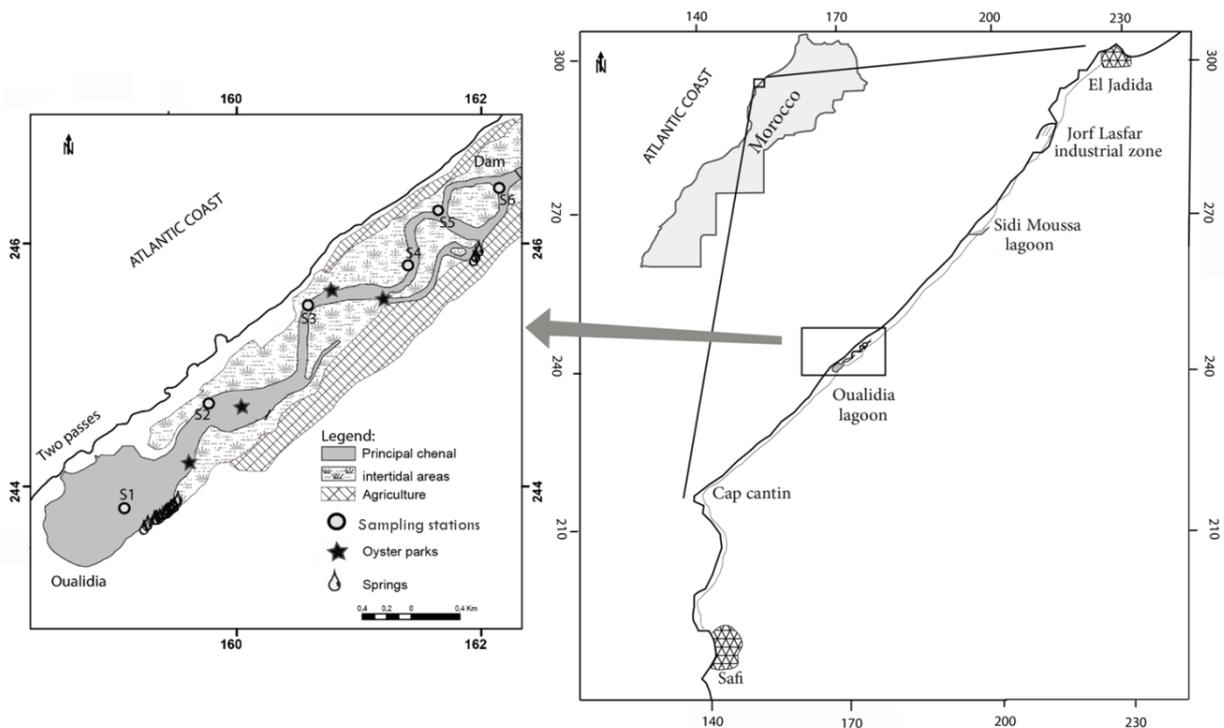


Figure 1: General map of the Atlantic northwestern coast of Morocco (right) and zoom on the Oualidia lagoon (left). The position of the six sampling stations S1 to S6 is shown in the lagoon map.

2.2. Sampling and analytical methods

Twenty-four sampling surveys were carried out during spring and summer periods of years 2011 and 2012, at high tide. Water samples were collected from the first 10 cm surface water for nutrient analysis and physico-chemical parameters were measured *in situ* concomitantly to that sampling. Six stations distributed in the lagoon from the downstream sea-side (S1) to the upstream land-side (S6) were studied in order to determine the spatio-temporal variability along that gradient as well as the influence of several human activities (oyster culture, agriculture; Fig. 1). The physico-chemical parameters: temperature, dissolved O₂ and salinity were measured using a calibrated multiparametric probe Multi340i (wtw82362 Weilheim). For nutrients analysis, water samples

were collected in triplicate by using 1 liter HD-PE plastic bottles. Water samples were stored at 4°C, brought to the laboratory and rapidly analyzed within 48 hrs. Water samples were filtered using a Millipore system with fiberglass Whatman GF/C filters of 47 mm diameter and 0.45µm porosity. Filtration is essential to eliminate any suspended matters that are susceptible to absorb light during the colorimetric analysis and to modify the chemical composition of the analyzed solution. Nutrient (ammonium, nitrite and orthophosphate) concentrations were determined by colorimetric approach using a spectrometer (BIOMATE 3) according to the standard method AFNOR (P: NF T 90-023, NO₂⁻: NF T90-013 and NH₄⁺: NF T 90-015) [14]. Specifying the triplicate measurements were performed on each samples, for each nutrient.

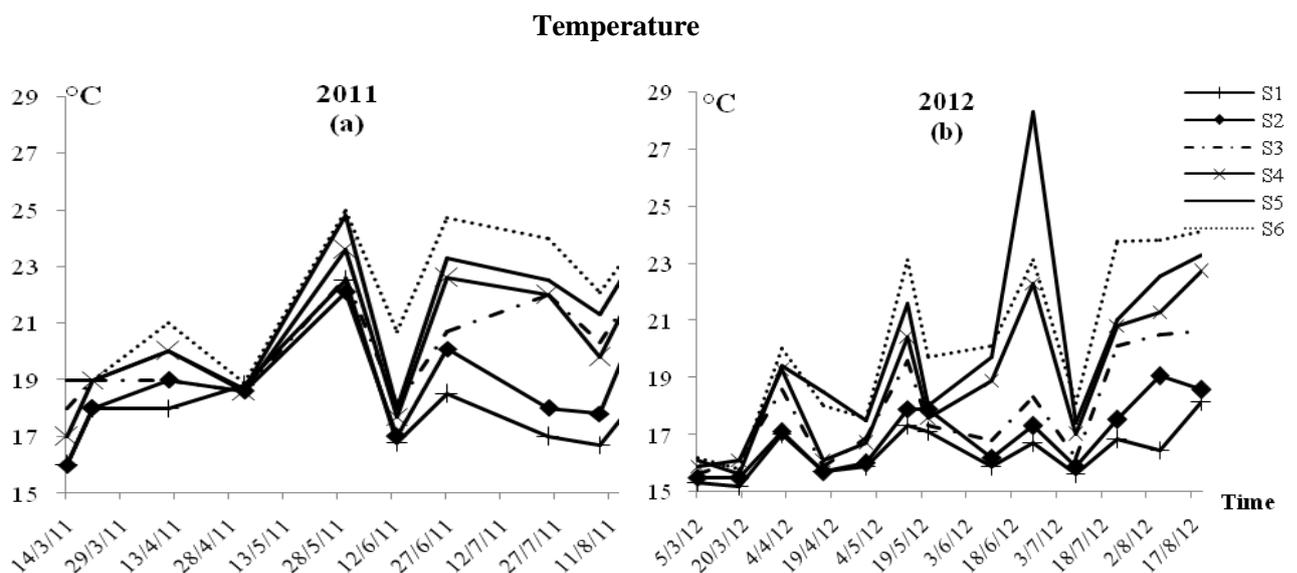
2.3. Mathematical and statistical analysis

