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Assessment of Water Quality Variations and Trophic State of the Joumine Reservoir (Tunisia) by Multivariate Analysis

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Abstract: North Tunisia's Joumine reservoir provides water for drinking and agriculture irrigation purposes. Therefore, its water quality is crucial, especially with the recurrence of dry years in a global climate change context. This study aims to evaluate its environmental parameters, phytoplankton community structure, and trophic status. The data were newly analyzed using multivariate statistical methods and redundancy analysis (RDA) with the Trophic State Index (TSI) and Trophic State Index deviation (TSID). Monthly sampling occurred from May 2021 to June 2022 at eight stations. Water samples were collected to assess physical-chemical parameters and Chlorophyll-a, as well as to identify phytoplankton species. Three seasonal clusters of summer, autumn, and spring were identified. Water nutrient variations primarily resulted from point and non-point source contamination, along with natural processes. Carlson's Trophic State Index (CTSI) indicates a eutrophic status for the Joumine reservoir. TSID indicated there was no algal turbidity in the reservoir. The study identified 25 phytoplankton taxa, with Chlorophyceae exhibiting high densities and diversities. RDA revealed that NO_3^-, NH_4^+, DO, pH, water flow, and water temperature were the most important environmental factors controlling phytoplankton structure in the Joumine reservoir. The outcomes of this study may provide helpful information to improve the management of the Joumine reservoir.

Keywords: Joumine; Tunisia; water quality; multivariate statistics; phytoplankton taxa; redundancy analysis

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1. Introduction

Deterioration of water quality and eutrophication are becoming increasingly preoccupying issues worldwide [1,2]. Population growth exerts pressure on the agriculture sector, as well as industrial and urban activities, which leads to an increased water demand despite the limited resources [3–9]. Among the main sources of water pollution are the large number of contaminants emanating from industries, urban zones (domestic/sewage) transported by rivers, streams, and their tributaries, and runoff from polluted agricultural fields [10].

On the other hand, climate change can also have a major impact on water quality [11–13] through water flow alteration, land use changes, and overexploitation of the land [13,14]. These changes can alter the balance of biogeochemical processes and material flows [15], leading to changes in water chemistry and potential impacts on ecosystems and human uses of water [5,12]. These consequences span across economic, social, health, and food security aspects [16].

The enrichment of water can cause its eutrophication by the appearance of blooms. In fact, the development of the phytoplankton community depends on many factors [17]. These include physical parameters (light, temperature, water movements, weather conditions), chemical parameters (nitrogen, phosphorus, calcium, magnesium, potassium, chloride) and biological factors (predation, competition) [17,18]. In addition, the World Health Organization (WHO) has established guideline values for drinking-water supplies and recreational waters which may contain toxic cyanobacterial populations [19]. Therefore, having reliable information on water quality in terms of physical-chemical and biological data is a key step for effective identification, pollution control, and a better characterization of the water quality and ecological status of studied ecosystems [5,9,20–22].

To assess the state of the environment and water quality, multivariate statistical techniques have been used, including cluster analysis (CA), factor analysis (FA), principal component analysis (PCA), and redundancy analysis (RDA) [9,10,22–25]. Carlson's Trophic State Index (CTSI), Trophic State Index Deviation (TSID), and [26] were widely used to assess water quality [27–29].

The aforementioned statistical tools play an important role in the assessment and interpretation of data with a large number of physical, chemical, and biological parameters [7]. Many studies have been performed to evaluate water quality. Bouguerne et al. [30] and Mamun et al. [31] used CA and PCA, respectively, to assess the water quality of the Ain Zada reservoir (Boussellem watershed, Algeria) and Paldang reservoir (Republic of Korea) using hydro-physicochemical dataset. Other studies, such as Singh et al., Dutta et al., Koklu et al., Li et al., and Varol et al. [32–36] used multivariate statistical techniques to study seasonal variation, cluster sampling sites, and identify pollution factors. In addition, Becker et al. [37] used RDA to assess the impact of the mixing regime on the seasonal dynamics of the phytoplankton community located at the Faxinal reservoir in subtropical southern Brazil. The RDA method was applied by Tian et al. [27] to evaluate the interaction between phytoplankton variation and environmental variables in Dongping Lake, located in Taian City (China). These previous studies revealed that multivariate statistical methods are important to underline the relationships between water quality parameters and cluster sampling sites as well as to identify factors of pollution.

