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Effects of Physicochemical Parameters and Some Heavy Metals on the Distribution of Phytoplankton in Lake Oubeira

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ABSTRACT

Our study focused on the effects of various physical and chemical parameters, along with certain heavy metals, on the spatiotemporal distribution of phytoplankton in Lake Oubeira from January 2021 to January 2022. Monthly sampling of phytoplankton, along with measurements of specific physicochemical parameters and heavy metals, was conducted at two stations characterized by distinct physico-chemical properties. All data analyses in this study were performed using R, version 4.0.1 (R Core Team 2020). The observations of the morphological and anatomical characteristics of phytoplankton collected from Lake Oubeira allowed us to identify 48 genera belonging to five classes: Cyanophyceae, Bacillariophyceae, Chlorophyceae, Euglenophyceae, and Dinophyceae. Notably, there was a dominance of cyanophytes, with 9 toxic genera identified. The measured levels of heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) in Lake Oubeira's waters revealed significant spatiotemporal variation. The highest concentrations of these heavy metals were recorded during the summer, while the lowest values were observed in autumn. An in-depth principal component analysis (PCA) considering both "station" and "season" factors indicated a spatiotemporal variation between several parameters, including pH, dissolved oxygen (O_2), Pb, Cd, and the density of certain phytoplankton taxa (Euglenophyceae, Dinophyceae, Bacillariophyceae, and Chlorophyceae). Our findings show that during summer, the waters of Lake Oubeira are warm, alkaline, and less oxygenated, with a high abundance of Euglenophyceae taxa. In contrast, spring conditions are characterized by cooler, well-oxygenated waters with a richness of Dinophyceae, Bacillariophyceae, and Chlorophyceae taxa. During winter, the waters are cold, less alkaline, and less oxygenated.

INTRODUCTION

Phytoplankton is regarded as the foundational link in the aquatic food chain, playing a crucial role in primary production. In addition, this taxon consists of a microscopic suspension of plant organisms (unicellular, filamentary or colonial) in the water column, which are distinguished by the presence of chlorophyll pigments, mainly chlorophyll a **(Djabourabi, 2014)**.

However, phytoplanktonic proliferations have become more common in lentic environments in recent years, and disrupt the functioning of their ecosystem by reducing the transparency of water and the concentration of dissolved oxygen, resulting in a loss of biodiversity at all tropical levels **(Talita *et al*, 2011).**

On the other hand, environmental degradation is a global concern due to its direct and indirect effects on natural resources such as water, soil and vegetation, as well as on human health. However, trace metals such as chrome (Cr), zinc (Zn), cadmium (Cd), and lead (Pb) are non-degradable substances that remain in the environment for prolonged durations. The term "metallic traces" is used to refer to these substances, since the quantities present in the environment are extremely small **(Baker & Walker, 1990)**. According to **Chaney (1988)**, sewage from households and industries contains organic matter and nutrients beneficial for fertilization.

In Algeria, numerous studies have explored freshwater phytoplankton and the effects of heavy metals on different water bodies, such as dams and lakes. These studies include research by **Hamidi *et al*. (2009)**, **Djabourabi *et al.* (2014)**, **Boussadia (2017)**, **Khereif *et al.* (2018)**, **Arab *et al*. (2019)**, **Draredja *et al.* (2019)**, **Boulefa and Bouldjedri (2020)**, **Chabaca *et al.* (2020)**, **Sehili *et al.* (2020)**, **Heramza *et al.* (2021)**, **Naili *et al.* (2021)**, **Djerboua *et al.* (2022)**, **Arif *et al*. (2023a, 2023b)**, **Benfarhi (2023)**, **Manamani and Bensouilah (2023)**, **Senouci *et al.* (2023)**, **Adaouri *et al.* (2024)**, **Belhaoues *et al.* (2024)**, **Hammana *et al.* (2024)** and **Kaddeche *et al.* (2024)**.

This research focused on:

- An inventory of the phytoplankton in the waters of Lake Oubeira.
- The effects of certain physicochemical parameters (such as pH, oxygen levels, and temperature) and heavy metals (such as lead, cadmium, and mercury) on the spatiotemporal distribution of phytoplankton.

By examining these factors, the study aimed to better understand the ecological dynamics of Lake Oubeira and the influence of environmental stressors on its primary producers.

MATERIALS AND METHODS

- **Study area**

Lake Oubeira is located between Lake Tonga and the El-Mellah Lagoon, 3 kilometers west of the city of El-Kala (East Algeria); it is fed by four rivers: the Oued

Demnet Rihana in the north, the Boumerchene Oued in the east, the L'Grâa Oued Dey in the eastern, and Oued Messida in the south. Lake Oubeira is located at 36°50' North and 08°23' East (Fig. 1).

The selection of sampling stations was made on the basis of the water supplies from the ponds that feed Lake Oubeira.

• **Station 01 (st1):** Oued demnet rihane: located in the northeastern part of the lake; this station is considered to be moderately exposed to the wind and is characterized by a sandy vascular sediment.

• **Station 02 (st2):** Oued messida: located in the southeastern part of the lake; this station is in the direction of the wind and is characterized by fresh water and vascular sediment.