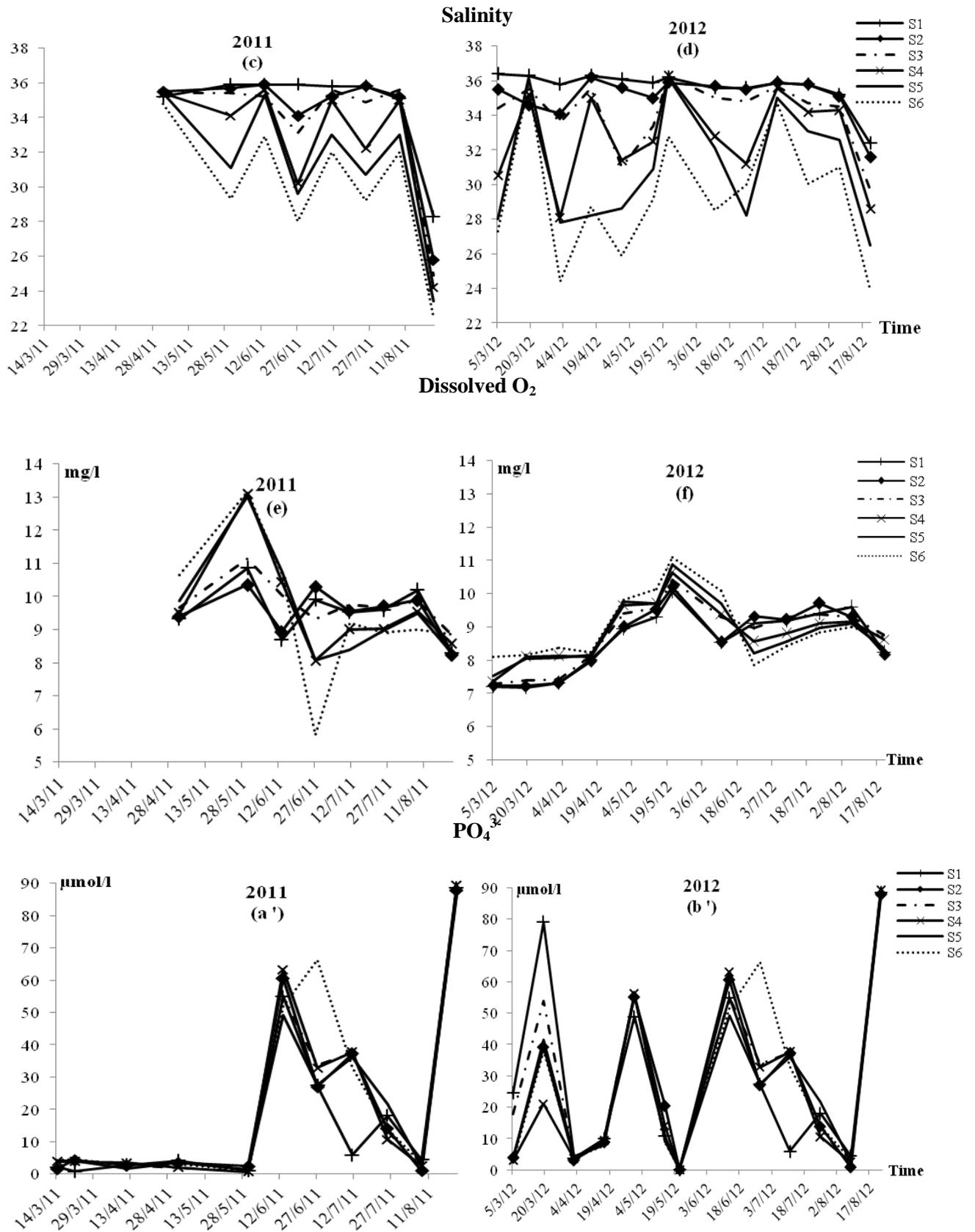
Data were processed in order to calculate seasonal and annual means, maximum and minimum values. The annual means were used to account for the spatial variability of physico-chemical parameters and nutrient concentrations of the lagoon surface water. Results were visualized as contour maps created using ArcGis (version 9.x, Esri). Correlations between the monitored variables (temperature, salinity, dissolved O₂, PO₄³⁻, NO₂⁻, and NH₄⁺) were assessed using the Spearman test. Principal Component Analysis (PCA) was performed on the correlation matrix of the 6 variables. Statistical analyzes were performed using SPSS (version 10 for Windows, SPSS, Chicago, IL, USA).

