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Study of the spatial and temporal variation of physical-chemical parameters characterizing the quality of surface waters of the lagoon Marchica – North-East Morocco

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Abstract

The study concerns the analysis of physical-chemical parameters (Temperature: T°, pH, electrical conductivity: E.C., dissolved oxygen: DO, orthophosphate: PO_4^{2-}, nitrate: NO_3^- and nitrite: NO_2^-) of the Nador lagoon in order to determine the effect of the new inlet on water quality of this lagoon. Thereby, water samples were taken at 11 different stations of the lagoon in October 2014, January 2015, April 2015 and July 2015. Our results show that the high concentration of NO_3^-, NO_2^- and PO_4^{2-}, found near the mouth of the Oued Selouan (station 8) was due to the terrigenous input received from that Oued and to the discharge of sewage effluent from wastewater treatment plants. However, at the Châala area (station 9) the high level of these nutrients could be due to Caballo river input. At the Kariat-Arekman area, the very low dissolved oxygen concentration may be caused by the degradation of organic matter, the very low hydrodynamics and to elevated temperatures. However, the high values of electrical conductivity and salinity found in this station could be due to a high temperature found in that station which increased the evaporation rate. For the remaining areas, the values obtained do not exceed the recommended threshold of good quality water; this is due to the renewal of the water of the lagoon through the channel that communicates with the open sea.

1. Introduction

Coastal lagoons are inland water bodies, usually oriented parallel to the shore, separated from the sea by a barrier, connected to the sea by one or more restricted inlets which remain open at least intermittently, and have water depths which seldom exceed a few meters [1]. These ecosystems occupy around 13% of the coastal areas worldwide and are important contributors to groundwater reservoirs, local and regional weather stability, preservation of biodiversity and also as water suppliers [1, 2]. Coastal lagoons are among the most productive ecosystems in the world [3, 4]. Human activity around coastal lagoons has increased considerably in recent years, and the impact on these productive and economically important environments has become a matter of concern in different lagoon around the world such as Thau pond in France, Venice lagoon in Italy and Moulay Bousselham in Morocco, Mar Menor in Spain and Ghar El Melh in Tunisia [5].

Because of their importance for human interests and their vulnerability, social concern is growing about the need to protect and manage coastal lagoons in an integrated and sustainable manner [6].

Nador lagoon, Marchica or Sebkha Bou-Areg, is a coastal system connected to the sea through an artificial inlet of 300 meters in width and 6.5 meters in depth. It is located on the northeast coast of Morocco (Figure 1), and it was classified as Ramsar site in 2005 and as a Site of Biological and Ecological Interest (SIBE) in 1996. In addition, this lagoon is considered one of the most productive areas of the Moroccan Mediterranean and plays an important biological and ecological role [7], it possesses a great biological wealth and it is of particular interest for some species of aquatic birds and fish and mollusk (the pink flamingo, European eel, large pearl, among others). In addition, the small-scale fisheries represent the main economic activity in the lagoon area [8].

Recently, this lagoon has been subjected to an increasing anthropogenic pressure owing to the growing population, agricultural and industrial wastes that are discharged directly or transported by various rivers into the lagoon [9]. These contaminants such as herbicides, pesticides, nitrogen and phosphate fertilizers, heavy metals... etc have negative impacts on both the stability of the natural lagoon system and on human health (intensification of eutrophication, contamination and disappearance of certain animal and plant species...). In 2011 a new pass, wide and deep, connecting the Mediterranean Sea to the lagoon Marchica was opened, allowing the renewal of the lagoon water throughout the basin. This new channel of 300 meters in width and 6.5 meters in depth improved the water quality of this aquatic ecosystem. The Physicochemical parameters such as temperature, pH, DO, turbidity, salinity, and nutrient are the most important parameters used to assess the pollution in different aquatic systems. These parameters have been reported to influence biochemical reactions within water systems and are used for testing the water quality of an aquatic ecosystem [10]. Such changes in the concentration of these parameters are indicative of changes in the condition of the water system [10]. The aim of this study was to evaluate the spatial and seasonal variability of physicochemical parameters in order to explain the sources and pollution status of Nador Lagoon and to evaluate the impact of the new pass and sewage treatment plant on the health status of this lagoon.

2. Materials and methods

2.1. *Study area*

Nador lagoon is the largest lagoon in Morocco, with a length of 25 km, a width of 7.5 km and an estimated area of 115 km^2. It is located on the northeast coast of Morocco between Cape Three Forks and Cape Water, more precisely between latitudes 35°05'N and 35°14'N and the longitudes 2°44'W and 2°56'W (Figure 1). It is separated from the sea by a coastal dune with an area of 760 ha oriented NW-SE. The lagoon still connects with the Mediterranean Sea through a new artificial channel of 300 meters in width and 6.5 meters in depth [11-13].

