Climatic changes, hydrology and trophic status of Lake Oubeira (extreme northeast of Algeria)

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Abstract. The Oubeira is the largest freshwater lake situated in the extreme eastern north part of Algeria. It is more particularly regarded as an integral part of El-Kala National Park. It is located in one of the most watered regions of the country between 800 and 900 mm. In order to characterize it from the hydrological point of view, a follow-up and a bi-monthly analysis of the volume waters and various parameters such as temperature, pH, dissolved oxygen (DO) , ammonium (NH_4), nitrates (NO_3), nitrites (NO_2), orthophosphate (PO_4), dissolved organic nitrogen (DON), dissolved organic phosphate (DOP), suspended particulate matter (SPM), particulate organic carbon (POC) and chlorophyll *a* were carried out between March 2004 and April 2005. The temperature of the water is similar across the whole surface of the lake and varies between 8 and 22°C. The pH is slightly acid to slightly alkaline and ranges from 6.2 to 8.9. Dissolved oxygen contents are viable with a maximum of 8.98 mg L^{-1}. The water volume of the lake ranges from 23 x 10^6 to 59.70 x 10^6 m^3 from one season to another. There is some compensation between the values of dissolved nutrients and organic matter over the study period. The concentrations of dissolved nutrients ranged from 0 to 21.50 µmol L^{-1} for ammonium (NH_4), from 0.038 to 21.58 µmol L^{-1} for nitrates (NO_3), and from 0 to 0.38 µmol L^{-1} for orthophosphates (PO_4), and for dissolved organic nitrogen (DON) from 0.58 to 67.17 µmol L^{-1} and also dissolved organic phosphorus (DOP) from 0 to 2.87 µmol L^{-1}. The highest concentrations of the chlorophyll *a* are measured during the dry season and evolve from 7.58 to 394.52 mg m^{-3}. We consider that our lake passes through two trophic states. A phase through which waters of the lake are mesotrophic when the rate of renewal of the waters is important from January to May. A second phase in which waters of the lake are hypereutrophic favored is in summer season extending from June to September. This leads to the reduction of lake waters to their lowest levels. Climate warming, rainfall patterns in the study area, and the extent of clogging of the lake outfall have a major impact on the evolution of the lake waters. These phenomena could plunge the lake into an era of strict endoreism that will swing its waters towards total destruction and will result in the filling of the basin of the lake.

Key Words: Oubeira Lake, dissolved nutrients, chlorophyll *a*, suspended solids, water flow.

Introduction. The Northeast of Algeria is the central site of the main wetlands lagoons and rivers with great ecological, cultural and economic features (Bouhaddada et al 2016; Mammeria et al 2019; Marcos et al 2019). Algeria ratified the Ramsar Convention in 1982, counting 50 wetlands, covering more than 50% of the estimated total area of wetlands in Algeria, of which 762 are natural and 689 are artificial (Mammeria et al 2019). Lake Oubeïra is among the best example of natural wetlands in the Mediterranean region. This lake wetland complex comes in third position after the Ebro Delta in Spain and the Camargue in France (Samraoui & Belair 1998). It has been classified as a Ramsar site since 1983 and an "Integral Nature Reserve" of El-Kala National Park, which is the most important wetland complex in the Maghreb (Van Dijk & Ledant 1983). The lake hosts a variety of rare flora and fauna species and receives migratory wild water birds, the largest numbers of these species counted at the beginning of winter (Loucif et al 2009; Bouhaddada et al 2016; Sarri 2017). The lake wetland complex and its surrounding area are an important wintering ground for many rare and sedentary species (De Belair 1990). Also they are an important feeding ground for species that nest in other wetlands in the region, such as ducks, mustachio and black terns (*Chlidonias hybrida* and *Chlidonias niger*), purple herons and squacco heron (*Ardea purpurea* and *Ardeola ralloides*), the little egret (*Egretta garzetta*) and heron guard beef (*Bubulcus ibis*) (Boulahbel 1999). Lake Oubeira is the unique site in the region that has a typical spatial organization of vegetation belts (Helophytes). A large area of the lake is colonized by floating Hydrophytes such as: water chestnut (*Trapa natans*), only found in the Lake Oubeira in Algeria and white water lily (*Nymphaea alba*) and yellow water lily (*Nuphar luteum*) found only in the Lake Oubeira which is the only North African station for this species (Samraoui & Belair 1998). At the end of the 1980s, our regions suffered from drought, which caused the total drying of the lake waters in 1990 and caused a large number of wildfires (Benyacoub & Chabi 2000). The combination of these factors with the hard rainy season amplify significant erosion phenomena in the lake's watershed (Dechemi et al 2000). This is main characteristic of the Mediterranean climate, which is not without effect on the relief, and it leads to an intense and continuing erosion phenomenon (Marre 1987). All these events have a great impact on the biological balance and the functioning of our aquatic ecosystem. Messerer (1999) reported that the lake basin faces a signification siltation problem (33% of the lake basin) and a considerable clogging of its emissary. These modifications produce several disturbances in the Lake Oubeira ecosystem. A decrease in the diversity of flora and fauna species observed in the study of Benyacoub (1993) and a significant proliferation of phytoplankton blooms with a predominance of Cyanobacteria found in the studies of Bensouillah et al (2003) and Branes (2007).

To our knowledge, information and studies on Lake Oubeira are still rare except for some studies on lake hydrology. The main efforts have focused on aquaculture and fishing exploitation, ecology and biodiversity of marine species (eg: Derbal et al 2006; Nasri et al 2008; Meddour & Bouderda 2011; Brahmia et al 2016). Despite the importance of biogeochemical and particulate matter parameters in the marine ecosystem, these parameters were neglected in lots of published studies. This significant lack on data affects considerably the publication speed of this work in the right possible time. This work aims to complete the scarcity of physicochemical and particulate matter parameters and gives a general overview of the state of the lake oubeira.

The main objectives of this work were to:

- complete the scarcity in biogeochemical and particulate matter parameters knowledge;
- monitor the evolution of lake water volume, dissolved inorganic and organic nutrients, mineral and organic particulate matter and finally asses the chlorophyll *a* mass during the study period;
- describe the causes of the evolution of particulate fractions, the chlorophyllian mass and their relationship with all the materials;
- determine the trophic state of the lake.