Tunisia is facing a significant decrease in water resource availability due to the recurrence of drought years over the past 30 years (1985–1986 to 2014–2023) [18]. This causes hydric stress, which impacts the availability of water for the population. According to the published statistics of the Tunisian agriculture ministry, the amount of available water will decrease from 357.9 (m^3/capita) in 2020 to 286.3 (m^3/capita) in 2050 [18]. Meanwhile, the proliferation of *Cyanobacteria* is increasingly important at the level of some Tunisian water bodies [19], which negatively affects the use of water resources either for drinking water or irrigation. In the North of Tunisia, the Joumine basin was reported as one of the exposed basins to this problem [24].

The watershed of Oued Joumine, located in the northwest of Tunisia, drains an area of 418 km^2. The Joumine reservoir was built in 1984 to protect the plain of Mateur against floods. The stored water, about 76 million m^3 in 2021, is mainly used for irrigation and drinking water supply. It is part of the mixed-use reservoirs. It is mainly used for irrigation and drinking purposes for the plain of Mateur and the greater Tunis, the supply of agricultural water to the region of Cap Bon, and the provision of fresh water to the ecosystem of Ichkeul if necessary. According to the classification of trophic levels of OCDE [26], the Joumine dam revealed a eutrophic status or hyper-eutrophic or super-eutrophic tendency [19]. Additionally, Fathalli [21] showed the existence of toxic *Cyanobacteria Microcystis aeruginosa* at the dam of Joumine. In this basin, a correlation between the expansion of cereal crop cultivation and the increased use of fertilizer was observed, resulting in nitrate pollution of nearby stream water, as reported in the study of Aouissi et al. [25] and Boukari et al. [15]. Due to these factors, it is necessary to improve the water quality assessments of the reservoir.

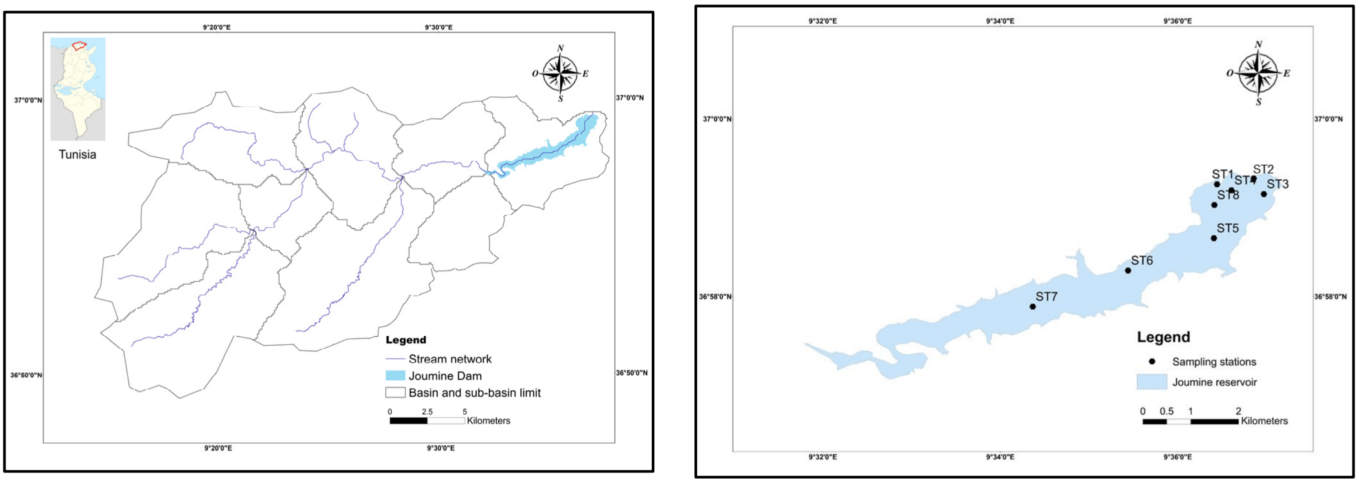
In the present paper, we assess spatial and temporal variation of water quality parameters. Using the TSI, TSID, and OCDE [26] methods, we also determine the trophic status of the reservoir and its variations throughout this study. The datasets obtained during the monitoring program are then processed through numerous multivariate statistical techniques to assess the spatial and temporal change in water quality and identify the major influencing factors.