3. Results and discussion

3.1. Distribution of physico-chemical water quality parameters

Distribution of surface water temperature in spring-summer 2011 in the Oualidia lagoon showed a minimum of 15.2°C for stations S1 and S2 (downstream) in spring and a maximum of 25°C for station S6 (upstream) in summer (Fig. 2a), with an average of 19.9°C (Table 1). In spring-summer 2012 the surface water temperature varied between a minimum of 15.2°C for station S1 (downstream) in spring and a maximum 24.1°C for station S6 (upstream) in summer (Fig. 2b), the average value being 18.4°C (Table 1). The surface water temperature in the Oualidia lagoon decreased from upstream to downstream (Figs. 3a, b) and was higher in 2011 compared to 2012 (except in summer in stations S5 and S6 (Table 1)). The Oualidia lagoon water temperature ranges were relatively narrow (15.2 - 25.0°C) during spring-summer 2011 and 2012. That observation was consistent with previous studies on this lagoon [15, 16, 17, 18, 19, 20, 9]. Seasonal variability of temperature (Table 1) could be explained by the influence of ocean and atmospheric temperature (12°C in winter and 24°C in summer) [21] on the freshwater feeding the lagoon. The present study showed a gradual rise of temperature from spring to summer. That seasonal increase in temperature could explain the phytoplankton blooms observed in spring [16].





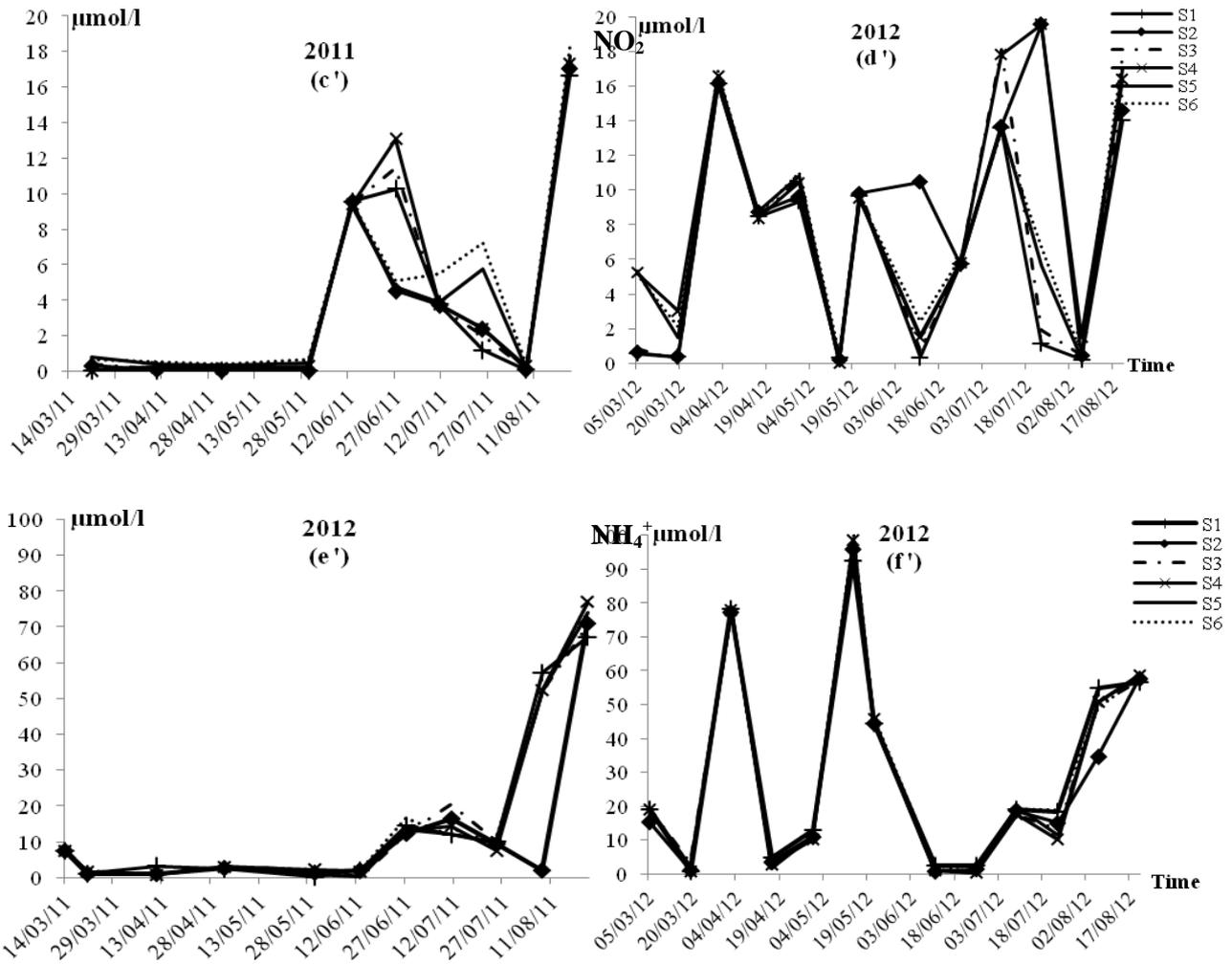


Figure 2: Fortnightly evolution of mean temperature (a, b), Salinity (c, d), dissolved O₂ (e, f), PO₄³⁻ (a', b'), NO₂⁻ (c', d') and NH₄⁺ (e', f') monitored in surface water (3 cm below the surface) at six stations (S1 to S6) of the Oualidia lagoon (Atlantic Coast, northwestern Morocco) during 2011 and 2012.

The higher surface water temperature recorded in upstream stations could be explained by the inflow of warmer freshwater [22]. The rapid temperature decrease recorded throughout the lagoon at the beginning of the survey in May and late June 2011 can be explained by the dredging of a defile and installation of pumping equipment and pressure at sea (part of Oualidia Halieutis project; 2011-2020). The oceanic influence on the surface water lower temperature was noticed throughout the lagoon and especially near the passes (downstream), due to the importance of water exchanges between the lagoon and the coastal ocean. Indeed, the important renewal of water in the Oualidia lagoon at each tidal cycle [23], which influence not only the temperature regime, but also the salinity [24]. Salinity showed a seasonal trend in 2011, varying between 22.5 for station S6 (upstream) in summer and 35.9 for station S1 (downstream) in spring (Fig. 2c), with an average of 33.3 (Table 1). In spring-summer 2012 the surface water salinity varied between 23.9 for station S6 (upstream) in summer and 36.3 for station S1 (downstream) in spring, the average value being 33.0 (Fig. 2d, Table 1). The surface water salinity in the Oualidia lagoon increased from upstream to downstream (Figs. 3c, d), was higher in spring 2011 than 2012 and inversely during summer (Table 1). The temperature was negatively correlated with, this correlation being statistically significant (Table 2). Thus, salinity variability in Oualidia lagoon can be explained by homogeneous salinity rate during rising tides where the values are similar to those of the ocean. The freshwater (28% of inputs of continental waters) that permanently flowed into the upstream part of the lagoon [25] can influence the general salinity of the lagoon surface water by decreasing its salinity. Studies conducted by [26] showed similarity with our results.