Material and Method

Description of the study sites. Lake Oubeira is located in the extreme northeast of Algeria, at 36°50′ N and 38°23′ E and at 25 m altitude. The Lake is situated 5 km as the crow flies from the Mediterranean Sea and 10 km from the city of El Kala. Figure 1 shows that Lake Oubeira is situated inside the El-Kala National Park in the wilaya of El-Tarf. It is located in one of the most important watered areas of Algeria, which is limited by isohyet curves 800 and 900 mm (ANRH & Labord 1990) and it is the largest freshwater lake in the country. The lake is part of Mafragh catchment because it is considered as sub-basin of El-Kebir-East River (ABH-CSM 2000; Labar 2003). The Lake Oubeira watershed covers a surface area of 99 km^2, with a moderate relief and water body with a surface area of 24 km^2 (Messerer 1999). It has an immature and undeveloped hydrographic network consisting of four wadis of order 4 (Messerer 1999). The Messida Wadi is located in the south-east part of the lake and plays the role of principal emissary. This wadi is linked to Wadi El-Kebir-East especially during flood periods (Labar & Alayat 2002).

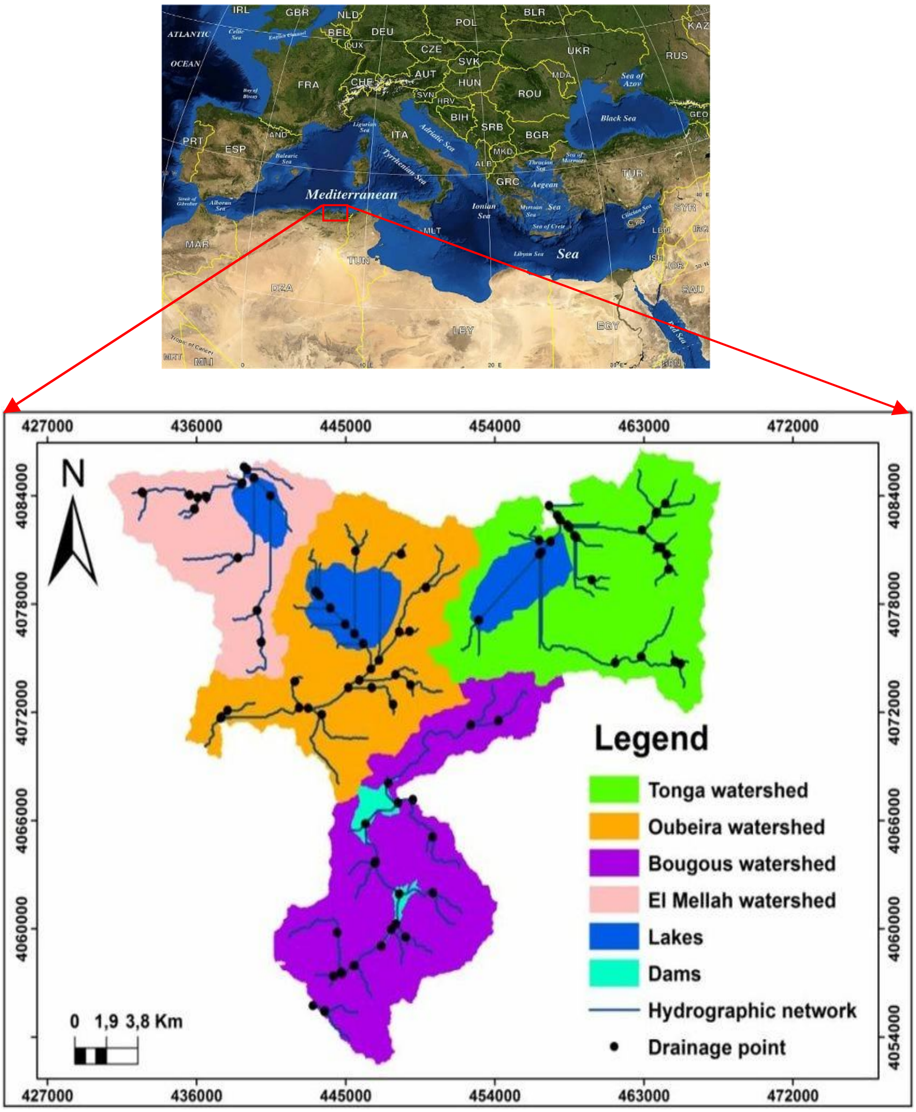

Figure 1. Map shows the location of Oubeira Lake in the boundaries of El-Kala National Park (EL-Tarf Wilaya) modified from Khallef et al (2018).

Analytical methods. Water sampling and various measurements were carried out bimonthly from March 2004 to April 2005, except for bathymetry measurements which were extended to June 2005. Water sampling and physicochemical analyses of lake surface water were measured and treated in the same year, but comparison and discussion of the results was blocked and required a lot of time to collect the necessary information due to scarcity on biogeochemical parameters and particulate matter data in the lake.

Physicochemical analyzes of lake surface water were measured at five stations spread reasonably across the lake. The stations (St A), (St B) are located north and east facing the wadis that feed the lake, the station (St D) is located south in the trajectory of its emissary, the station (St C) is situated in the center, while the station (St E) is located in the west protected from the effects of dominant winds. Temperature (T °C), pH, dissolved oxygen (DO) were measured in situ in the lake by a multi parameter consort c535 and water transparency (Tr) was measured by secchi disk. Bathymetry of the lake was carried out through twelve parallel transects. The bathymetric measurements were realized on verticals according to layer of water and treated using surfer software 8. The determination of nitrates (NO_3), nitrites (NO_2), ammonium (NH_4), orthophosphate (PO_4) and dissolved organic phosphorus (DOP) were analyzed according to the methods of Rodier et al (1996). The dissolved organic nitrogen (DON) measured according to the method of Parsons et al (1984). Chlorophyll a (Chl *a*) was determined by modified method of Lorenzen (1967). The suspended particulate matter (SPM) were measured after filtration on Whatman GF / C, filter dried at 105°C for 24 hours according to the standard method of AFNOR (1978). Particulate organic carbon (POC) was determined by the Corre method according to the manual of Aminot & Chaussepied (1983).

Statistical analysis. In order to understand the relationships between all dissolved and particulate materials, Pearson's linear correlation matrix was performed between the fourteen physicochemical studied materials. The data were statistically analyzed using Minitab statistics software.