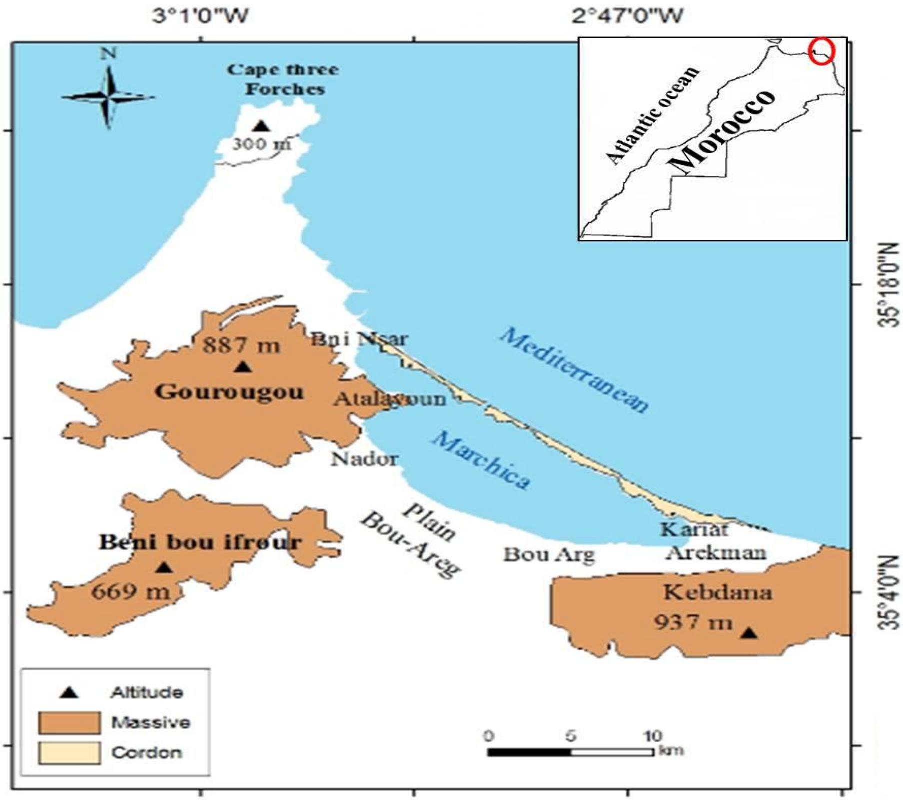


Figure 1: Location of the Nador lagoon [13] modified by Aknaf et al. (present study)

2.2. *Spatial distribution of sampling sites*

Analysis of physical-chemical parameters was performed in *Situ* and in laboratory. Eleven sampling stations have been performed in this study (Figure 2). The seawater samples were taken at -50 cm from the surface during the period 2014-2015.

2.3. *Methods of analysis:*

The study concerns the analysis of physical-chemical parameters (Temperature: T°, pH, electrical conductivity: E.C., dissolved oxygen: O_2, phosphate: PO_4^{2-}, nitrate: NO_3^- and nitrite: NO_2^-) of the Lagoon Nador in order to establish a diagnosis of the state of pollution of that water. Temperature, salinity and electrical conductivity (EC) were measured in situ by portable conductivity measuring instrument (Model Cond 197i). A pH-meter

(SUNTEXTS) was used to assess the pH of the water samples. The dissolved oxygen measurement was determined by Eutech DO 6+ Meter and Turbidimeters was used for turbidity determination.