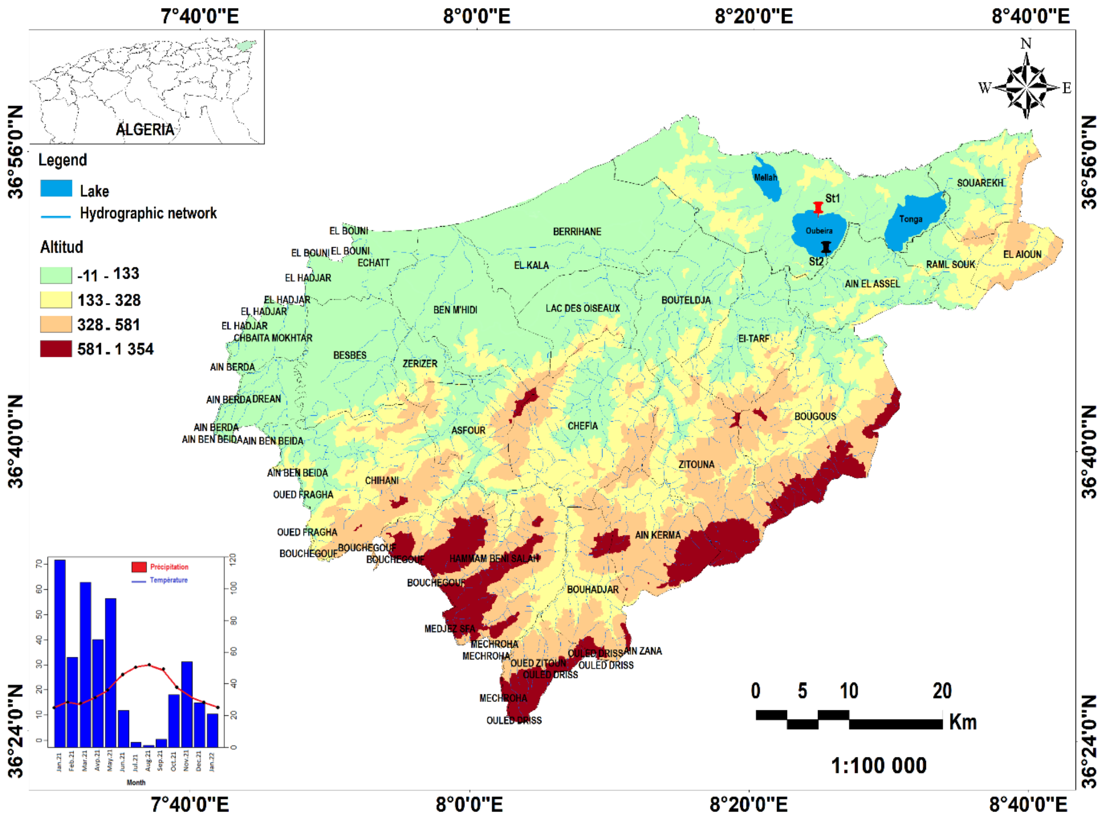

Fig. 1. Geographical location of sampling stations

➢ Methods of study

- *Physicochemical measurements*

Measurements of certain physical and chemical parameters such as temperature (T°C), dissolved oxygen (O2, mg. L-1) and pH and conductivity were performed monthly from January 2021 to January 2022 at two stations selected using a multi-parameter suitcase (Consort C5010). On the other hand, nutrients (nitrite, nitrate, orthophosphate, and ammonium) were evaluated using the spectroscopic method **(Aminot & Chausspied, 1983)**. For the suspension material, we used the centrifugation method to measure the different concentrations **(Apha, 2005)**, then proceeded to the separation of the solid and liquid phases. Centrifugation also provides the ability to separate and dissolve solid substances from the liquid phase. This method is detailed in the French standard NF T90-105-2, which outlines a procedure for determining suspended materials in sewage and effluents using a centrifuge.

In addition, the dosage of chlorophyll was measured using spectrophotometry according to the protocol defined by the standard NF T 90-117. All these analyses were carried out at the Horizon Annaba water and soil analysis laboratory.

- **Sampling**

The phytoplankton was harvested using a 20 micrometer plankton mesh,

- **Identification**

Species identification was performed by microscopic observation based on morphological anatomical characteristics using the identification keys proposed by **Bourrelly (1985a, b, c)**

- **Dosage of heavy metals in water**

The dosage of lead and cadmium was analyzed using the flame atomic absorption spectrophotometry method at Dithizone **(Todedji *et al*, 2020)**.

On the other hand, mercury dosing was done using a Perkin Elmer 4100 Z cold-damp atomic absorption spectrophotometer **(El Himri & El Himri, 2012)**.

Statistical analysis of data

Statistical analysis was performed using R, version 4.0.1 (R Core Team 2020). The relationships between the physico-chemical and biological parameters were analyzed by Spearman's non-parametric correlation using "ggcorrplot".

We also carried out the analysis of the main components (PCA) using the packets “FactoMineR” and “facto extra” on standardized data to characterize the spatiotemporal variation of the biotic and abiotic variables measured in Lake Oubeira. The results were given as an average ± SD (standard deviation), with a level of significance $\alpha = 0.05$.

RESULTS

1. Spatial-time variation physicochemical parameters and some pollutants

Temperature

Table (1) shows significant seasonal variations in temperature in Lake Oubeira. However, the highest value was observed in the summer period (T=27.93 - 28.9°C), while the lowest was in winter (T=14.48 - 14.65°C).

Dissolved oxygen

The monitoring of dissolved oxygen levels in the stations studied recorded some spatiotemporal fluctuations. Indeed, the measurements of dissolved oxygen showed maximum percentages at the 2nd station during spring (O_2=10.93), and minimum at the level of the 1st station during winter.

pH

The pH of the water in Lake Oubeira was relatively neutral to basic for all the studied resorts. In fact, the pH varied between 7.60 and 9.11, with the highest value (pH=9.11) being observed at station 2 during the autumn period. By contrast, a minimum value (pH=7.60) was observed at station 1 level in summer.

Conductivity

The conductivity measurement provides a quick but very accurate assessment of the overall mineralization of the water and allows to track its evolution. The study stations have an electrical conductance ranging from 362.33 to 828µS/ cm.

Suspended matter (SM)

Suspended matter concentrations at the stations and throughout the study period showed two peaks during autumn, one at station 1 and the other at station 2 (MES=46. MES=24, respectively). However, the lowest value was observed at station 2 during the winter.

Chlorophyll a

The variation in chlorophyll a shows that the values peaked during the autumn at both stations, 1 and 2 (Chla= 0.09 – 0.10, respectively). However, the lowest value was recorded during winter at the level of station 1 (Chla= 0.019).

Nitrate content

Nitrates were in the range of 28.5 - 35.33mg/ l. However, the highest value was recorded at station 1 in summer ($NO3$= 35.33mg/ l), while the lowest value was recorded at the same station in winter.

Nitrite levels

Nitrites were in the range of 0.22 – 0.25mg/ l

The concentrations of orthophosphates

The concentrations of orthophosphate observed during the study period were notably high at Station 2, particularly during summer (PO_4^{3-} = 5.16mg/ L) and autumn (PO_4^{3-} = 5.00mg/ L). In contrast, lower levels of orthophosphate were recorded during the winter season, with values ranging between 2.2 and 2.4mg/ L.

Ammonium

Ammonium analysis results showed that NH4 values ranged from 0.36 to 1.79. However, the highest values recorded at station 1 during autumn were in the range of 0.22 – 0.25mg/ l

Cadmium

Cadmium levels fluctuated seasonally between the two stations, with the highest concentration recorded during the spring at both stations (0.28mg/ L). In contrast, bioaccumulation at station 2 during the summer was relatively low (0.18mg/ L).

Lead

Lead concentrations were notably high during the autumn at station 2 (0.11mg/ L), while the lowest levels were observed at station 2 during winter and spring (0.03mg/ L).

Mercury

Mercury levels ranged from 0.46 to 0.76mg/ L. The highest mercury concentration was recorded at station 1 during summer, whereas the lowest concentration was observed at station 2 during the same season (Fig. 2).

Table 1. Spatiotemporal characterization of the physicochemical parameters of Lake Oubeira

Parameter (average ± SD)	**Station**		**Seasons**			
	St1	**St2**	**Summer**	**Autumn**	**Winter**	**Spring**
T	20.75±2.97	20.90±2.75	28.41±0.50	20.20±0.05	14.57±0.08	20.12±0.80
pH	7.85±0.18	8.22±0.31	7.75±0.48	8.74±0.37	7.74±0.06	7.91±0.28
O_2	8.48±0.56	9.20±0.80	9.03±0.15	9.18±0.44	6.98±0.10	10.18±0.75
PO_4^{3-}	3.98±0.96	4.41±1.14	4.75±1.60	4.90±0.98	2.30±0.13	/
NO_3^-	32.75±4.11	29.88±5.45	34.17±5.70	32.17±6.95	25.75±1.89	/
NO_2^-	0.25±0.03	0.22±0.04	0.22±0.04	0.25±0.04	0.25±0.02	/
NH_4^+	0.55±0.12	0.94±0.54	0.54±0.13	1.08±0.73	0.58±0.18	/
MES	29.38±7.67	17.38±4.78	23.33±8.55	32.83±6.81	9.25±4.39	/
Chla	0.06±0.03	0.06±0.04	0.04±0.03	0.10±0.06	0.02±0.01	/
CON	590.68±92.30	617.19±95.51	735.66±16.33	778.33±49.67	516.75±3.00	385.00±22.67

SD: Standard deviation.