Results. Figure 2a shows that temperature in lake waters is almost similar at the five sampling stations. They reflect seasonal temperatures with annual average of 19°C. The highest temperatures were measured between May and October and fluctuated from 22 to 29°C. The lowest temperatures were measured between December and February and recorded values ranging from 8 to 12°C.

According to Figure 2b, the pH of the waters had a slightly alkaline tendency from April to the end of November, with values ranging from 8 to 8.9. During the winter (from December to March), pH values reflected neutral to slightly acidic waters with values ranging from 6.2 to 7.5.

Figure 2c shows that the highest concentrations (7 to 8.98 mg L^{-1}) of DO are measured between the months of March to April 2004 and from November to March 2005. The lowest values (5.40 to 6.70 mg L^{-1}) are measured between May and the end of October 2004.

Figure 2d indicates the fluctuation of lake water volumes and their mean depths produced between two successive hydrological years. The wet season of the first hydrological year is represented only by its last months (March, April and May). The maximum water volume of 41.5 x 10^6 m^3 and the greatest depth of 1.80 m were measured during the flood period of April 2004.

The dry period of the first hydrological year starts from June 2004 and ends at the end of October 2004. During this period, the minimum water volume is 23 x 10^6 m^3 and the smallest average depth is 1 m. The second hydrological year starts from November 2004. The wet season of the second year (flood period) shows during the month of May 2005 a maximum volume of 59.70 x 10^6 m^3 and the greatest average depth of 2.60 m. The dry period (recession period) of this second hydrological year is limited only to measurements taken during June 2005. This period is marked by a significant decline in the volumes and depths of the lake's water. According to Figure 3a the concentrations of ammonium (NH_4) varied from 0 µmol L^{-1} (during several dates and stations) to 21.50 µmol L^{-1} (St C 31.I.05) and this implies averages of ammonium waters ranging from 0 to 17.60 µmol L^{-1}. The highest levels of ammonium (NH_4) in lake waters occurred between September 2004 and February 2005. The average monthly concentration of (NH_4) was 4.11 µmol L^{-1} and it is depending on the station: 4.50 µmol L^{-1} (St A), 4.80 µmol L^{-1} (St B), 4.40 µmol L^{-1} (St C), 3 µmol L^{-1} (St D), and 3.90 µmol L^{-1} (St E).

Figure 3b shows that nitrate (NO_3) concentrations ranged from 0.038 µmol L^{-1} (St E, 16.X.04) to 21.58 µmol L^{-1} (St D, 16.III.05), commuting the averages of nitrate waters ranged from 0.05 µmol L^{-1} to 19.47 µmol L^{-1}. It should be noted that the lowest levels of nitrates (NO_3) occurred during 08 months from May to the end of December. The monthly average of nitrate was 5 µmol L^{-1} and expressed in the following concentrations per station which are: 5.75 µmol L^{-1} (St A), 5.50 µmol L^{-1} (St B), 5.27 µmol L^{-1} (St C), 5.86 µmol L^{-1} (St D), and 4.53 µmol L^{-1} (St E).

The concentrations of nitrites (NO_2) are very low and according to Figure 3c, their values varied from 0 µmol L^{-1} (during several dates and stations) to 2.54 µmol L^{-1} (St A, 18.IX.04). The average annual concentrations of NO_2 in the Lake water ranging from 0.018 to 0.74 µmol L^{-1}. The monthly average concentration of NO_2 in the water was 0.36 µmol L^{-1}, followed by its distribution in each station: 0.41 µmol L^{-1} (St A), 0.33 µmol L^{-1} (St B), 0.33 µmol L^{-1} (St C), 0.36 µmol L^{-1} (St D), and 0.37 µmol L^{-1} (St E).

Figure 3d indicates that orthophosphate (PO_4) was present in waters from August with concentrations ranging from 0 µmol L^{-1} (during several dates and stations) to 0.38 µmol L^{-1} (St B, 28.IX.04). As a result, the orthophosphate (PO_4) average values changed from 0 to 0.27 µmol L^{-1}. The monthly average of orthophosphate waters was 0.041 µmol L^{-1} and is distributed from one sampled station to another: 0.031 µmol L^{-1} (St A), 0.046 µmol L^{-1} (St B), 0.033 µmol L^{-1} (St C), 0.052 µmol L^{-1} (St D), and 0.04 µmol L^{-1} (St E).

Figure 3e indicated that the concentrations of DON showed large differences between all values. They fluctuated from 0.58 µmol L^{-1} (St E on 06.VIII.04) to 69.17 µmol L^{-1} (St D on 26.VII.04) and this produced averages of DON ranged from 2.32 to 53.24 µmol L^{-1}. The monthly average value of DON was 18.83 µmol L^{-1}, distributed in ascending order through the sampled stations: 12.12 µmol L^{-1} (St A), 17.80 µmol L^{-1} (St E), 18.72 µmol L^{-1} (St B), 20.54 µmol L^{-1} (St C), and 25 µmol L^{-1} (St D).