Table 1: Seasonal variability of physico-chemical parameters and nutrients of surface water of the Oualidia lagoon (Atlantic coast, Morocco) for spring-summer 2011 and 2012.

		Temperature (°C)	Salinity	Dis O ₂ (mg/l)	PO ₄ ³⁻ (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	10.10±0.21 (106.8%)	2.2±0.2	0.1±0.0	2.8±0.3
	S2	18.7±0.3	35.6±0.1	9.88±0.13 (104.5%)	2.9±0.1	0.1±0.0	2.7±0.3
	S3	19.4±0.2	35.4± 0.0	10.40±0.20 (112.3%)	2.6±0.2	0.2±0.0	3.1±0.3
	S4	19.6±0.3	34.8±0.2	11.30±0.50 (122.0%)	2.8±0.2	0.2±0.1	3.0±0.3
	S5	20.3±0.3	33.3±0.6	11.45±0.43 (126.2%)	2.9±0.2	0.5±0.3	2.8±0.3
	S6	20.6±0.3	32.1±0.8	11.92±0.35 (131.4%)	3.2±0.2	0.6±0.0	2.8±0.3
Summer 2011	S1	17.7±0.1	34.5±0.3	9.37±0.08 (97.0%)	33.2±3.7	6.9±0.7	27.1±3.1
	S2	18.9±0.2	33.7±0.4	9.44±0.08 (101.9%)	37.9±3.6	6.2±0.7	18.8±2.9
	S3	20.2±0.2	33.2±0.5	9.58±0.05 (105.6%)	38.3±3.5	7.4±0.7	27.6±3.1
	S4	20.8±0.2	32.0±0.5	9.11±0.09 (102.3%)	39.4±3.7	7.7±0.7	27.7±3.4
	S5	21.7±0.2	30.8±0.5	9.00±0.11 (101.1%)	37.2±3.2	6.9±0.7	26.9±3.3
	S6	23.1±0.2	29.4±0.4	8.75±0.18 (102.2%)	42.5±3.6	7.7±0.7	28.0±3.2
Total average		19.9	33.3	10.02 (110.4%)	20.4	3.7	14.4
Spring 2012	S1	16.2±0.1	36.1±0.0	8.29±0.12 (84.1%)	25.3±3.0	6.4±0.6	36.1±3.8
	S2	16.5±0.1	35.3±0.1	8.36±0.13 (84.8%)	18.7±2.2	6.5±0.6	35.6±4.0
	S3	17.1±0.1	34.3±0.1	8.52±0.13 (88.2%)	21.7±2.4	6.6±0.7	36.2±3.9
	S4	17.4±0.2	32.7±0.3	8.81±0.12 (91.2%)	15.4±2.0	7.6±0.6	36.5±4.1
	S5	18.1±0.2	30.8±0.4	8.32±0.25 (88.0%)	17.5±2.3	7.5±0.6	36.7±4.0
	S6	18.6±0.3	29.2±0.4	9.14±0.13 (96.7%)	16.7±2.2	7.7±0.5	37.3±4.1
Summer 2012	S1	16.6±0.1	35.1±0.2	9.02±0.06 (91.5%)	22.5±3.3	5.8±0.7	25.7±2.7
	S2	17.4±0.1	34.9±0.2	9.05±0.06 (93.7%)	19.4±3.3	10.7±0.8	21.4±2.4
	S3	18.8±0.2	34.1±0.2	9.17±0.03 (99.0%)	24.3±3.2	7.1±0.9	23.3±2.7
	S4	20.5±0.2	32.8±0.3	8.94±0.04 (98.5%)	20.5±3.5	10.4±0.9	23.1±2.9
	S5	22±0.4	31.3±0.4	8.82±0.06 (101.1%)	19.2±3.1	7.4±0.7	23.6±2.8
	S6	22.2±0.3	29.7±0.4	8.82±0.08 (101.1%)	18.2±3.3	7.8±0.7	24.7±2.7
Total average		18.4	33.0	8.77 (92.8%)	20.0	7.6	28.1

The Oualidia lagoon surface water was well oxygenated in spring 2011-2012 with a minimum value of 9.1 mg/l (96.3.0%) for station S2 and a maximum value of 10.5 mg/l (114.8%) for station S6 (upstream; Fig. 2e) with an average of 10.02 mg/l (110.4%) (Table1). In summer 2011-2012 the surface water dissolved O₂ varied between a minimum of 8.8 mg/l (102.8%) for station S6 and a maximum 9.4 mg/l (101.5%) for station S3 (Fig. 2f), the average value being 8.77 mg/l (92.8%) (Table 1). The surface water dissolved O₂ in the Oualidia lagoon increased from upstream to downstream in summer and decreased in spring (Figs. 3e,f). In spring 2011-2012 dissolved O₂ levels were higher than those recorded in summer 2011-2012. The dissolved O₂ was positively correlated with temperature, this correlation being statistically significant (Table 2).