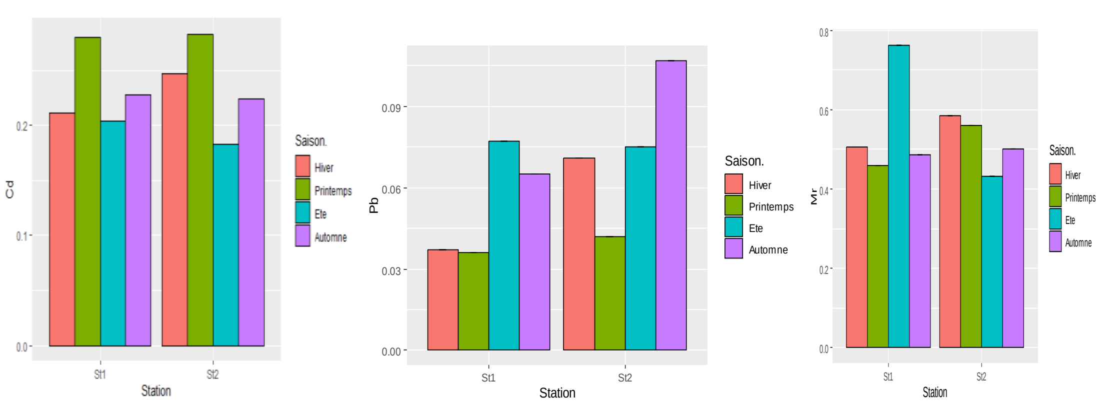

Fig. 2. Spatiotemporal variation of the three heavy metals in Lake Oubeira

2. Composition of the phytoplanktonic communities of Lake Oubeira

The phytoplankton inventory enabled us to identify 48 genus belonging to five (5) classes, which include: Cyanophyceae (17 genera), Chlorophyaceae (14 genera), Bacilliarophyidae (11 genera), Euglénofhyceae (3 genera), and Dinophyae (3 genres).

Table 2. Inventory of the plankton community of Lake Oubeira

Class	Genera	Species
Cyanophyceae	*Microcystis*	*Microcystis delicatissima*
		Microcystis aeruginosa
	Chroococcus	*Chroococcus turgidis*
	Gloecapsa	*Gloecapsa* sp.
	Merismopedia	*Merismopedia tenuissima*
	Gomphosphaeria	*Gomphosphaeria pallidum*
		Gomphosphaeria kuetzingianum
	Synechococcus	*Synechococcus* sp.
	Anabaena	*Anabaena* sp.
	Aphanizomenon	*Aphanizomenon* sp.
	Nostoc	*Nostoc entophylum*
	Lyngbya	*Lyngbya perelegans*
	Oscillatoria	*Oscillatoria bubisalsa*
	Pseudanabaena	*Pseudanabaena* sp.
	Spirulina	*Spirulina major*
	Raphidiopsis	*Raphidiopsis meditterranea*

	Planctothrix	*Planctothrix* sp.
	Synechocystis	*Synechocystis* sp.
	Palikiella	*Palikiella elegans*
	Cylindrospermopsis	*Cylindrospermopsis* sp.
Bacilariophyceae	*Coscinidiscus*	*Coscinidiscus radiatus*
	Mélosira	*Mélosiragr anulata*
		Mélosira ambigna
	Thalassionema	*Thalassionema* sp.
	Synedra	*Synedra ulina*
	Navicula	*Navicula cryptotenella*
	Cymbella	*Cymbella* sp.
	Surirella	*Surirell alinearis*
	Nitzschia	*Nitzschia signoidea*
	Achnanthes	*Achnanthes* sp.
	Aulacoseira	*Aulacoseira granulata*
	Medium	*Medium iridis*
Dinophyceae	*Peridinium*	*Peridinium limbatum*
	Gymnodinium	*Gymnodinium* sp.
	Prorocentrum	*Prorocentrum compressum*
Euglenophyceae	*Euglena*	*Euglena limnophila*
	Phacus	*Phacus arbicularis*
	Trachelomonas	*Trachelomonas hispida*
Chlorophyceae	*Closterium*	*Closterium aciulare*
		Closterium rostratum

		Closterium gracile
	Coelastrum	*Coelastrum astrodeon*
		Coelastrum spharicum
	Monoraphidium	*Monoraphidium controtum*
		Monoraphidium circinalis
	Pediastrum	*Pediastrum clathratum*
		Pediastrum boryanum
		Pediastrum simplex
		Pediastrum fotos
	Scenedesmus	*Scenedesmus opliensis*
		Scenedesmus bicaudatus
		Scenedesmus acuminatus
	Staurastrum	*Staurastrum encyclopedia*
		Staurastrum johnii
	Tetraedron	*Tetraedron caudatum*
	Actinastrum	*Actinastrum* sp.
	Bicuspidellopsis	*Bicuspidellopsis triangularis*
	Spirogyre	*Spirogyre* sp.
	Coenochloris	*Coenochloris* sp.
	Neospongiococcum	*Neospongiococcum vacuolatum*
	Volvox	*Volvox* sp.
	Enallax	*Enallax alpina*

3. Spatiotemporal study of phytoplankton

- Spatiotemporal variation of phytoplanktons

Evaluation of phytoplankton density at both study stations revealed that station 2 hosted the highest number of phytoplanktons (DM=59.44%) compared to station 1 (DM= 40.97%). Furthermore, monitoring the temporal variations in the density of phytoplankton at station 2 revealed that the highest density was observed in autumn (DM = 100%). In contrast, during the other seasons, phytoplankton were completely absent from this station. With regard to station 1, the highest density was recorded during summer (DM=42.7%), followed by spring (DM =32.58%), then winter (DM=2.03%), and autumn (DM=1.69%) (Fig. 3).