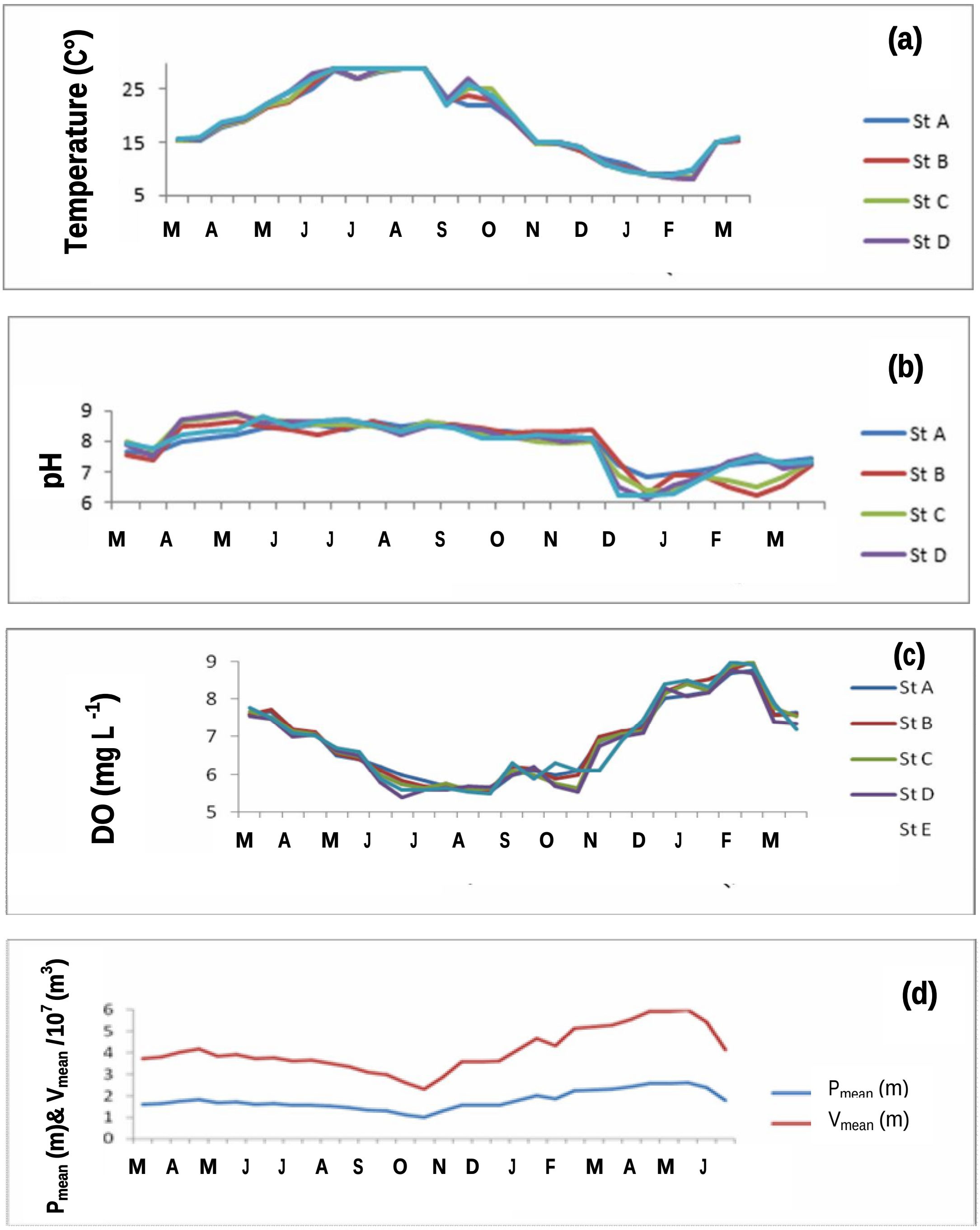

Figure 2. Spatio-temporal evolution of the physicochemical factors, water volume and their mean depth in Lake Oubeira: (a) temperature, (b) pH, (c) dissolved oxygen, (d) V_{mean}: volume/(10^7 m^3) and P_{mean} (m): average depth.

The concentrations of DOP showed remarkable fluctuations (Figure 3f). The DOP concentrations ranging from 0 µmol L^{-1} (during several dates and stations) to 2.87 µmol L^{-1} (St A, 31.III.05) indicating averages of DOP concentrations varied from 0.0024 to

1.47 µmol L^{-1}. The average monthly concentration of DOP was 0.46 µmol L^{-1}. In the D and A stations the DOP measured 0.75 and 0.58 µmol L^{-1} respectively, followed by the values of 0.33 µmol L^{-1} in (St B), 0.31 µmol L^{-1} in (St E), and 0.30 µmol L^{-1} in (St C).

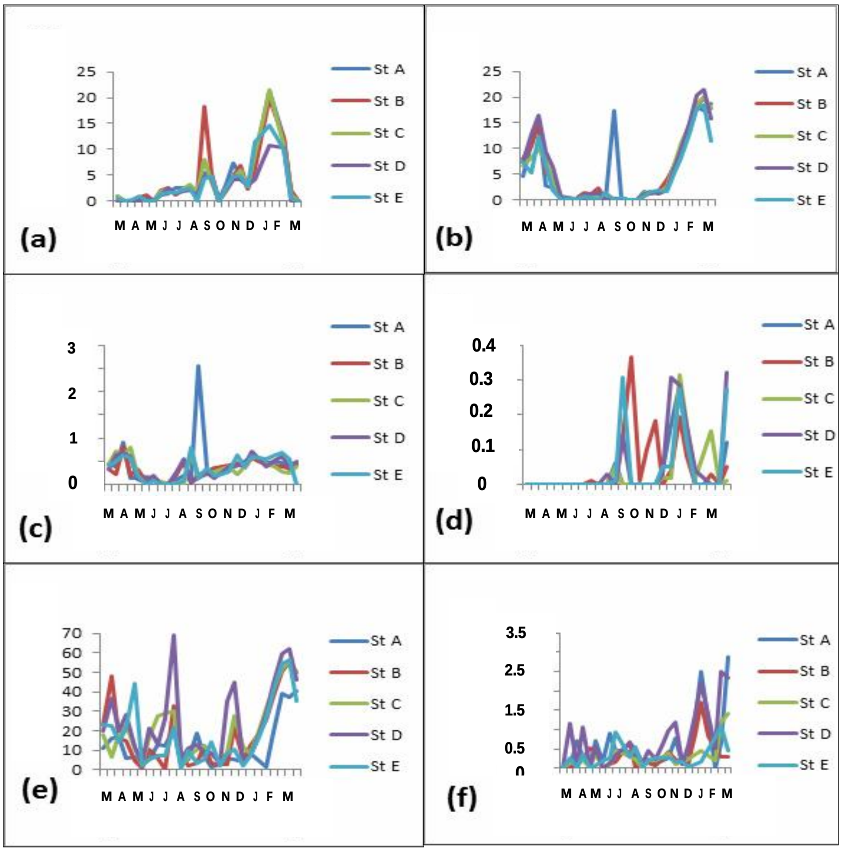

Figure 3. Spatiotemporal evolution of dissolved nutrients (µmol L^{-1}) in Oubeira lake waters: (a): ammonium (NH_4), (b): nitrates (NO_3), (c): nitrites (NO_2), (d): orthophosphate (PO_4), (e): dissolved organic nitrogen (DON) and (f): dissolved organic phosphorus (DOP).

The mean concentration of POC ranged between 0.40 mg L^{-1} (St E 23.V.04) and 21.30 mg L^{-1} (St B 23.V.04), which induced an averages concentrations ranging from 1.59 to 19.56 mg L^{-1}. The monthly average concentration of POC was 9.78 mg L^{-1} and varied through the sampled stations in descending order as follows: 10.41 mg L^{-1} (St B), 10.34 mg L^{-1} (St D), 9.91 mg L^{-1} (St C), 9.28 mg L^{-1} (St A), and 8.92 mg L^{-1} (St E) (Figure 4a).