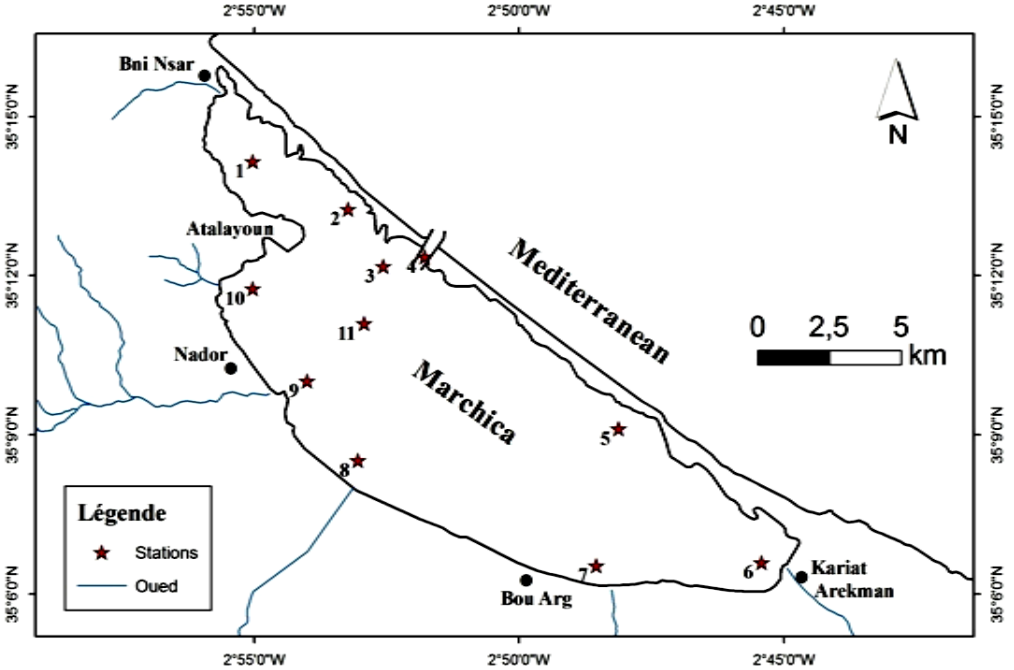


Figure 2: Map of the distribution of the sampling stations

The nitrates (NO_3^-) are determined by measuring the NO_2^- ions obtained from the quantitative reduction of NO_3^- ions by passing through a Cu-treated Cd column and the nitrites (NO_2^-) are determined by the method of Greiss by a visible UV spectrophotometer [14, 15]. Phosphates are determined by the method of Aminot and Chaussepied [15]. The phosphate ions react with ammonium molybdate in the presence of antimony (III) to form a complex which is reduced by ascorbic acid [14].

2.4. *Statistical analysis:*

In order to seek correlation between the different parameters governing the operation of the lagoon system, the Principal Component Analysis (PCA) was used. The data were processed using SPSS 21 software. Spatial variations in nutrient water elements are determined based on the Geographic Information System (GIS).

3. Results

3.1. *Spatio-temporal variation of physicochemical parameters (Table 1) and nutrients (Table 2) of the water of the lagoon.*

The change in water temperatures of the lagoon closely follows the atmospheric temperature and displayed a remarkable seasonal variation (Table 1 and Figure 3a). Indeed, the temperature varies between a minimum value of (14.5°C) registered in January 2015 at the station 5 and a maximum value of 31°C recorded in July 2015 at station 6 (Table 1 and Figure 3a). The temperature on all stations sampled is relatively homogeneous.

The results of pH didn't show remarkable variations with high pH values (8.46) in April 2015 at the station 6 and low values of 7.8 in July 2015 at the same station (Table 1 and Figure 3b). The electrical conductivity (EC) shows a clear sinusoidal evolution with a maximum in the summer of 2015 (58.6 ms/cm) at the station 6 and a minimum in April 2015 (53.1 ms/cm) at station 8 (Table 1 and Figure 3c). The salinity levels followed the same pattern as did the electrical conductivity, since the minimum was obtained in April 2015 at the station 8 with a concentration of 36.67 g/l and the maximum was recorded at the station 6 in July 2015 with 39.5 g/l (Table 1 and Figure 3d).

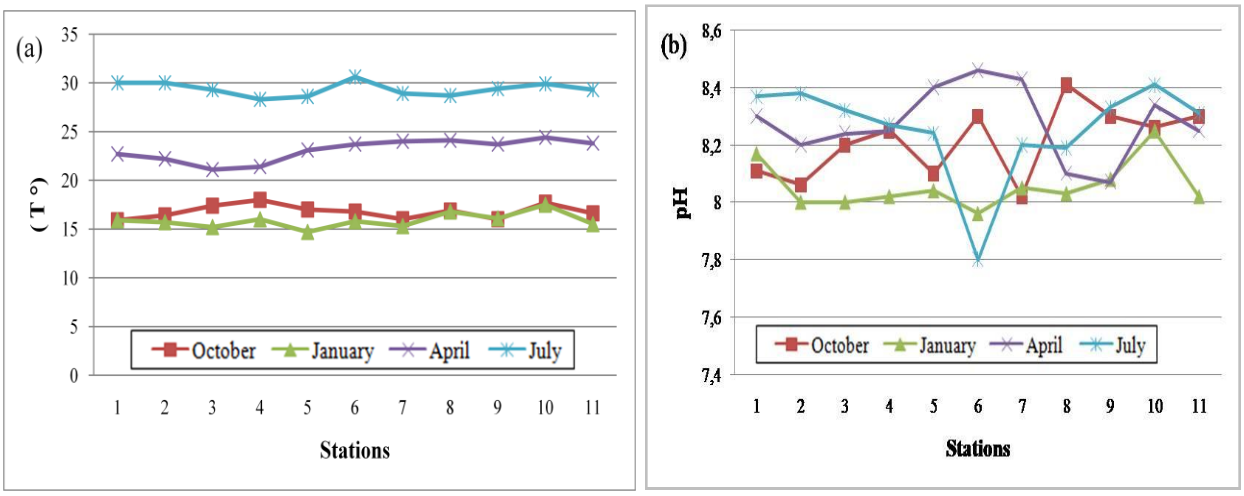
The concentration of dissolved oxygen in surface waters of the lagoon shows a temporal variability, the higher concentrations were found during the winter at the stations 8 and 10, reaching the values of 10.61 mg/l and 12.75 mg/l, respectively. However the low level was recorded in summer 2015 (2.5 mg/l) at the station 6 (Table 1 and Figure 3e). The spatial and temporal variation of turbidity shows that the lowest values were found in

October 2014 and April 2015 at the station1 (0.04 NTU) and the highest values were recorded during October 2014 (10.6 NTU) and April 2015 (18.5 NTU) at the station 10 (Table 1 and Figure 3f) for the other sites the water is clear.