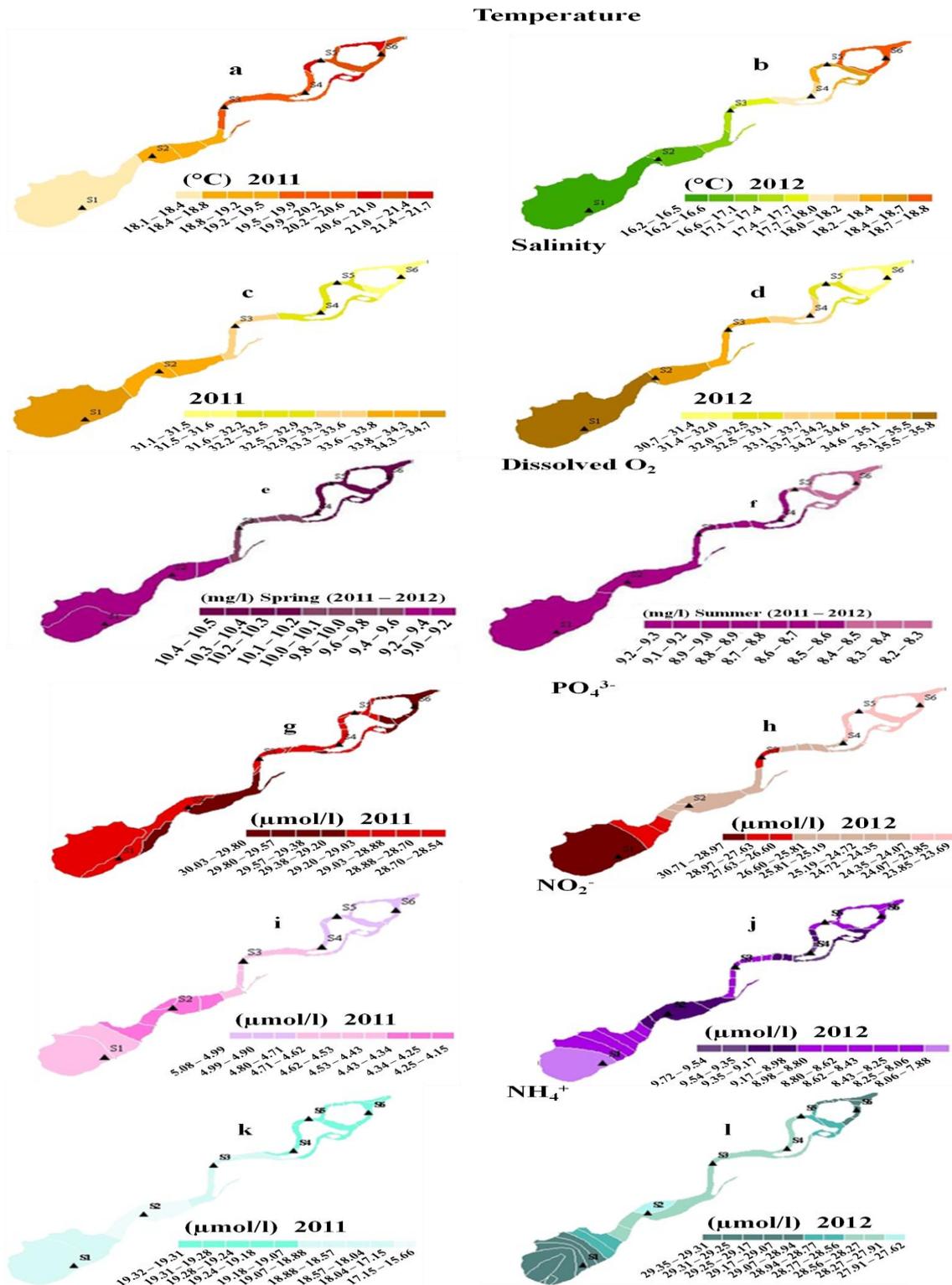


Figure 3: Spatial variability of physico-chemical parameters (Temperature (°C): a and b; Salinity: c and d during spring-summer 2011 and 2012; Dissolved O₂ (mg/l): e (spring 2011-2012) and f (summer 2011-2012) and nutrients (µmol/l; PO₄³⁻: g and h; NO₂⁻: i and j; NH₄⁺: k and l) monitored in surface water (from the first 10 cm water surface) of the Oualidia lagoon (Atlantic Coast, northwestern Morocco) during spring-summer 2011 and 2012.

Globally, the agitation of the surface water, the upstream freshwater supply [25] and the low bathymetry of Oualidia lagoon are the possible factors contributing to the good oxygenation of the water body. The analysis of dissolved O₂ at our study revealed a subdivision of the Oualidia lagoon into two distinct parts in spring: a less oxygenated zone downstream (S1, S2, S3) and a more oxygenated one upstream (S4, S5, S6). That spring

gradient was inversed in summer. These results were compatible with previous works on the lagoon [17], and could be explained by the influence of oceanic surface water. Indeed, downstream dissolved O₂ levels were similar to those measured in the open ocean. Regarding the higher values of dissolved oxygen measured upstream, they resulted from the spring phytoplankton bloom [16]. The dissolved O₂ values gradually decreased during the period post-bloom, probably due to the increased respiration of organisms (i.e. the degradation of organic matter by aerobic heterotrophic bacteria) and the summer water temperature increase that limits the dissolution of O₂.

Table 2: Spearman correlation matrix between physico-chemical parameters (T: temperature; Sal: salinity and Dis O₂: dissolved oxygen) and nutrients (PO₄³⁻: orthophosphates; NO₂⁻: nitrite and NH₄⁺: ammonium) of surface water of the Oualidia lagoon (Atlantic coast, Morocco).