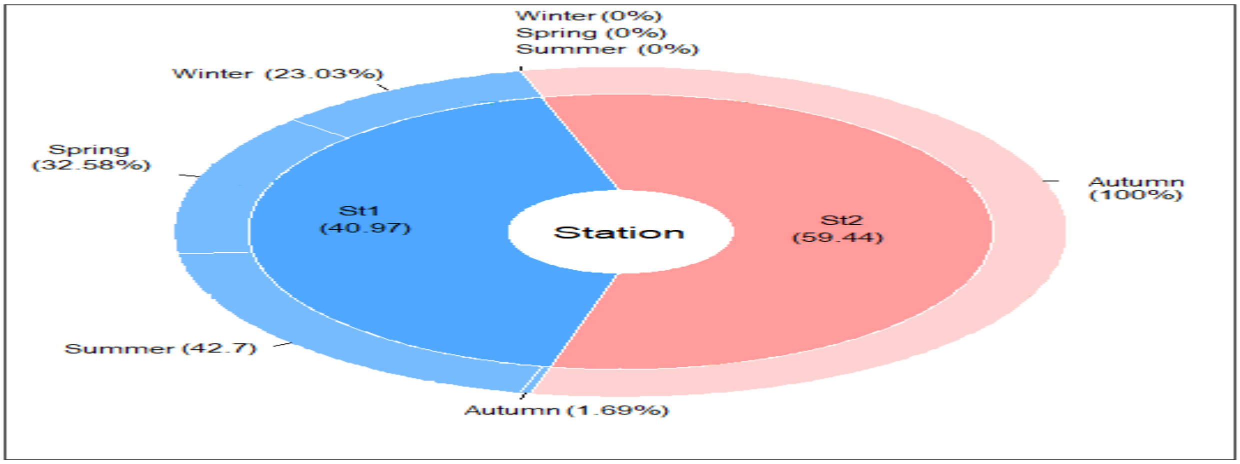

Fig. 3. Spatiotemporal variation of the phytoplankton at St 1: station demnet Rihane and St 2: oued Messida

- Spatiotemporal variation of phytoplanktons classes

Evaluation of phytoplankton density at both study stations revealed that the densities of the five classes are significant at station 2 (Oued Messida). However, the highest densities of Cyanophycees were observed during the summer (AD=2300000 cell/l) and autumn periods (AD =2270000 cell/l); Bacillariophycees (AD =775000 cell/l) and Chlorophycees (AD=1000000 cell/l), on the other hand, have peak values in the spring period. Furthermore, the Euglenophyceae (AD =1500000 cell/l) showed maximum values in the summer period. At last, Dinophycees (AD =80000 cell/l) showed maximum values in the spring period.

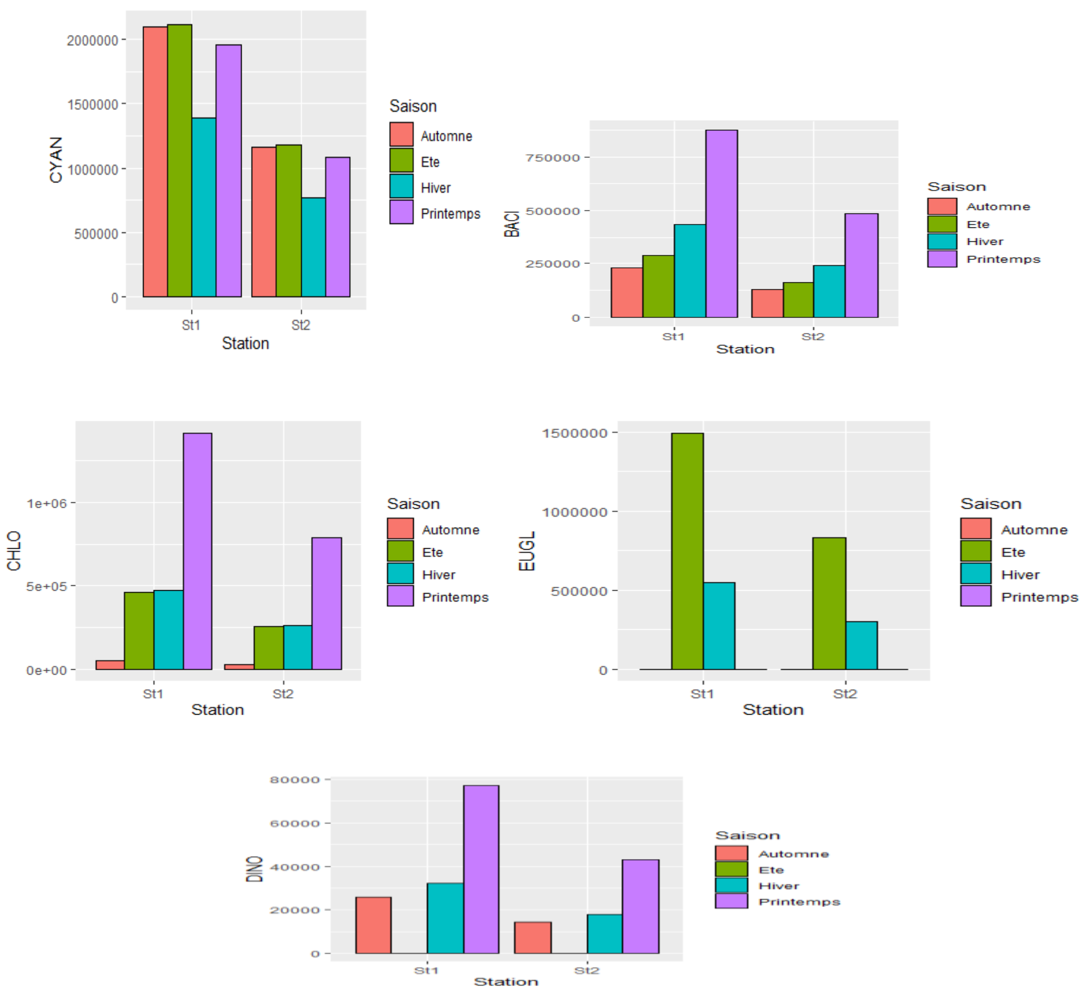

Fig. 4. Spatiotemporal variation of phytoplankton classes at St 1: Station demnet Rihane and St 2: Oued Messida

4. Statistical analysis of data

- The descriptive statistics (average ± SE) for biotic and abiotic variables at both stations across the four seasons are presented in the table below.

Pearson correlation analysis:

- Between BACI and other parameters:
    - BACI–pH: r=0.67 (positive correlation)
    - BACI–Pb: r=−0.88 (negative correlation)
    - BACI–O2: r=0.77 (positive correlation)

- BACI–CON: r=−0.68(negative correlation)

- Between CHLO and other parameters:
  - CHLO–BAC: r=0.70 (positive correlation)
  - CHLO–pH: r=−0.94 (negative correlation)
  - CHLO–Pb: r=−0.57 (negative correlation)
  - CHLO–O2: r=−0.57 (negative correlation)
  - CHLO–CON: r=2.059 (positive correlation)
- Between EUGL and other parameters:
  - EUGL–SM: r=0.8 (positive correlation)
  - EUGL–NO3: r=0.86 (positive correlation)
  - EUGL–CHLO: r=0.97 (positive correlation)
  - EUGL–BACI: r=2.051 (positive correlation)
  - EUGL–DINO: r=0.52 (positive correlation)
  - EUGL–pH: r=0.09 (positive correlation)
  - EUGL–O2: r=0.51 (positive correlation)
- Between Chla and other parameters:
  - Chla–PO4: r=0.68 (positive correlation)
  - Chla–EUGL: r=0.73 (positive correlation)
  - Chla–SM: r=2.052 (positive correlation)
  - Chla–CHLO: r=0.70 (positive correlation)
  - Chla–Cd: r=0.89 (positive correlation)
  - Chla–DINO: r=0.82 (positive correlation)
  - Chla–pH: r=0.52 (positive correlation)