Table 1: Spatio-temporal variations of the physicochemical parameters of water in the Nador lagoon

	Stations										
Parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Tm-October	15.9	16.4	17.4	18	17	16.8	16	16.9	16	17.7	16.6
Tm-January	15.9	15.7	15.2	16	14.7	15.8	15.3	16.8	16.1	17.5	15.5
Tm-April	22.7	22.2	21.1	21.4	23.1	23.7	24	24.1	23.7	24.4	23.8
Tm-July	30	30	29.3	28.3	28.6	30.6	28.9	8.32	29.4	29.9	29.3
pH-October	8.11	8.06	8.2	8.25	8.1	8.3	8.02	8.41	8.3	8.26	8.3
pH-January	8.17	8	8	8.3	8.04	7.96	8.05	8.03	8.08	8.25	8.02
pH-April	8.3	8.2	8.9	8.25	8.4	8.46	8.43	8.1	8.07	8.34	8.25
pH July	8.37	8.38	8.32	8.27	8.24	7.8	8.2	8.19	8,.33	8.41	8.31
EC-October	56.2	56	55.9	55	55.2	56.3	55.4	53.3	55.2	54.1	55.2
EC-January	65.1	56	56.1	55.9	56	55.8	55.6	55.5	55.2	55.5	55.3
EC-April	55	55.5	54.2	54.6	54.9	55.6	54.4	53.1	53.8	54	55.3
EC-July	57.8	58	55.5	55.1	55.7	58.6	55.5	54.8	55.7	55.3	55.4
Salinity-October	38.73	38.52	38.52	37.84	37.97	38.53	38.1	37.22	37.97	37.9	37.97
Salinity-January	38.6	38.5	38.6	38.46	38.4	38.52	38.25	38.16	38	38.16	38.04
Salinity-April	37.91	38.18	37.29	37.56	37.77	38.25	37.42	36.67	37.01	37.15	38.04
Salinity-July	38.9	39.2	38.18	38	38.32	39.5	38.18	37.7	38.32	38.04	38.11
DO-October	9.24	9.3	9.87	9.14	9.08	9.74	9.04	10.3	9.2	9.36	9
DO-January	12.3	10.01	9.88	9.33	9.62	6.49	9.54	10.61	9.82	12.75	9.2
DO-April	8.68	8.2	8.1	8.53	9.39	9.83	9.69	7.8	8.35	10.35	8
DO-July	7.16	7.9	9.02	8.6	8.45	2.5	7.32	6.86	5.78	6.15	8.38
Turb-October	0.25	1.08	2.2	2.79	0.23	2.22	1.2	0.9	2	10.6	1.23
Turb-January	2.65	3..15	12.3	1.45	1.75	1.6	1.17	3.77	6.21	2.39	1.86
Turb-April	0.04	018	1.04	1.05	046	0.88	12.97	7.78	16.27	18.5	10
Turb-July	6.95	0.66	0.81	0.93	1.17	4.56	1.2	9.79	7.56	1.21	2.31

Tm: Temperature; EC: Electrical Conductivity; DO: Dissolved Oxygen; Turb: Turbidity