	T (°C)	Sal	dis O ₂ (mg/l)	PO ₄ ³⁻ (µmol/l)	NO ₂ ⁻ (µmol/l)	NH ₄ ⁺ (µmol/l)
T (°C)	1.000	-.546**	.236**	-.075	-.193**	.107
		.000	.001	.274	.005	.116
		197	198	216	214	216
Sal		1.000	-.037	-.107	-.105	-.224**
			.610	.136	.141	.002
			197	197	197	197
Dis O ₂ (mg/l)			1.000	-.388**	-.172*	-.167*
				.000	.015	.019
				198	198	198
PO ₄ ³⁻ (µmol/l)				1.000	.496**	.213**
					.000	.002
					214	216
NO ₂ ⁻ (µmol/l)					1.000	.404**
						.000
						214
NH ₄ ⁺ (µmol/l)						1.000

** The correlation is significant at the 0.01 level (bilateral).

* The correlation is significant at the 0.05 level (bilateral)

3.2. Distribution of nutrients

Surface water PO₄³⁻ concentrations varied in the Oualidia lagoon in spring-summer 2011 from a minimum of 0.7 µmol.l⁻¹ in spring for station S1 (downstream) to a maximum of 89.4 µmol.l⁻¹ in summer for station S4 (upstream) (Fig. 2a'), the average value being 20.4 µmol.l⁻¹ (Table 1). In spring-summer 2012 surface water PO₄³⁻ concentrations fluctuated between a minimum of 0.1 µmol.l⁻¹ in spring for station S6 (upstream) and a maximum of 79.8 µmol.l⁻¹ in summer for station S4 (upstream; Fig. 2b'), the average value being 19.9 µmol.l⁻¹ (Table 1). A decreasing gradient from upstream to downstream was recorded for that nutrient (Figs 3g,h). Surface water PO₄³⁻ concentrations recorded in spring-summer 2012 were similar to those of 2011 (Table 1). In the present study, measured PO₄³⁻ concentrations were higher than those recorded for NO₂⁻ and NH₄⁺. This finding could confirm the influence of oceanic water, which is the main source of phosphate for coastal waters. The PO₄³⁻ concentration was positively correlated with NO₂⁻ and NH₄⁺ and negatively correlated with dissolved O₂ (Table 2), these three correlations being statistically significant (Table 2). The higher PO₄³⁻ values and the low dissolved O₂ concentrations reported during summer periods could be related to reduced primary production rates. The presence of higher concentration of nutrients is due to the influence of muddy sediment of shallow depth of the lagoon [27]. Moreover, leaching agriculture areas, which are rich in phosphate fertilizers and the presence of phosphate mine between the two Moroccan cities El jadida and Safi [28] potentially, contribute to the water quality of the interior part of the lagoon. PO₄³⁻ enrichments of surface waters noted in Oualidia lagoon were higher those recorded in other lagoon (Table 3).

NO₂⁻ surface water concentrations varied in spring-summer 2011 from a minimum of 0.1 μmol.l⁻¹ in spring for station S1 (downstream) to a maximum of 18.4 μmol.l⁻¹ in summer for station S6 (upstream) (Fig. 2c'), the average value being 3.7 μmol.l⁻¹ (Table 1). In spring-summer 2012 water surface NO₂⁻ concentrations fluctuated between a minimum of 0.04 μmol.l⁻¹ in spring for station S4 and a maximum of 19.6 μmol.l⁻¹ in summer for stations S2 and S4 (Fig. 2d'), the average value being 7.6 μmol.l⁻¹ (Table 1). A decreasing gradient from upstream to downstream was recorded for that nutrient (Figs 3i,j). NO₂⁻ concentrations were higher in spring 2012 compared to spring 2011 and similar during the summer period of both years (Table 1). The NO₂⁻ concentration was positively correlated with NH₄⁺ and negatively correlated with dissolved O₂ (Table 2), these correlations being statistically significant (Table 2). The analysis results of this study clearly showed higher maximum nitrogen concentration in Oualidia lagoon in comparison with other coastal waters (Table 3), although relative scarcity of these elements near the lagoon passes during the study period were noticed. The spatial variation of NO₂⁻ could be explained by an important sediment-water exchange in the downstream lagoon. This feature disadvantages the residence time of nitrifying bacteria and causes the inhibition of nitrification [29]. This is particularly the case in the upstream lagoon, characterized by lower depth and further influenced by continental inputs (fertilizers, mudflat...). The lowest value of NO₂⁻ was recorded downstream and this can be caused by freshwater runoff between S1 and S2 (34 springs) [25] that makes dilution of the seawater. The seasonal variation showed that the highest NO₂⁻ values observed in summer might be controlled by phytoplankton and zooplankton excretion. NH₄⁺ surface water concentrations varied in 2011 between a minimum of 0.1 μmol.l⁻¹ in spring for station S1 (downstream) and a maximum of 74.1 μmol.l⁻¹ in summer for station S5 (upstream) (Fig. 2e'), the average value being 14.4 μmol.l⁻¹ (Table 1). In spring-summer 2012 the lowest NH₄⁺ concentration of 0.2 μmol.l⁻¹ was recorded in summer for station S5 (upstream) and the highest one of 100.3 μmol.l⁻¹ in spring for station S6 (upstream) (Fig. 2f'), the average value being 28.1 μmol.l⁻¹ (Table 1). The lagoon surface water NH₄⁺ concentration showed a decreasing trend from upstream to downstream, except for the southern lagoon-side stations S1 and S2 (Figs 3k,l). NH₄⁺ concentrations were higher in spring 2012 compared to spring 2011 and inversely during the summer period, except for station S2 summer sample (Table 1). The NH₄⁺ concentration was negatively correlated with dissolved O₂ and salinity (Table 2), these correlations being statistically significant (Table 2). Recorded higher concentration of NH₄⁺ could be partially due to the death and subsequent decomposition of phytoplankton, secondly to the excretion of ammonia by planktonic organisms [30] and summer tourism. Our results remain close to those registered in Nador lagoon [31]. The nutrient concentrations recorded in this work clearly show a significant increase from summer 2011. That increase could be explained by sediment resuspension [32], by the start of the Oualidia Halieutis project activities from May 2011 (dredging of a defile and installation of pumping equipment and waste water treatment).

Table 3: Comparison of physico-chemical parameter values and nutrient levels between surface water of lagoons of the African Atlantic coast.