- o Chla–T: r=0.56 (positive correlation)

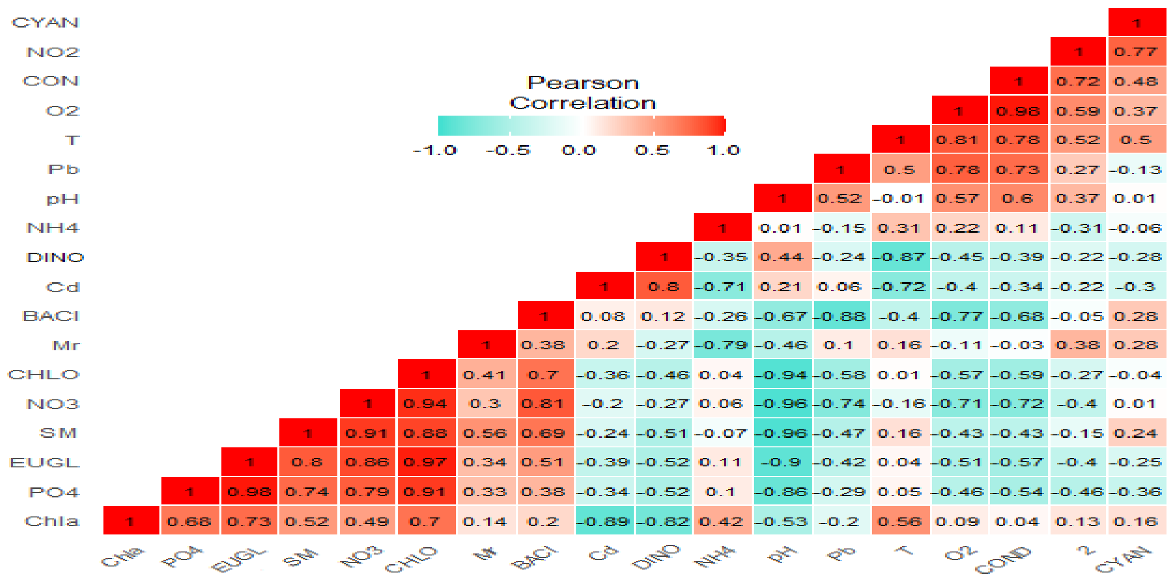

Fig. 5. Corrplot of the calculated Pearson correlation between all analyzed physico-chemical parameters and inventory taxon charges. T: temperature (°C), O2: dissolved oxygen: (mg/L), pH, SM: suspension material (mg/L), NO2-: nitrites (mg /L -1), NO3-: nitrates (mg/L), PO43-: orthophosphates (mg /L), NH4+: ammonium (mgs /L); Chla: chlorophyll a (mg/L), CON: electrical conductivity (µs/cm), Pb: Lead, CD: Cadmium, Mr: Mercury, CYAN: Cyanophycees, EUGL: Euglénophycees, CHLO: Chlorophycees, BACL: Bacillariophycees, DINO: Dinophycees

Principal component analysis (PCA)

The multivariate analysis aims to examine the physico-chemical and biological structure of the stations of the present study and to explore the influence of the physico-chemical parameters on the distribution of the diatoms. However, abiotic parameters are used as explanatory quantitative variables, while taxon densities are treated as an explained (supplementary) variable.

Indeed, the application of the PCA showed that 66.10% of the total variability (inertia) of our matrix of biotic and abiotic variables is explained by the first two main components (Fig. 6).

The 1st axis of PCA alone explained 42.47% of the total variability; it is positively correlated with temperature (T) (r=0.624; cos2=0.39), pH (r =+0.50; cos 2=0.25), conductivity (CON) (R = +0.97; cos 2,0.95), lead (Pb), (r +0.87; cos2,0.79).

This axis, on the other hand, is negatively correlated with cadmium (Cd) (r= -0.73; cos2=-0.54), BACI (r = -0.81; Cos2= 0.66), CHLO (R = -0.74; cos 2=-0.54) and DINO (R= -0.82; cos-2=-0.68). Furthermore, the 2nd axis alone explained 23.64% of the total variation; it is characterized by a strong positive correlation with pH (r=0.73; cos2=0.53), dissolved oxygen O2 (r = 0.77; Cos2= 0.60), cadmium (Cd) (R = 0.51; cos 2= 0.26), as well as negative correlations with mercury (Mr) (r = -0.50; Cos 2 = 0.24), with EUGL (r=" -0.76; cos-2=-0.58).

The analysis of the main component revealed that temperature, conductivity, lead and pH have a positive effect on EUGL and a negative effect on DINO, BACI and CHLO. However, the CD influences these latter taxons positively. In addition, O2 negatively affects the EUGL taxon (Fig. 7).

The detailed analysis of the PCA for the two factors "station" and "season" has shown:

- The waters of stations 1 and 2 during the autumn are warm, alkaline, well oxygenated and characterized by high levels of Pb and conductivity.
- The waters of stations 1 and 2 during the summer are warm, alkaline, less oxygenated and characterized by high levels of Mr, Pb and conductivity, they are rich in taxons EUGL
- The waters of stations 1 and 2 during the spring are cold, less alkaline, well oxygenated and characterized by high levels of Cd, they are rich in the taxons DINO, BACI, and CHLO.
- The waters of stations 1 and 2 during the winter are cold, less alkaline, less oxygenated

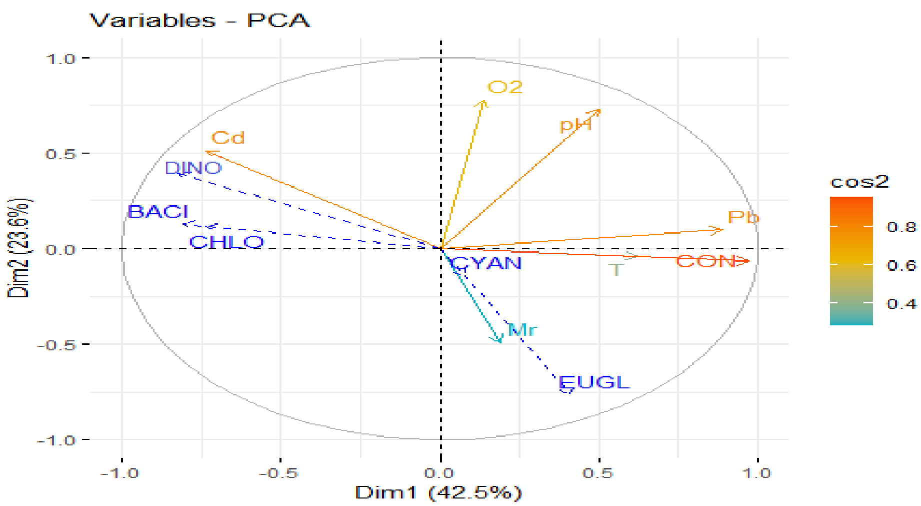

Fig. 6. Circle of correlation of the physico-chemical parameters the taxon densities inventoried with the first two axes of PCA for the two study stations and during the four seasons (taxon densities are mentioned in blue are considered as additional variables)