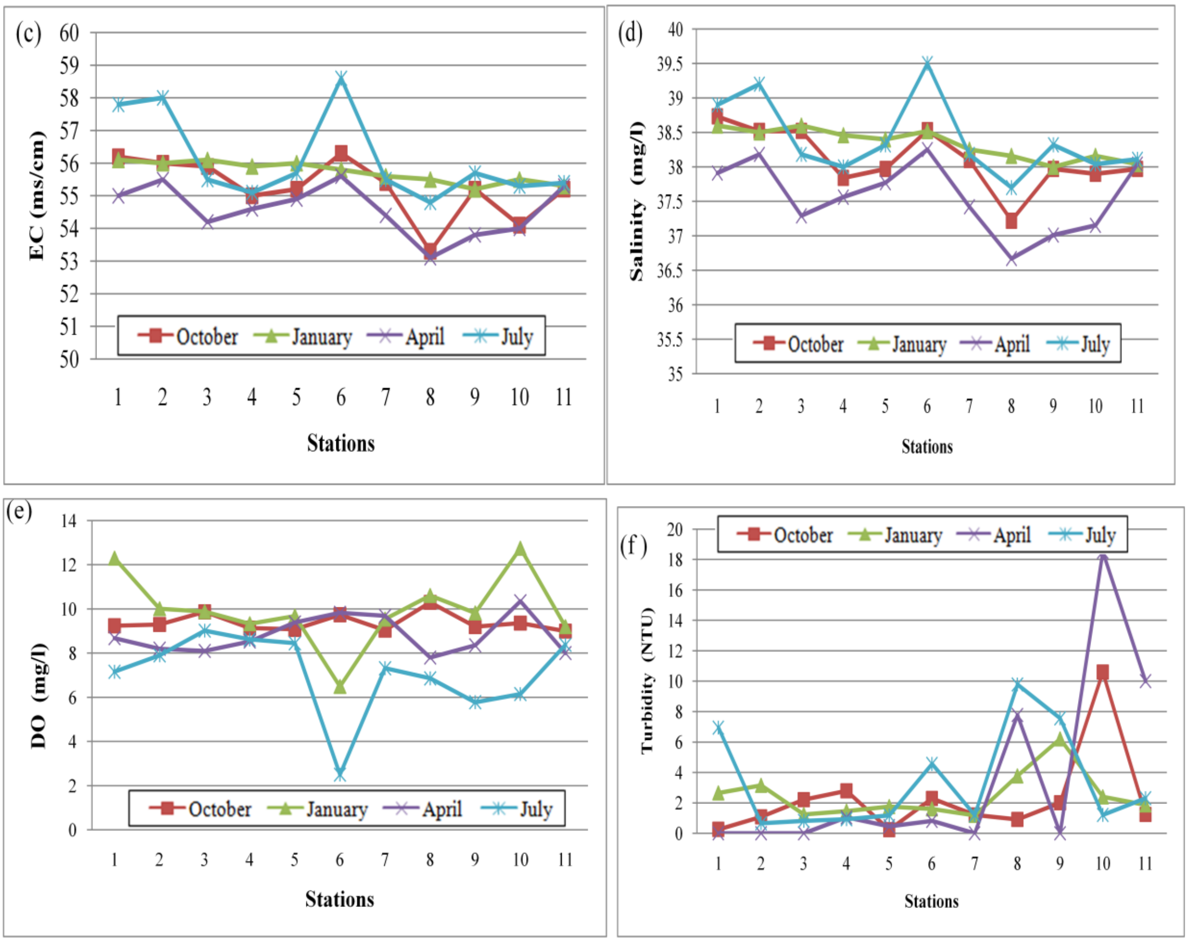


Figure 3: Spatio-temporal variation of the physical-chemical parameters in 2014-2015: temperature (a), pH (b), C.E (c), salinity (d), dissolved oxygen (e) and Turbidity (f).

Table 2: Spatio-temporal variations of nutrients in the water of the Nador lagoon

	Stations										
parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
NO_3^--October	0.02	0.051	0.033	0.036	0	0.052	0	0.071	0	0.05	0
NO_3^--January	0.116	0.037	0.012	0.102	0.015	0.021	0.233	0.204	0.07	0.1	0.14
NO_3^--April	0.024	0.2	0.2	0.023	0.036	0.021	0.074	1.4	1.9	0.072	0
NO_3^-- July	0.081	0.09	0.1	0.007	0.006	0.1	0.038	0.18	0.01	0.02	0
NO_2^--October	0.0106	0.004	0.004	0.008	0	0.01	0	0.007	0	0.0156	0
NO_2^--January	0.018	0.011	0.013	0.011	0,01	0.011	0.01	0.1	0.044	0.013	0.012
NO_2^--April	0.0003	0.0002	0.0005	0.0003	0.0004	0.0008	0.0015	0.005	0.012	0.0013	0
NO_2^-- July	0.015	0.002	0.014	0.012	0.005	0.011	0.02	0.016	0.006	0.011	0
PO_4^{2-}-October	0	0.008	0	0	0	0.14	0	0.301	0	0	0
PO_4^{2-}-January	0	0	0	0	0	0.004	0	0.047	0.127	0.008	0
PO_4^{2-}-April	0.008	0.008	0.006	0	0.006	0.006	0.21	0.095	0.137	0.03	0.04
PO_4^{2-}-July	0.007	0	0	0	0	0.008	0	0.018	0.019	0	0

Figure 4(g) and Table 2 present the nitrate concentration at different stations during October 2014, January 2015, April 2015 and July 2015. The high levels of nitrates were maximum at the station 8 in January and April 2015 (2.2 mg/l and 1.4 mg/l, respectively) and in station 9 in April 2015 (1.9 mg/l). Concerning nitrites (Table 2 and Figure 4h) the highest values (0,1 mg/l) were found in summer at the station 8 and the lowest values (0.0002 mg/l) were recorded in the spring at the station 2. For other stations concentrations remain within the range of French standards adapted to the context of the Mediterranean lagoons, established by the IFREMR [16].