Sites	T (°C)	Dissolved O ₂ (mg/l)	Salinity	NH ₄ ⁺ (μmol/l)	P (μmol/l)	NO ₂ ⁻ (μmol/l)	References
Oualidia lagoon (Morocco)	Min=17.0 ; Max= 21.0	Min=4.80; Max=13.78	Min=24.8; Max=36.3	Min=0.187; Max=100.5	Min=0.031; Max=43.174	Min=0.002; Max=19.557	This study
Massa lagoon (Morocco)	Min=16.1; Max=25.0	Min=3.00; max=6.36	Min=12.0; Max=24.6	255.000	Min=0.273; Max=1.977	nd	[33]
Aghien lagoon (Ivory Coast)	Min=31.8 Max=33.0	Min=3.60 Max=6.70	Min=0.0 Max=0.1	Min=450.000 Max=3150.000	Min=0.000 Max=4.523	Min=0.043 Max=0.130	[34]

3.3. PCA analysis

PCA analysis of physico-chemical parameters and nutrients data showed that, for all 6 stations monitored during spring-summer 2011 and 2012, the joined input of the first two axes explained 97.25% of the total variability of the correlation matrix. Axis1 accounted for 58.85% of the variability and was essentially a combination of NO₂⁻, PO₄³⁻, NH₄⁺ and temperature. Axis 2 accounted for 38.37% of the variability, and was mainly a combination of dissolved O₂ concentrations and salinity. Seasonal variability was mainly recorded along axis 1, with spring and summer 2012 samples located in the direction of increasing NO₂⁻, PO₄³⁻, NH₄⁺ concentrations and temperature and spring and summer 2011 samples in the direction of increasing salinity and dissolved O₂ (Fig. 4).

The results of the principal component analysis (PCA) showed a low inter-stations variability of hydrological parameters and nutrients concentration. Different water masses are mixed by the lagoon dynamics that most

probably prevent the establishment of a vertical stratification (although not monitored) and lead to the observed upstream-downstream decreasing gradient of the investigated variables. Unlike, the spatial variation, the measured parameters showed significant seasonal variations (Fig. 4). A significant station variation was observed in temperature, salinity and dissolved O₂. This finding reveals that the waters of Oualidia lagoon define two ecological entities:

Zone 1 represented by stations 1 and 2, marked by oceanic influence. Zone 2 represented by stations 3, 4, 5 and 6, influenced by the presence of fresh water resurgence and anthropogenic activities.

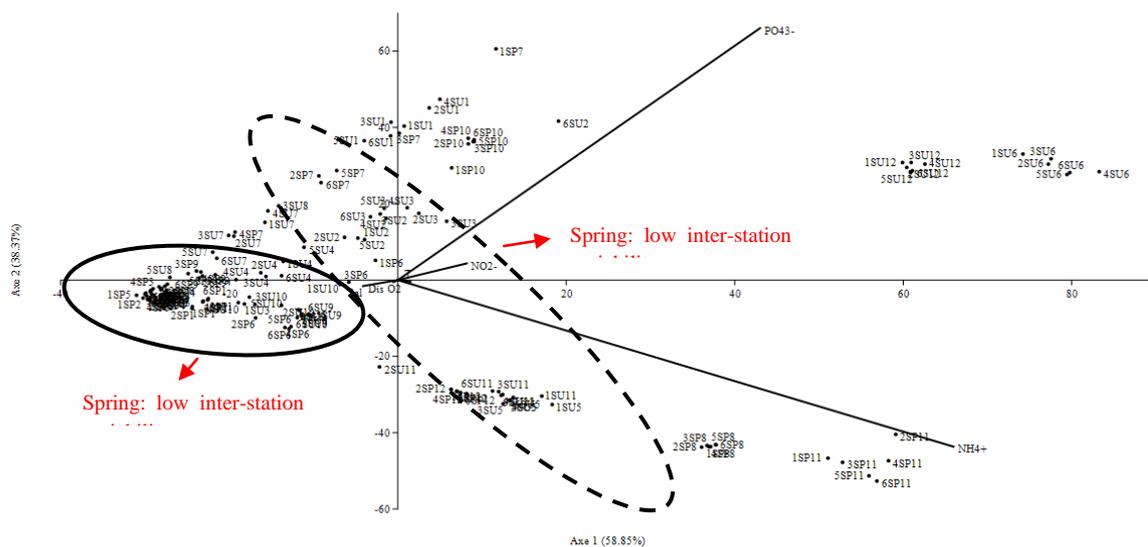


Figure 4: Principal component analysis (PCA) of physico-chemical parameters and nutrients monitored in surface water (to 10 cm) of the Oualidia lagoon (Atlantic Coast, northwestern Morocco) during spring (SP)-summer (SU) 2011 and 2012 at 6 stations (xSP or xSU, x being respectively equal to 1, 2, 3, 4, 5 or 6). Factorial variables: Axe 1 (58.85%) and Axe 2 (38.37%). Bold lines: variables according to spatial and temporal variability. T: temperature, Dis O₂: dissolved oxygen, Sal: Salinity, PO₄³⁻: orthophosphates, O₂⁻: nitrite, NH₄⁺: ammonium.

Conclusion

Short-term variability of environmental variables (physico-chemistry and nutrient loadings) has rarely been documented in African Atlantic coastal water bodies.

This present study shows a richness of nutrient of Oualidia lagoon, with a seasonal variability and low spatial variability. The higher nutrient concentration of Oualidia lagoon surface water recorded from summer 2011 was due to increasing human activities (intense agricultural, fishing and tourism activities and Oualidia Halieutis project 2011-2020 construction).

Results presented in this study provide a good example of lagoon ecological study in Morocco. It provided pioneer information on the spatial and seasonal changes of water quality parameters in the Oualidia lagoon. Our results indicated that this lagoon is an interesting, but exploited aquatic system than can therefore be weakened. That system thus needs further study as well as a scientific management plan in order to avoid its environmental degradation. In order to prevent drastic and potentially irreversible changes to the ecological character of the Oualidia lagoon, temporal trends in nutrient (NO₃⁻, NO₂⁻, NH₄⁺, PO₄³⁻, but also Si) and biological (phytoplankton and zooplankton) dynamics should be continuously monitored.

The data collected in this study will be useful to conceptualize the functioning of Oualidia lagoon ecosystem, using the measured state variables and forcing parameters, to develop the first ecological model of a Moroccan coastal zone.