According to Figure 4b the concentrations of SPM did not have a regular tendency. They varied between 2.5 mg L^{-1} (St E 23.V.04) to 169 mg L^{-1} (St B 23.V.04). This fluctuation produced averages values of SPM fluctuated from 10.34 to 122 mg L^{-1}. The monthly average concentration of SPM was 51.57 mg L^{-1} and expressed through each sampled station with a content of: 44.95 mg L^{-1} (St A), 65.32 mg L^{-1} (St B), 54.08 mg L^{-1} (St C), 57.50 mg L^{-1} (St D), and 35.97 mg L^{-1} (St E).

Figure 4c shows that for the same sampling companion, Chl *a* concentrations had the same tendency over the whole surface of the lake waters. In contrast, at the temporal scale the concentration of Chl *a* showed big differences. Its concentrations varied between 7.58 to 394.52 mg m^{-3} at (St C 31.III.05) and (St C 18.IX.04) respectively. During the study period, the mean Chl *a* concentration ranged from 13.27 to 311.60 mg m^{-3} with a monthly average concentration of about 85 mg m^{-3}. The mean Chl *a* in all sampled stations is given in the following order: 92.20 mg m^{-3} (St C), 87.37 mg m^{-3} (St D), 83.07 mg m^{-3} (St A), 80.91 mg m^{-3} (St B), and 79.94 mg m^{-3} (St E).

The transparency of the lake waters was characterized by very low values ranging from -0.20 (St E, in several dates) to -0.50 m (St D, 31.III. 05) (Figure 4d). The mean water transparency ranged from -0.23 to -0.47 m with monthly value of -0.32 m. The water transparency distributed through the sampled stations with the values of: -0.29 m (St E), -0.31 m (St A and St B), -0.33 m (St C) and -0.36 m (St D).

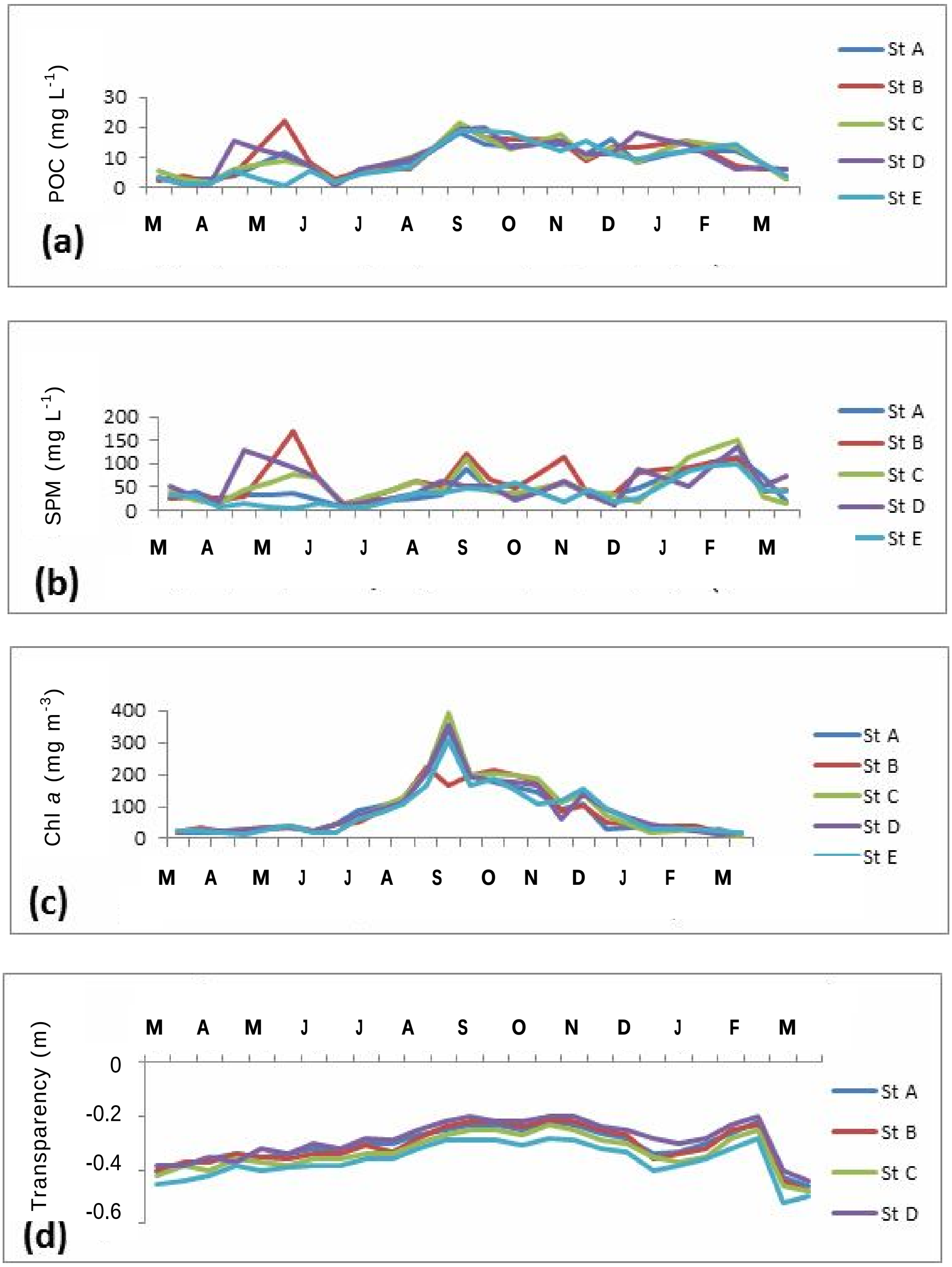

Figure 4. Spatio-temporal evolution of particulate matter and transparency in Lake Oubeira waters: (a) particulate organic carbon (POC), (b): suspended matter (SPM), (c): chlorophyll *a*, and (d): water transparency.