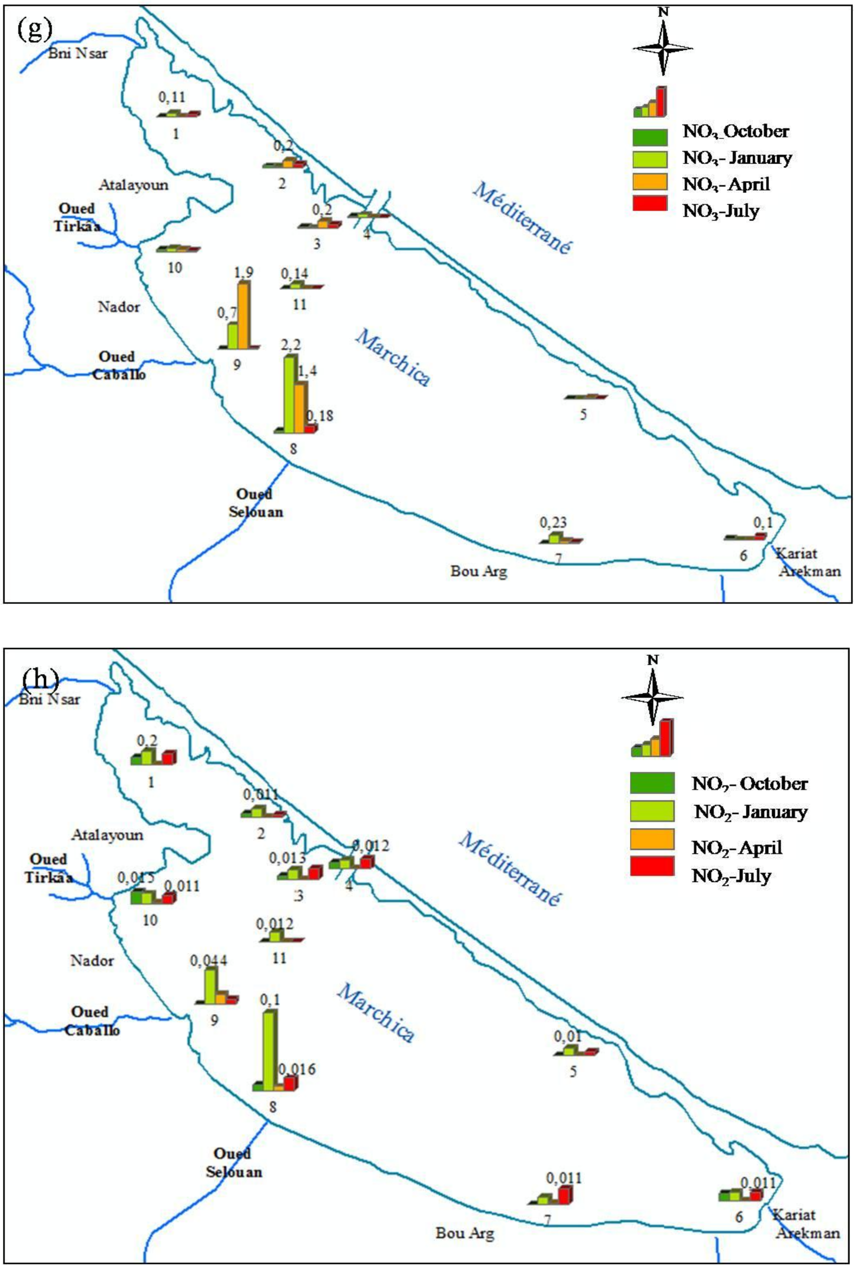


Figure 4. Spatio-temporal variation of nitrate (g) and nitrite (h) in Marchica lagoon.

Figure 5 and table 2 show spatial distribution and temporal variation of orthophosphates in Nador lagoon. The higher values were found in station 6 (0.14 mg/l in October 2014), station 7 (0.21 mg/l in April 2015), station 8 (0.30 mg/l and 0.13 mg/l, respectively in October and April) and station 9 (0.12 mg/l and 0.13 mg/l, respectively in January and April).

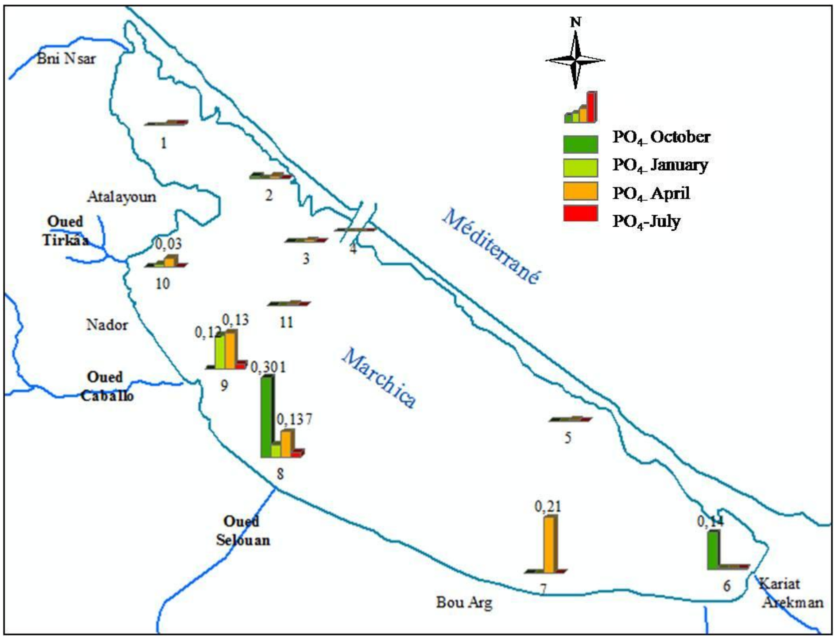


Figure 5: Spatial and temporal variation contents Orthophosphates at Nador lagoon (2014-2015)

3.2. Principal Component Analysis (PCA) (Figures 6 and 7)

In this statistical analysis, the rotation method used is the Varimax with Kaiser Meyer-Olkin (KMO=0.62). The PCA was applied to the contents of the waters of the lagoon of Nador NO_3^-, NO_2^-, PO_4^{2-}, and the variables: temperature, EC, salinity and O_2. The inertia carried by the two factors is of 795.6%, 57.15% for the factor F1 and 22.41% for the factor F2.