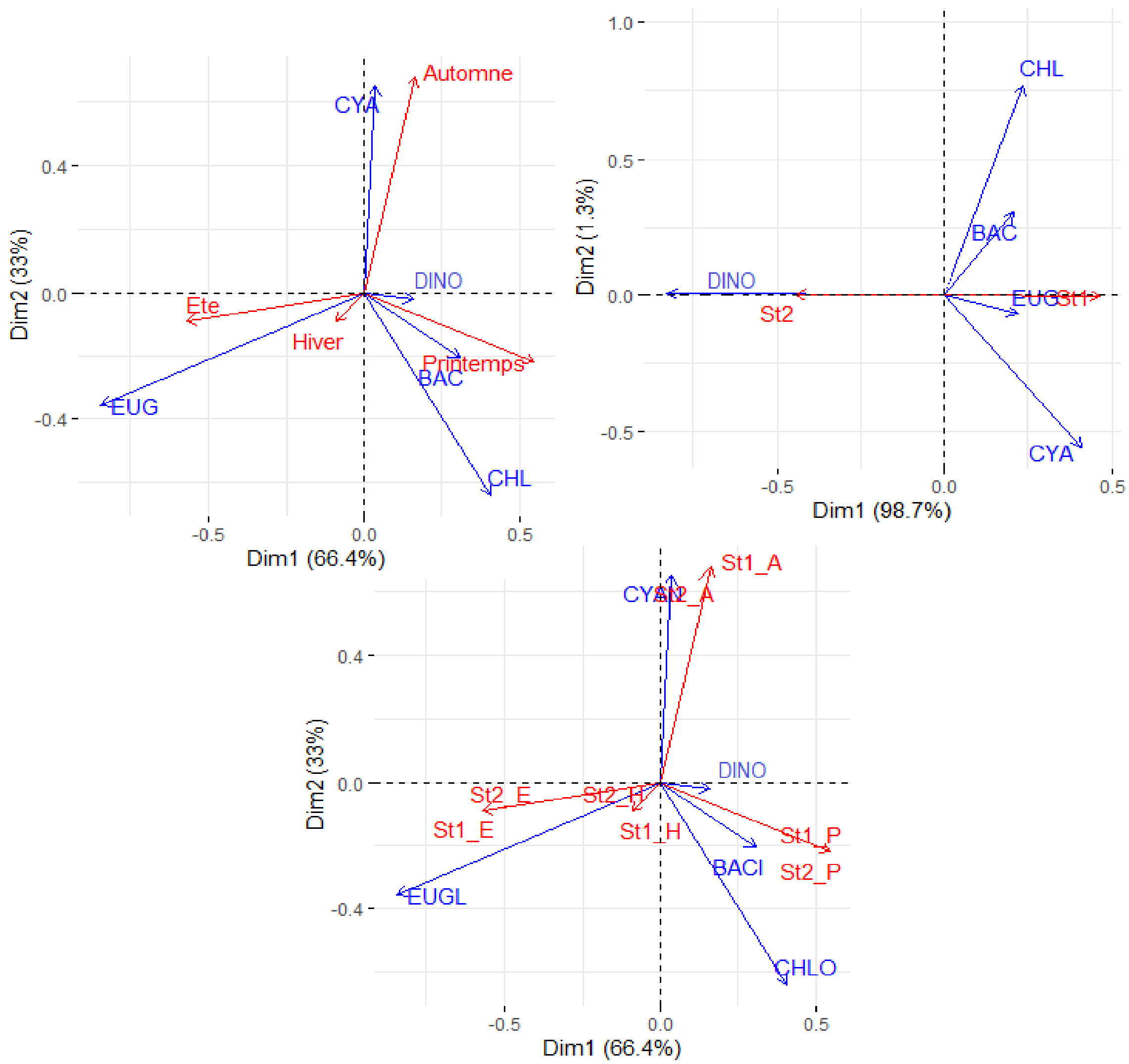

Fig. 7. Principal component analysis (PCA) on the standardized data matrix; A: Factorial plan (Dim 1 vs Dim2) according to the "station" factor, B: Factorial plan (Dem 1 vs. Dim2) by the "season" factor; C: Biplot of the factorial plan (DIM 1 vs dim2) by both "station", "season"factors. T: temperature (°C), O2: dissolved oxygen: (mg/L), pH: hydrogen potential, CON: electrical conductivity (μs/cm), Pb: Lead, CD: Cadmium, Mr: Mercury, CYAN: Cyanophycees, EUGL: Euglénophycees, CHLO: Chlorophyceae, BACL: Bacillariophycees, DINO: Dinophycees

DISCUSSION

Physicochemical studies

Temperature

Temperature, which significantly influences biological activities, showed notable seasonal variations in Lake Oubeira, with the highest values observed in summer (28.927.93−28.9°C) and the lowest in winter (14.48−14.65°C), consistent with the findings from previous studies **(Djabourabi *et al*., 2014; Djabourabi *et al*., 2017; Bensafia *et al.*, 2020; Sehili *et al*., 2020; Naili *et al*., 2021)**.

Draredja *et al*. (2019) observed significant fluctuations in temperature in the Mellah Lagoon depending on the seasons. Moreover, **Kherief *et al*.** (**2018)** observed significant fluctuations in temperature in the Béni Haroun Dam.

Dissolved oxygen

Our results show the existence of seasonal variations in dissolved oxygen during the study period. These same results have already been reported in Lake Oubeira by **Djabourabi *et al.* (2014)**, **Bensafia *et al.* (2020)** and **Sehili *et al.* (2020)**, in Lake Tonga by **Djabourabi *et al.* (2017)**, **Bensafia *et al.* (2020)** and **Naili *et al.* (2021)**, and in both lake lalla Séti and lake sedi m'hamed Benali by **Senouci *et al*. (2023)**. On the other hand in the Mellah lagoon, **Draredja *et al.* (2019)** noted that seasonal variations in dissolved oxygen were less significant.

pH

pH is an essential parameter in the study of aquatic environments; it is strongly influenced by chemical and biological mechanisms. The pH of the water at Lake Oubeira is relatively neutral toward basic for all the stations studied.

The existence of seasonal variations in pH has been documented in Lake Oubeira **(Djabourabi *et al*., 2014; Bensafia *et al*., 2020; Sehili *et al*., 2020)**, Lake Tonga **(Djabourabi *et al*., 2017; Bensafia *et al*., 2020; Naili *et al*., 2021)**, El Mellah Lagoon **(Draredja *et al*., 2019)**, as well as Lake Lalla Séti and Lake Sedi M'Hamed Benali **(Senouci *et al*., 2023)**. This abiotic parameter is influenced by the photosynthetic activity of algae, which leads to intense carbon dioxide absorption, a rise in pH, and carbonate precipitation **(Leynaud, 1976)**.

Conductivity

Conductivity measurement offers a quick but very precise assessment of the overall mineralization of water and allows its evolution to be monitored, the study stations have an electrical conductivity ranging from 362.33 to 828µS/ cm.