Acknowledgments—The authors would like to thank Mr. Khbaya Bouchaib, Mr. Brahim Moutaki and the INRH staff for assistance during sampling collections. We thank Mr. Achtak and Mr. Nakhcha for assisting in statistical and cartographic data processing. My sincere thanks also go to Mr. Simone Libralato, Mr. Santanu Ray and Mr. Henri Tonnang for their help in English language. This research has been supported by “Centre national de la recherche scientifique et technique, CNRST (ScVie 12/11)” and “The World Academy of Sciences, TWAS NO: 11-225 RG/EAS/AF/AC_C”, we acknowledge this support. Z. Damsiri is a CNRST Scholar. We thank the anonymous reviewers for helpful comments.

References

1. Perilla O.L., Gómez A.G., Díaz C.A., Cortezón J.A.R. *Ecological Indicators* 13 (2012) 129-143.
2. El himer H. *PhD thesis, Cadi Ayyad University, Morocco* (2015) 202 p.
3. Deborde J., Anschutz P., Auby I., Glé C., Commarieu M.V., Maurer D., Lecroart P., Abril G. *Marine Chemistry* 109 (2008) 98-114.
4. Souza M.F.L., Kjerfve Knoppers B., Landim de Souza W.F., Damasceno R.N. *Estuarine Coastal and Shelf Science* 57 (2003) 843-858.
5. Hung J.J., Kuo F., *Estuarine Coastal and Shelf Science* 54 (2002) 887-900.
6. Collos Y., Vaquer A., Bibent B., Souchu P., Slawyk G., Garcia N. *Aquatic Ecology* 37 (2003) 227-236.
7. Natij L., Damsiri Z., Chaouti A., Loudiki M., Khalil K., Elkalay K. Accepted in *Journal of Materials and Environmental Science* (2016).
8. Pérez-Ruzafa A., Fernández A.I., Marcos C., Gilabert J., Quispe J.I., García-Charton J.A. *Hydrobiologia* 550 (2005) 11-27.
9. Damsiri Z., Natij L., Khalil K., Loudiki M., Rabouille Ch., Ettahiri O., Bougadir B., Elkalay K., *International journal of advanced research* (2) (2014 a) 609-618.
10. Damsiri Z., Natij L., Elkalay K., khalil K., Loudiki M. 2014b. *Science libre journal* 6 (2014b) (140701).
11. Day J.W., Christian R.R., Boesch D.M., Arancibia A.Y., Morris J., Twilley R.R., Naylor L., Schaffner L., *Estuaries and Coasts* 31 (2008) 477-491.
12. Liu S.M., Li R.H., Zhang G.L., Wang D.R., Du J.Z., Herbeck L.S., Zhang J., Ren J.L., *China Marine Chemistry* 125 (2011) 49-68.
13. Andersen H.E., Kronvang, B., Larsen S.E., Hoffmann C.C., Jensen T.S., Rasmussen E.K., *Science of the Total Environment Journal* 365 (2006) 223-237.
14. Afnor. 2nd edition. *French norms of "water, testing methods". Recueil* (1983) Paris.
15. Damsiri Z. *PhD thesis Cadi Ayyad University, Morocco* (2012).
16. Natij L., Damsiri Z., Khalil K., Loudiki M., Ettahiri O., Elkalay K., *International Journal of Advanced Research*, 2, Issue 6 (2014) 1022-1032.
17. Bennouna A., 1999. *PhD thesis, Faculty of Science, El Jadida, Morocco* (1999) 153 p.
18. El Attar J., Thesis 3rd cycle. Faculty of Sciences, El Jadida (1988) 124 p.
19. Ouldessaib E., Thesis 3rd cycle, Faculty of Sciences, El Jadida, Morocco (1997) 145 p.
20. Chbicheb A., *Thesis Doctoart. Univ. NANTES* (1996).
21. Shafee M.S., Sabatie M.R. *Aquaculture* 53 (1986) 201-214.
22. Asha P.S., Diwakar K.. *Journal of the Marine Biological Association of India* 49 (1) (2007) 07-11.
23. Rharbi N., Ramdani M., Berraho A., Lakhdar Idrissi A., *Marine life* 11 (1-2) (2001) 3-9.
24. Hilmi K., Orbi A., Lakhdar Idrissi J., *Bulletin de l'Institut Scientifique, Rabat, section Sciences de la Terre* 31 (2009) 29-34.
25. El himer H., *Personal communication in 1st Water Environment International Conference 26-29 October, Marrakech, Morocco* (2011).
26. Cremer H., Sangiorgi F., Wagner-Cremer F, Mcgee C., Lotter A.F., Visscher H., *Caribbean Journal of Science*, 43 (1) (2007) 23-58.
27. Barbantia U., Cocherelli V., Frascari F., Rosso G., Reggiani G., *Marine costal Eutrophication*, 2 suppl (1992) 475-488.
28. Kaimoussi A., Chafik A., Mousdahir A., Bakkas S. *Earth Planet Science* 333 (2001) 337-341.
29. Sarf F. Mem. géologie Navy. Mohamed V University, Rabat, Morocco (1995) 40 p.
30. Segar K., Hariharan V. *Journal Marine* 18 (1989) 170-173.
31. Daoudi M., Serve L., Rharbi N., El Madani F., Vouvé F. *Transitional Waters Bulletin* 6(1) (2012) 4-19.
32. De Casabianca M.L., Laugier T., Marinho-Soriano E. *Journal of Marine Science* 54 (1997) 905-916.
33. Badsı H., Oulad Ali H., Loudiki M., El Hafa M., Chakli R., Aamiri A. *African Journal of Environmental Science and Technology* Vol. 4(11) (2010) 751-762.
34. Traore A., Soro G., Kkouadio E., Barthélémy Siaka Bamba E.B., Marie Solange, O.G.A M.S., Soro N., Biemi J. *Int. J. Biol. Chem. Sci.* 6 (6) (2012) 7048-7058.

(2017) ; <http://www.jmaterenvirosci.com/>