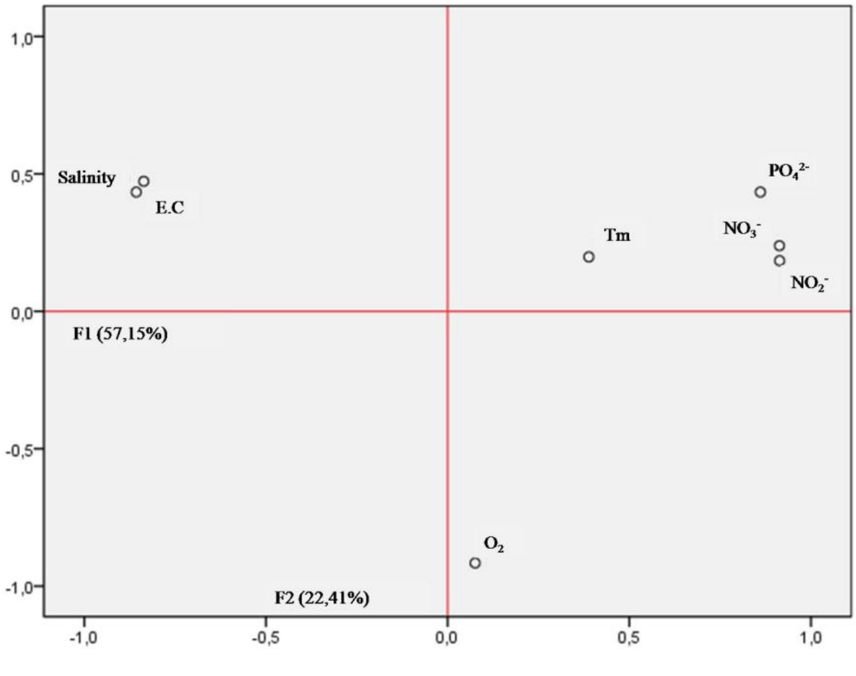


Figure 6. Built point cloud projection parameters studied in factorial designs.

The axis F1. Are well correlated positively between the elements NO_3^-, NO_2^-, PO_4^{2-} and Tm against the axis A2 is defined by the element O_2 who positively correlated with F1 axis, for the EC, salinity and temperature are correlated with the medium axis F1 and F2 (Figures 6 and 7).

Station 6 is characterized by a depth of 1.9 m. The column of water easily heats with increasing temperature and the resulting increase in salinity and electrical conductivity due to a large evaporation and the decrease of the dissolved oxygen.
Stations 8 and 9 show high levels of nutrients. The station 8 near the mouth of Oued Selouan and sewage characterized by the predominance to nitrogenous original organic matter and fertilizer use in agriculture in the plain of Bou-Areg. For the station 9, the prevalence was recorded orthophosphate compared with nitrogenous original development work in to the site.

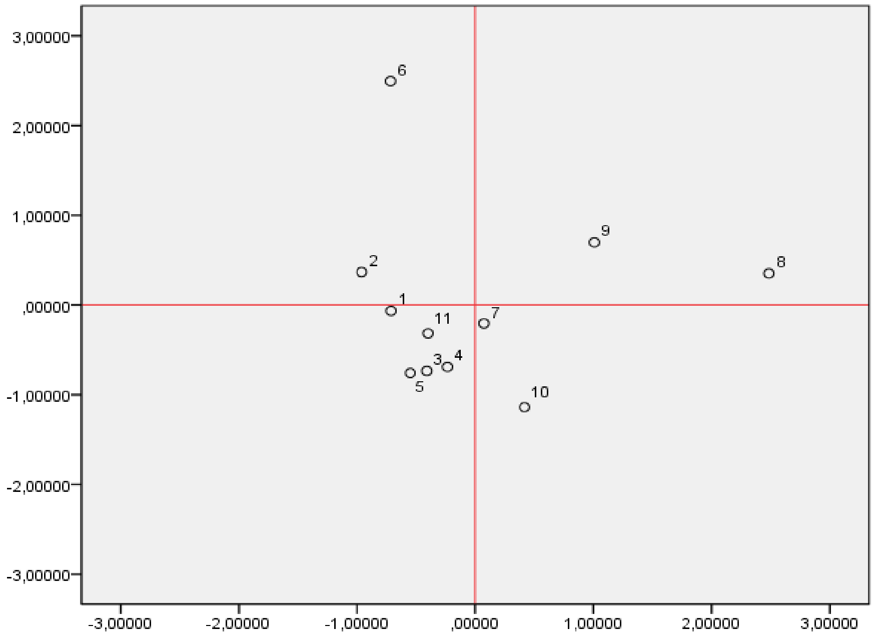


Figure7: Point cloud projection constructed by the stations studied in factorial designs