The seasonal variations in conductivity during our study period have already been revealed in Lake Oubeira **(Djabourabi *et al.*, 2014; Bensafia *et al.*, 2020; Sehili *et al.*, 2020)** and Lake Tonga **(Djabourabi *et al.*, 2017; Bensafia *et al.*, 2020**; **Naili *et al.*, 2021)**.

According to the evaluations of **Olsen (1950)**, when the conductivity of Oubeira water exceeds 500µS/ cm, this lake can be considered eutrophic. The waters of Lake Oubeira present an average mineralization accentuated with significant mineralization. Conductivity is also a function of water temperature; it is greater when the temperature is high **(Detay, 1993)**.

Suspended matter (SM)

The concentrations of suspended matter (SM) at the stations showed two peaks during the fall, with values of SM=46 at station 1 and SM=24 at station 2. These maximum values are likely linked to the high density of microalgae and elevated chlorophyll a content. Pearson correlation analysis reveals positive correlations between suspended matter and Chlorophyceae (r = 0.88), suspended matter and orthophosphate concentration (r = 0.78), and suspended matter and chlorophyll a (r = 0.52). Additionally, the shallow depth of the lake likely contributes to the transfer of sediment particles into the water column, driven by waves created by wind.

Our results are in agreement with those reported in the Lake Tonga **(Djabourabi *et al.*, 2017; Bensafia *et al,* 2020)**, in Lake Oubeira **(Bensafia *et al.*, 2020; Arif *et al.*, 2023)**, , in the Ain Dalia Dam **(Heramza *et al.*, 2021)**, and in Lake Mégarrine **(Manamani &Bensouilah, 2023**).

According to **Lounnas (2008)**, the suspended matter encountered in water (mainly surface water) is very diverse; it corresponds to all mineral or organic matter insoluble in water. It includes clays, sands, silts, small organic and mineral matter, plankton and other aquatic microorganisms.

Chlorophyll a

It emerges from the variation in the contents of chlorophyll a that the values are maximum during the fall (a peak) at the two stations, 1 and 2 (Chla= 0.09 – 0.10, respectively). However, the lowest value is recorded during winter at station 1 (Chla= 0.019).

The results of the Pearson correlation analysis show the existence of a positive correlation between chlorophyll a and: suspended matter (r = 0.52), chlorophyll a and orthophosphate concentration (r = 0, 68).

The existence of seasonal variations in the levels of chlorophyll a during the study period has already been shown in Lake Oubeira **(Djabourabi *et al.*, 2014; Bensafia *et al.*, 2020)**, and in Lake Mégarrine **(Manamani & Bensouilah, 2023)**.

Nitrate

Nitrate levels in the study ranged from 28.5 to 35.33mg/ l, with the highest value recorded at station 1 during summer (NO3 = 35.33mg/ l) and the lowest in winter at the same station. Seasonal variations in nitrate levels have also been observed in other lakes, such as the Mellah Lagoon **(Draredja *et al.*, 2019)**, Lake Oubeira **(Bensafia *et al.*, 2020)**, Lake Mégarrine **(Manamani & Bensouilah, 2023)**, as well as Lake Lalla Séti and Lake Sedi M'hamed Benali **(Senouci *et al.*, 2023)**. In unpolluted natural waters, nitrate concentrations typically range from 1 to 15mg/ l, with 2 to 3mg/ l considered normal **(Rodier, 2009)**. Nitrates are naturally occurring ions formed from the oxidation of nitrogen by microorganisms and are highly soluble and mobile in water and soil. Excessive nitrate levels can penetrate groundwater when they exceed plant uptake capacity **(Kemoukh, 2007)**.

Nitrite

Nitrites in this study are in the range of 0.22 – 0.25mg/ L. Consequently, in the absence of contamination, there are no or very few nitrites in the water. Especially in places where self-purification is active, concentrations are extremely low (about 0.01mg/ L). Under 0.01mg/ L, water can be considered pure with the action of active self-purification, which becomes significant beyond 1mg/ l **(Rodier, 2009)**.

According to **Manamani and Bensouilah (2023)**, an experimental study showed that ammonium oxidation and sulphate reduction effects were increased in the presence of nitrite and nitrate by nitrifying bacteria, but also by the decrease of nitrates.

Ammonium

The results of the ammonium analyses show that the NH4 values vary from 0.36 to 1.79. However, the highest values are recorded at station 1 during the fall. These levels would be attributed to increased anthropogenic inputs in association with the high abundance of coastal trees in the region. Ammonium nitrogen from surface waters can also be created by plant material in waterways and chlorophyll a as our study shows (r= 0.68).

The existence of seasonal variations in ammonium concentrations has already been revealed in Lake Oubeira **(Bensafia *et al.*, 2020; Arif *et al.*, 2023)** and in Lake Tonga **(Bensafia *et al.*, 2020)**.

Orthophosphates

During the study period, orthophosphate concentrations peaked at very high values at station 2 during summer (PO_4^{3-} = 5.16) and autumn (PO_4^{3-} = 5.00). Conversely, lower concentrations were observed at both stations, particularly during winter (PO_4^{3-} = 2.2 – 2.4).

Our results revealed the existence of seasonal variations of orthophosphates during the study period, this was also observed in Lake Oubeira **(Bensafia *et al.*, 2020; Arif *et al.*, 2023)**, in Lake Tonga **(Bensafia *et al.*, 2020)**, in Lake Mégarrine **(Manamani & Bensouilah, 2023)**, as well as in both Lake Lalla Séti and Lake Sedi m'hamed Benali **(Senouci *et al.*, 2023)**.

This increase in orthophosphate levels seems to be linked to the increase in inputs generated by flooding and the degradation of organic matter by bacteria **(Manamani & Bensouilah, 2023)**.

Phytoplankton community

Planktonic community inventory

The observation of the morphoanatomical characters of the plankton individuals collected at the two stations during our study period allowed us to list 48 genera belonging to five classes which include: Cyanophyceae (17 genera), Chlorophyceae (14 genera), Bacilliarophyceae (11 genera), Euglenophyceae (3 genera), and Dinophyceae (3 genera), with the dominance of cyanobacteria at the two stations. Among these genera, there are 8 known to be potentially toxic belonging to *Cyanophyceae Aphanizomenon, Pseudoanabaena, Oscillatoria, Lyngbya, Microcystis, Synechocystis, Anabaena,* and *Gomphosphaeria* (**Bourrelly, 1985**).
Djabourabi *et al.* (2014) reported the presence of 45 genera of phytoplankton belonging to three classes: (Cyanophyceae, Bacilliarophyceae and Dinophyceae)

In Lake Oubeira, **Amri (2008)** recorded the presence of 79 genera of phytoplankton belonging to eight classes: Bacillariophyceae, Chlorophyceae, Cyanophyceae, Euglenophyceae, Cryptophyceae, Dinophyceae, Chrysophyceae, and Xanthophyceae.

In the same lake, **Branes *et al.* (2007)** recorded the presence of 36 genera of phytoplankton belonging to four classes: Bacillariophyceae, Chlorophyceae, Cyanophyceae, and Euglenophyceae.