Table 1 describes the Pearson correlation matrix of the fifteen parameters determined for this study. Examination of the correlation matrix indicates that there are positive and negative correlations. Temperature (T°C) is positively correlated with pH and negatively correlated with DO, volume (V), mean depth (P_{mean}) and dissolved mineral nitrogen (NH_4, NO_2, NO_3) with a threshold value of ($p < 0.001$). The volume of water and its mean depth are positively correlated ($p < 0.001$) with DO, transparency (Tr) of water, NO_3, DON, DOP and negatively with Chl *a*, POC and pH. The DOP was positively correlated with orthophosphates, nitrates, and DON. In the lake surface water DON was highly correlated ($p < 0.001$) with nitrates. The Chl *a* was positively correlated with POC and negatively correlated with DO. In the Lake Oubeira Chl *a* was highly and significantly ($p < 0.001$) correlated with water transparency, nitrates and DON ($p < 0.001$) and significantly correlated ($p < 0.05$) with DOP.

Table 1

Pearson's linear correlation matrix between the physicochemical factors studied in Lake Oubeira

	NH_4	NO_2	NO_3	PO_4	*DON*	*DOP*	*POC*	*SPM*	*Chl a*	*pH*	*T°C*	*DO*	V_{mean}	P_{mean}	*Tr*
$\mathrm{NH_4}$	**1**														
$\mathrm{NO_2}$	0.26	**1**													
	0.04														
$\mathrm{NO_3}$	0.20	-0.49	**1**												
	0.11	0.00													
$\mathrm{PO_4}$	0.08	0.13	0.22	**1**											
	0.55	0.30	0.08												
DON	0.10	0.14	0.76	0.20	**1**										
	0.42	0.26	0.00	0.12											
DOP	0.23	0.12	0.49	0.45	0.42	**1**									
	0.06	0.36	0.00	0.00	0.00										
POC	0.46	0.13	-0.26	0.11	-0.32	0.01	**1**								
	0.00	0.32	0.04	0.38	0.01	0.97									
SPM	0.61	0.20	0.34	0.11	0.19	0.23	0.54	**1**							
	0.00	0.11	0.01	0.38	0.14	0.10	0.00								
Chl *a*	0.02	0.01	-0.54	-0.03	-0.48	-0.26	0.70	-0.01	**1**						
	0.87	0.96	0.00	0.84	0.00	0.04	0.00	0.95							
pH	-0.57	-0.38	-0.51	-0.35	-0.36	-0.32	-0.13	-0.28	0.27	**1**					
	0.00	0.00	0.00	0.01	0.01	0.01	0.30	0.03	0.03						
T°C	-0.57	-0.55	-0.63	-0.23	-0.39	-0.33	-0.15	-0.42	0.35	0.82	**1**				
	0.00	0.00	0.00	0.07	0.00	0.01	0.25	0.00	0.01	0.00					
DO	0.56	0.50	0.73	0.18	0.49	0.33	-0.03	0.44	-0.52	-0.80	-0.95	**1**			
	0.00	0.00	0.00	0.15	0.00	0.01	0.85	0.00	0.00	0.00	0.00				
$\mathrm{V_{mean}}$	0.22	0.21	0.83	0.24	0.71	0.53	-0.41	0.25	-0.76	-0.50	-0.49	0.67	**1**		
	0.07	0.01	0.00	0.06	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00			
$\mathrm{P_{mean}}$	0.21	0.22	0.84	0.24	0.71	0.53	-0.42	0.24	-0.76	-0.50	-0.49	0.67	1.00	**1**	
	0.09	0.08	0.00	0.06	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00		
Tr	0.32	0.03	0.44	-0.04	0.33	0.13	-0.68	-0.32	-0.68	0.12	0.08	0.24	0.60	0.60	**1**
	0.01	0.84	0.00	0.78	0.01	0.32	0.00	0.01	0.00	0.34	0.52	0.06	0.00	0.00	

Discussion

Environmental factors. The lake water was characterized by near neutral pH ranged between 6 and 9. The same values were recorded by Amri (2008), Meddour & Bouderda (2011), Alayat et al (2014), Bendjama et al (2016). This near neutral pH had an effect on the physiological activities of organisms and the biological diversity of the lake (Stumm & Morgan 1996; Herkovits et al 2015). During winter, the pH levels were among the lowest values recorded during the study period. This is due to the influence of the continental water delivering from the Lake Oubeira catchment. For example, depending on the type of vegetation community present in the lake, these waters may contain large amounts of acidifying organic substances (Hade 2002). In contrast, pH values that were slightly alkaline can be controlled by the activity of various aquatic organisms and particularly the importance of photosynthesis process (Dussart 1966; Herkovits et al 2015). Monthly variations in lake water temperature flows the atmospheric temperature (Wetzel 2001; Jacobsen & Dangles 2017). This main factor acts on the solubility of salts and gases, and affects the whole ecosystem (Fieux et al 2017). Concentrations of dissolved oxygen in lake waters support the regular life of aquatic organisms (Water watch Australia Steering Committee 2003). The highest levels of dissolved oxygen occurred during low and medium water temperature, however the lowest oxygen concentrations coincide with the highest temperatures (Amri 2008; Bendjama et al 2016). Despite the difference in the concentration of dissolved oxygen in the lake from one season to another, values of dissolved oxygen were near to the saturation rate (Arrignon 1985; Rodier et al 1996; Hade 2002).

This might be explained by the amount of dissolved oxygen that is introduced into the water lake during the day by photosynthetic activity (Eisenstadt et al 2010). On the other hand, the lake was influenced by the dominating winds during the fourth seasons (Benyacoub & Chabi 2000), and according to Blottière et al (2014), the agitation of the water by the wind facilitates the enrichment of water with oxygen.

Dissolved nutrients. The dissolved mineral nitrogen is composed of ammonium (NH_4), nitrates (NO_3) and nitrites (NO_2) and their values were near to the normal concentrations of unpolluted surface waters. The majority of ammonium (NH_4) concentrations are very low according to Loquet et al (2000). The nitrates (NO_3) are the main form of inorganic dissolved nitrogen in lake waters. The nutrients concentrations were approximately near to 1 mg L^{-1} (16 µmol L^{-1}) mentioned by the OCDE (1982), Meybeck et al (1989), Barroin (1991), Lacaze (1996), Sehili (2008), Mouissi & Alayat (2016). The nitrites (NO_2) concentrations in the lake waters are very low and they are near to the values of 25-50 µg L^{-1} (0.40 to 0.80 µmol L^{-1}) described by Lacaze (1996), Sehili (2008), Mouissi & Alayat (2016), and Guellati (2018) in natural surface waters.