4. Discussion

In order to study the effect of water renewal rate in different area of the lagoon, we selected 11 stations along the lagoon. The results of this study highlight the important effect of the new pass and rivers outflowing to the lagoon on the spatial and temporal variability of physicochemical parameters and the quality of water in different sampling sites.
Indeed, before the opening of the new pass and the installation of the treatment plant in Bou-Areg area, the water quality of the lagoon of Nador experienced summer anoxia at the sites with high anthropogenic inputs (stations 7, 8, 9 and 10) and sites with low depths and proliferation of opportunistic algae such as *Chaetomorpha* [17]. The new inlet, wide and deep, connecting the Mediterranean Sea to the lagoon was opened allowing the renewal of the lagoon water through the basin. The salinity decrease from 42.2 g/l before the opening the new pass [18-20] to 40 g/l after the opening of the new pass [21].
The water temperature is one of the most important environmental parameters of an aquatic system. Water temperature is strongly influenced by the environmental conditions and to the geographical location of the different stations [22]. Water temperature of the Marchica lagoon varied significantly with sampling stations and showed a regular seasonal cycle with minimum reached in January and a maximum in July, and therefore did not appear to pose any threat to the lagoon system.
The pH is one of the most important quality parameters that is used to assess the state of the health of aquatic ecosystems. The pH of water in the Nador lagoon is between 7.8 and 8.46 characterized by very low spatial-temporal variations. This parameter is related to the development of macroalgae [23]. The high pH value (8.46) recorded in the station 6 in april 2015 is due to the algae growth during this period, increasing the consumption of CO_2 as part the photosynthesis process and consequently driving up the pH. The low pH (7.8) in July at the station 6 was explained by algal mortality period and the decomposition of plants and organic matter generated by eutrophication. The highest salinity and electrical conductivity values found at station 6 (Kariat Arkmen) was probably due to the shallowest depth of this station and to the low rate of water renewal in this site which is very fare from the inlet. The same results were found by El madani [24], Zerrouqi et al. [25], Ruiz et al. [26] and Abouhala et al. [27], suggesting that the highest value of salinity and electrical conductivity found in Kariat

Arkmen was due to the insufficient water renewal in this confined area. However, the lowest salinity value recorded at the station 8, was caused by enhanced freshwater flow into the lagoon from the Oued Selouan.
Seasonal variations in dissolved oxygen (DO) concentrations show that the Nador lagoon surface waters were well oxygenated (6.15 to 9.02 mg/l). These results were supported by those of [25], who reported the same values of dissolved oxygen (from 6.6 and 11.2 mg/l). High dissolved oxygen values are probably due to the good oxygenation of the surface water as a consequence of the new inlet which reduces the time (26 days) of the water residence in the Nador lagoon [28]. Whereas the lower DO found in summer was due to the algal growth cessation and algal death, which consume dissolved oxygen [29].
On the other hand, the high DO values found at the stations 8 during January and station 10 during January and April was due to bloom of algae including *Ulva lactuca Caulerpa prolefera* and *Gracilarea gracilis*, characterized by high primary production due to photosynthesis contributing to the oxygenation of bottom water [30] and the minimum value of oxygen was observed at the station 6 in July (2.5 mg/l) (Figure 3(e)), probably caused by the temperature rise which reduced the levels of dissolved O_2 [24] and by Low rates of water renewal. In relation to the turbidity (Figure 3(f)), the higher values found in sites 8, 9 and 10, were probably due the Oued Selouan and Oued Tirkâa flows into these stations.
The results of nutrient concentration in lagoon water showed that the levels of nitrates and nitrites exceeded the levels proposed by IFREMER [16], especially at the stations 8 and 9. These stations receive terrigenous inputs from Oued Selouan and Oued Caballo, respectively. Oued Caballo transport urban wastewater of Zeghanghane municipality and partly of Nador city and Oued Selouan (Selouan stream) carries the urban and industrial wastes of the Selouane village into the lagoon [31]. The agricultural activities in the Bou Areg area are also the main source of surface and groundwater pollution by nitrate, nitrite and phosphate in Marchica lagoon. On the other hand the waste-water treatment plant is unwittingly increasing these nutrients in the lagoon system.
Concerning orthophosphates, whose concentration at the stations 6, 7, 8 and 9 exceeded the standards promulgated by IFREMER [16] was probably caused by the deposition of organic matter, produced by the large macroalgal biomass who develops in these stations every year in springtime and causing the accumulation of phosphorus [24], while the low PO_4^{2-} levels recorded at the pass and throughout the lido can be explained by high water renewal rate. Finally, our results suggested that the decrease in waste water discharges into the lagoon and to the opening of the new pass that affected positively the physic-chemical parameters and improves the water quality of the lagoon [9].

Conclusions

Study of physico-chemical parameters of water in the Nador Lagoon (Marchica) highlighted that the installation of the wastewater treatment plants and the opening of the artificial inlet whose width is 300 meters and depth is 6.5 meters have positively affected the oxygenation of the surface water and reduced the eutrophication of the lagoon. However, the agricultural activities in Bou Areg area and the river inputs increased significantly the pollution of the lagoon, thus the development of a sustainable agriculture and the upstream water treatment directly cuts off incoming pollutants to the lagoon.

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