Souissi *et al*. (2004) recorded the presence of 11 genus of phytoplankton belonging to the Cyanophyceae class.
In Lake Tonga, **Djabourabi *et al*. (2017)** recorded 75 genera of phytoplankton belonging to three classes: Cyanophyceae, Bacilliarophyceae and Dinophyceae.

In the El Mellah lagoon, **Draredja *et al.* (2019)** recorded 160 genera of phytoplankton belonging to the class Bacilliarophyceae (diatoms). While, in Lake Mégarrine, **Manamani and Bensouilah (2023)** recorded the presence of 29 genera of phytoplankton belonging to three different classes: Cyanophyceae, Bacilliarophyceae and Dinophyceae.

Quantitative analysis of phytoplankton

The class *Cyanophyceae* exhibits clear dominance during the study period, comprising 53% of the total phytoplankton density inventoried. Our findings align with the results of several authors who have reported significant densities of *Cyanophyceae*: **Souissi *et al.* (2004)**, **Branes *et al.* (2005)**, **Amri (2008)**, **Djabourabi *et al.* (2014)**, **Djabourabi *et al.* (2017)**, **Arif *et al.* (2023)**, **Manamani and Bensouilah (2023)**, and **Belhaoues *et al*. (2024)**.

Pearson correlation analysis between the physicochemical parameters and phytoplankton classes shows a positive correlation between the density of *Cyanophyceae* and nitrite (r = 0.77) and temperature (r = 0.5). *Cyanobacteria* generally have an optimal growth rate at high temperatures (around 25°C), although they can tolerate lower temperatures and survive in polar regions **(Djabourabi, 2014)**.
For *Chlorophyceae*, our study identified 14 genera, which account for 17% of the total phytoplankton density inventoried. This is supported by previous studies showing significant densities of *Chlorophyceae*, as for example, the studies of **Branes *et al.* (2005)**, **Amri (2008)**, **Hamaidi *et al.* (2013)** and **Djerboua *et al.* (2022)**. Correlation analysis reveals positive relationships between the density of *Chlorophyceae* and the density of *Euglenophyceae* (r = 0.97), nitrate (r = 0.94), suspended matter (r = 0.88), and chlorophyll a (r = 0.7).
The *Euglenophyceae* class is represented by only 3 genera, constituting 15% of the total phytoplankton density. This class exhibits maximum densities in autumn and minimal densities during winter. Their presence reveals unsatisfactory environmental conditions (negative correlation between the density of the Euglenophytes and dissolved oxygen (r= - 0.51)). For Bacillariophycees we were able to identify 11 genera (15% of the total density of the plant inventory). Moreover, our results show the highest density of harvested diatoms was recorded during the month of April (spring period); the high density is also explained by the existence of sufficient concentrations of nitrates (a positive correlation between the densities of Bacillariophycees and nitrate, r= 0.81).
Our data are supported by the results of some authors who have noted significant densities of diatoms in their work **(Branes *et al.*, 2005; Amri, 2008; Djabourabi *et al.*, 2014; Djabourabi *et al.*, 2017; Manamani & Bensouilah., 2023)**.

The class *Dinophyceae* is represented by only 3 genera, making up 1% of the total phytoplankton density inventoried. Our data align with previous studies that have noted the presence of *Dinophyceae*: **Djabourabi *et al.* (2014)**, **Djabourabi *et al.* (2017)**, and **Manamani and Bensouilah (2023)**.

Pearson correlation analysis shows positive correlations between the density of *Dinophyceae* and pH (r = 0.44) and cadmium concentration (r = 0.28). Factors such as temperature, local illumination conditions, and the hydromorphology of the environment can also contribute to the development of this class of phytoplankton **(Djabourabi, 2014)**.

Heavy metals

Our results concerning the spatiotemporal evolution of heavy metals show significant fluctuations. Cadmium levels exhibit seasonal variation at both stations, with notable values during spring (0.28mg/ L), whereas bioaccumulation at station 2 is lower in summer (0.18mg/ L). Lead concentrations are significantly higher in fall at station 2 (0.11mg/ L), while the lowest values are recorded during winter and spring at the same station (0.03mg/ L).

Mercury levels range from 0.46 to 0.76mg/ L, with the highest value recorded at station 1 during summer, and the lowest value observed at station 2 during the same season. These findings are consistent with the spatiotemporal variations of heavy metals reported by **Bendjama *et al.* (2011)** in Lake Oubeira, Lake Tonga, and the Mellah Lagoon; **Belabed *et al.* (2013)** in the Gulf of Annaba; **Ouali *et al*. (2018)** in the North African coasts of the Mediterranean Sea; **Zeghdoudi *et al.* (2019)** in the Gulf of Skikda; and **Senouci *et al.* (2023)** in Lake Lalla Séti and Lake Sedi M'hamed Benali.

Bendjama *et al.* (2011) also reported spatial fluctuations in the concentrations of seven heavy metals in Lake El Mellah, Lake Tonga, and Lake Oubeira. Our analysis of the waters of Lake Oubeira indicates contamination with heavy metals in the order: Hg > Cd > Pb.

Our results demonstrate spatiotemporal variations in phytoplankton density in Lake Oubeira and a correlation between physicochemical parameters and certain heavy metals (lead, cadmium, mercury) affecting the distribution and density of phytoplankton classes. Additionally, other studies on lakes and dams in northeastern Algeria have shown correlations between phytoplankton densities and nutrient concentrations **(Ounissi *et al*., 2002; Nasri *et al*., 2007, 2008; Amri *et al.*, 2010; Djabourabi *et al*., 2014; Djabourabi *et al*., 2017; Draredja *et al.*, 2019; Bensafia *et al.*, 2020; Heramza *et al*., 2021; Manamani & Bensouilah, 2023)**.

CONCLUSION

This study highlights several key findings:

- Significant spatiotemporal variations in physical and chemical parameters, as well as heavy metals, were observed in Lake Oubeira.
- A total of 48 genera of phytoplankton were identified, representing five classes: *Cyanophyceae* (17 genera), *Chlorophyceae* (14 genera), and *Bacillariophyceae* (11 genera).
- *Cyanophyceae* demonstrated clear dominance throughout the study period.
- Oued Messida station showed the highest microalgae density.
- Peak phytoplankton densities were recorded during summer and autumn.
- Lead, cadmium, and mercury were detected in both stations throughout the study period.

Principal component analysis and Pearson correlation analysis revealed positive correlations between *Euglenophyceae* and suspended matter (r = 0.8), *Euglenophyceae* and chlorophyll a (r = 0.73), and *Chlorophyceae* and chlorophyll a (r = 0.70), among others. Negative correlations were observed between *Chlorophyceae* and pH (r = -0.94) and between *Euglenophyceae* and pH (r = -0.9). Additionally, negative correlations between *Chlorophyceae* and lead (r = -0.57) were noted.

Future work should focus on establishing a comprehensive monitoring program for the lake, increasing sampling efforts to better understand its dynamics, extending the study to cover an annual cycle or several years, and including other sites within the lake and other lakes in the PNEK region of northeastern Algeria. It would also be beneficial to analyze additional metals and physicochemical parameters to gain a more complete picture of the lake's condition.

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