An impoverishment phase for all of the dissolved mineral nitrogen decreased during a period of 6 months from May to October with critical values less than the threshold of 50 to 100 µg NL^{-1} (4 to 7 µmol N L^{-1}). This significant modification lead to nutrient deficiency in nitrogen and limited production in lake waters (Mischler et al 2014; Scott et al 2019). These conditions produce a significant proliferation of cyanobacteria, the main fixer of atmospheric nitrogen in the environment (Paerl 2008). The enrichment period in dissolved inorganic nitrogen started from the end of December to March 2005. During this period lake's water was rich in NH_4 from January to February 2005 and rich in NO_3 from February to March 2005. This enrichment is due to the nitrogen leaching under agricultural lands, because the NO_3 values exceed the threshold established by the OCDE (1982), Meybeck et al (1989), and Barroin (1991). Concentrations of dissolved organic nitrogen (DON) in lake waters were higher than the concentrations of dissolved inorganic nitrogen (DIN). It represented 65.53% of the total dissolved nitrogen estimated during our study. The DON mean concentration is approximately near to the value reported by Mouissi & Alayat (2016). In the aquatic environment DON comes from the metabolism of microorganisms, lysis cells, decomposition of organic matter and rainwater (Meybeck 1982). It is used by bacteria as a nitrogen source and regenerated in mineral form (dissolved inorganic nitrogen, noted DIN) assimilated by the plants. DON is usually an important stock in the lake. This organic fraction plays an important ecological role in the food web. The orthophosphate (PO_4) showed null values over a long period between March and July. The viable concentrations exceed the threshold value of 0.1 μmol L^{-1} according to Dauta (1982), Cembella et al (1984), Lacaze (1996), they occurred only during 18 September, 15 December, 14 January and 31 March 2005. The values of PO_4 were very low compared to those reported by Sehili (2008), Bensafia (2005), and Guellati (2018). PO_4 concentrations increased in lake waters mainly during the rainy season. According to Barroin (1990) and Tufekcioglu et al (2012), PO_4 is well retained by watershed soils and is difficult to erode it outside this season. The reduction of PO_4 values was often followed by high concentrations of Chl *a* practically throughout all the study period. This can only linked to the high productivity of phytoplankton in lake waters, of which PO_4 is an essential nutrient (Capblanq & Decamps 2002). We must not neglect the action of the wind, it is one of the major sources of mixing and destratification of the water column, but it is also the main mechanism behind resuspension of the sediments. This process can cause the adsorption of orthophosphates by suspended solids and especially metal particles of iron and aluminum (Barroin 2003). The source of phosphorus is strictly geological, averaging 0.1% in soils and very low in natural systems (Barroin 2003). The scarcity of phosphorus in freshwater and its presence in the form of orthophosphate (PO_4^-) accounts for only 10% of the total phosphorus directly assimilated by plankton and algae (Premazzi & Cardoso 2001). Concentrations of dissolved organic phosphorus (DOP) generally report levels identical to those of natural waters (Loquet et al 2000). They were ten times higher than those of PO_4 and constitute 92% of the total dissolved phosphorus measured in lake waters. DOP is another bioavailable form of phosphorus. It can be used by plankton and algae through phosphatases linked to their cell membranes or released into the environment (Lin et al 2016). Consumption of DOP occurs by plankton outside a deficiency of cells in phosphorus. We observed that the lowest values of DOP concentrations are measured between March and December and especially during May 5, June 6 and September 18. It can cause nutritional deficiencies of phosphorus in the environment. Phytoplankton has the possibility to store phosphorus inside its cells to use it in depletion phase (Brembu et al 2017; Hunter et al 2018; Huang 2019). According to Fogg (1973) intercellular phosphorus reserves appear in the form of metachromatic granules. It increases in number and size when phosphorus is abundant in the environment and decreases during periods of deficiency. On the other hand, the particulate organic phosphorus constitutes an important fraction within the total phosphorus but this fraction was neglected in several studies (Meybeck 1982; Wang 2015).

Particulate matters and transparency. The suspended materials (SPM) were composed on average of 81% of inorganic material and 19% of organic matter or particulate organic carbon (POC). This implies that the erosion phenomenon is very important in our region and the mineral fraction constitutes the majority of the SPM (Meybeck & Moatar 2012; Youcef & Amira 2017; Amira & Boughdah 2018). This suspended matter is important in lake waters even during the dry season (May to September) following its resuspension by the winds. Concentrations of particulate organic carbon (POC) are strongly influenced by the importance of phytoplankton blooms in lake waters, especially during the dry season (Ounissi et al 2018). This is demonstrated by the highest concentrations of POC and Chl *a* between June and December, resulting in a 62.55% of POC contribution to the total stock. This amount of POC is considered to be part of our hydro system during the period indicated as autochthone (Orange et al 2004). Concentrations of SPM in natural waters are always less than 25 mg L^{-1} according to Rodier et al (1996) outside flood periods. It is estimated that SPM values for lake waters are relatively high, this value is largely exceeded during the low water period between July and October. On the other hand, starting from the value of 75 mg L^{-1} of the SPM, the situation is said to be atypical or unusual (Nisbet & Verneaux 1970). This is observed during the month of September and also between January and February 2005. These very high levels can reduce the production and diversity of the lake's water (Arrignon 1985) by the consumption of dissolved oxygen and decrease of the nutrient stock (Nisbet & Verneaux 1970; Rodier et al 1996). According to Orange et al (2004), POC occurs in the waters of our lake with relatively high concentrations. It is found that POC values greater than 10 mg L^{-1}, which were recorded between the end of August and February 2005, may modify the biological life of the lake's waters. The transparency of the waters is generally unimportant because of the low depth of the lake's waters. This favors resuspension of the sediment under the action of the winds and because of the abundance of phytoplankton during the dry season and the amount of suspended matter load, especially during the rainy season.

Enrichment mechanisms and production. Chlorophyll *a* is considered in our lake as an indicator of the abundance (biomass) of microscopic algae, which is the basis of food chains (Pourriot et al 1982; Ramaraj et al 2013). The different levels of Chl *a* could be an indicator of enrichment by nutrients. During the first hydrological cycle, its rainy season is accompanied by a production of Chl a and which is estimated at only 7.40% of the total quantity considered in the waters of the lake. These concentrations are below the monthly average and range from 19 to 38.50 mg m^{-3}. According to Rydin & Rast (1994) these concentrations are considered high. This production is followed by contribution rates of nitrogen and phosphorus compounds in relation to their total bioavailabilities. They contributed as follows: 29% of the nitrates ($NO_3^{-)}$, 14% of the ammonium (NH_4^+), 20.40% of the DON and 12.70% of DOP. Production in this rainy season is supported mainly by nutrients that reach the lake through runoff. It is based on NO_3 and DOP due to its rapid remineralization (Golterman 1960; Pourriot et al 1982; Lacaze 1996; Guildford 2000). DOP constitutes an important bioavailable source since it is assumed that orthophosphates (PO_4^-) are completely consumed. We suggest that during this rainy season the algal production (chlorophyllian) is called new production. In our case this is due to an extrapolation of the coastal marine system described by Lacaze (1996), when production depends on nitrates. The dry season is marked by the high levels of Chl *a*. They reach between August and October the highest values, which vary from 118.50 to 311.60 mg m^{-3}. It is estimated that concentrations of Chl *a* participated during this season with 64% of the total amount measured during our study cycle. According to Lacaze (1996), the production that generated this biomass is called regeneration production. It is based essentially on nutrients produced from the recycling of materials released and excreted from the food web of the ecosystem and more specifically ammonium and organic nitrogen. The percentage contribution of nutrients during this production in relation to their total bioavailable quantity is: 26% of ammonium (NH_4^+), 6.60% of nitrates (NO_3^-), 23.70% of DON, 17.20 orthophosphate (PO_4^-) and 24.70% DOP. It has been reported that this period is characterized by the highest temperatures, low concentrations of dissolved oxygen, the lowest depths and volumes of water in the lake. This assumes that some of the concentrations of orthophosphates during this period are favored by salting out from sediments (Hasnaoui et al 2001). The rainy season of the second hydrological cycle includes the most important participation rates of nitrogen and phosphorus compounds in relation to their total bioavailability. They contributed with the following percentage: 73% of ammonium (NH_4^+), 64.50% of nitrates (NO_3^-), 56% of DON, 83% of orthophosphate (PO_4^-) and 62.50% DOP. This nutrient enrichment of the lake produced between the months of January to March 2005. Despite these large contributions, mainly from the leaching water, the concentrations of Chl *a* represent only 28.50% of the amount total produced. The highest concentrations of Chl *a* during this rainy season occurred between the months of November and January, with mean values decreasing from 157 to 51 mg m^{-3}. The essential of the chlorophyllian mass, produced during this season but in low nutritive conditions. This season is characterized by the biggest volumes of water in the lake (the flood period), following significant rainfall in the study area. This will increase the rate of regeneration of the waters of the lake, by their spills in Wadi El-Kebir-East through its emissary Oued Mesida. Water renewal affects the true estimate of chlorophyll produced because a large amount of phytoplankton is removed from the water body. This explains the reduction in Chl *a* concentrations during the January to March 2005 period, despite the larger bioavailability of nutrients during our study cycle. We consider that the rainy season is at the origin of the enrichment of the lake's water by the dissolved nutrients and organic matters but it remains that this one is dependent on the importance of the of the precipitations events.

Trophic level and water circulation. The trophic level reflected by the lake's water was hypereutrophic. It is deduced by comparing the values of Chl *a* concentrations, its annual average concentration, the total phosphorus load (the sum of the concentrations of PO_4^- and DOP) and the values of transparency in the work of the OCDE (1982). If we integrate the notion of the hydrological cycle we consider that, our lake passes by two trophic states. A phase where the water is mesotrophic when the rate of water renewal is high from January to May (OCDE 1982). A second phase where the waters are hypereutrophic from June to September (the summer season) and lake's water are characterized by the lowest levels. Lake is filling with mud by the outlet (oued Mesida) and reduces the discharge of water from the lake to Wadi El-Kebir East. This made it impossible to renew the waters of the lake during the months of October and November despite the high rainfall amount. This situation plunges the waters of the lake into a partial endorism. The long residence time of the lake waters maintains the high phytoplankton biomass generated during the dry season. The hypereutrophic state of the lake's waters is maintained until the beginning of the discharge of waters and that from the month of December. The water discharge of the lake occurs under cumulative rainfall of 592 mm. This causes a breaking volume in the lake waters of 36 million m^3 and an average depth of 1.55 m. During the 1996/97 hydrological year, the lake suffered a total endorheism following an annual rainfall of 432 mm. This generated a maximum volume in the lake waters of 32 million m3 and an average depth of 1.40 m (Messerer 1999). We can conclude that our volume of rupture and our average depth measured during the month of December imply the notion of the minimum level to reach for a possible emptying happen to Wadi El-Kebir East. The rainy season accumulated until January height precipitation of 700 mm and which provoked an increase in the volume of the lake to 41 million m^3 and its average depth to 1.80 m. This is followed by significant water flow from the lake to Wadi El-Kebir East. The significant reduction in the values of Chl *a* during the month of January is perceived as a good renewal of lake's water and can only be realized from this significant amount of precipitation.

Conclusions. The environmental factors of the lake are influenced by its watershed and the climate of the area. They are reproduced by values favorable to a good functioning of our ecosystem. Nutrients evolution show that the rainy season stretching from October to April feed of lake water by these a significant amount of dissolved nutrients. They come from runoff and leaching water and we find that the period between January and March expresses the maximum of this enrichment. This season does not have a great influence on chlorophyll *a* concentrations since it is manifested with low values. The production of phytoplankton biomass revealed by significant concentrations of chlorophyll *a*, derives mainly from dissolved mineral and organic compounds that produced from internal recycling during the dry season. Global warming, manifested in the region of study, by the prolongation of the dry season and the successive unfolding of the years of deficit rainfall, with an average annual rainfall lower than 800 mm. This maintains the hypereutrophic state of the lake's water which is aggravated by the evolutionary clogging of the lake emissary and which causes an obstruction in the waters discharge. These phenomena could plunge the lake into an era of strict endorheism that will switch its waters towards total disintegration and which will result in the filling of the lake basin. This accelerated evolution can be avoided if the circulation of water between the lake and El-Kebir-East wadi is rebalanced by an adequate development. To better understand the trophic state of our ecosystem, more detailed nutrient studies need to be developed. The monitoring of the different forms of phosphorus are to be considered in the future. The control of the phytoplankton composition, the biogeochemical cycle of sediment and hydric cycle of the lake's water are to be considered at the same time. Particular attention should be paid to a possible reduction in the volume of lake water that could pose a serious threat to its survival.

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