2. Materials and Methods

2.1. Study Area, Sampling, and Sample Analysis

The Joumine reservoir is located in the northwestern part of Tunisia (36°59′49″ N and 9°36′49″ E). This region is characterized by a sub-humid to semi-arid climate with large seasonal and annual precipitation variability [38]. The average annual precipitation is estimated at around 700 mm/year from 1988 to 2012 [39]. The Joumine Dam was built in 1983 for irrigation, for supplying drinking water to the downstream Plaine Mateur, and for flood control [40]. This dam is characterized by a capacity of 118 Mm^3. According to National Observatory of Agriculture (Onagri) data in 2022, the actual available water in the dam is around 26 Mm^3.

To cover the water quality parameters' spatiotemporal variability in the reservoir, Joumine reservoir water was sampled at eight points, as indicated in Figure 1a,b.



(**a**) (**b**)

Figure 1. Location of (**a**) Joumine reservoir in the north of Tunisia and (**b**) displays the water quality monitoring sites.

In terms of sampling locations, sampling points were chosen to cover almost the entire dam. Added to that, the sampling points were focused on the central basin upstream of the dam, representing the deepest part of the zone. Sites were selected on the basis of their accessibility and degree of exposure to wind and domestic effluent, as well as the surface area covered by the water.

In terms of seasonal division and based on the life cycle of phytoplankton, particularly blue-green algae as highlighted in the Limam [40] study, we have chosen to conduct sampling during three specific seasons of spring, summer, and autumn in 2021. This selection aims to ensure more efficient sampling.

The number of samples taken in each season may not be consistent due to variations in water depth at different sampling sites. In some locations, the water depth may differ, especially during summer when there is a reduction in water levels due to the absence of rain. These factors can impact the coherence of the sample distribution across seasons.

Additionally, we repeated the sampling in 2022, specifically in March and June. Sampling during 2022 is considered as a separate year of sampling, and we only utilized the data available at that time. A total of 190 water samples of 1 L were collected at monthly intervals from sampling sites (ST1 to ST8) between March 2021 and June 2022. Samples were stored at 4 °C.

In order to assess the evolution of the water quality of the Joumine reservoir, water samples were collected from the surface to the deepest part of the Joumine reservoir at 0, 5, 10, 15, and 20 m on eight sampling sites of the reservoir during six months (May, June, August, and October 2021 plus March and June 2022).

Two sets of samples were collected for chemical analysis and phytoplankton species studies. The water temperature (WT), pH, salinity, and dissolved oxygen (DO) were measured directly using a multiparameter probe (WTW multi 340i). The water transparency (SD) was measured using a Secchi disk. The euphotic depth (Zeu) was derived from (SD). The concentration of the suspended solid (CSS) was determined by measuring the dry weight of the residue after filtration through a Whatman GF/C membrane. The nutrient analysis for nitrate ($NO_3{}^-$), nitrite ($NO_2{}^-$), chloride (Cl^-), ammonium ($NH_4{}^+$), total phosphorus (TP) when detected, calcium (Ca^{2+}), magnesium (Mg^{2+}), sulphate ($SO_4{}^{2-}$), sodium (Na^+), and potassium (K^+) was determined using ionic chromatography [41].

For Chlorophyll-a (Chl-a) determination, the row water was filtered through a glass microfiber filter (GF/C Whatman), and Chlorophyll was then extracted by immersion of the filters in 10 mL of acetone 90%. The concentration of Chlorophyll-a was detected spectrophotometrically with a 665 nm excitation filter and 750 nm emission filter according to the method described by [42]. Phytoplankton samples collected in 1-litre plastic bottles were fixed with 10 mL of formaldehyde (35%) for phytoplankton identification and their quantification until analysis. The identification and quantification of the different taxa were carried out using sedimentation chambers and an inverted microscope, as described by [43].

2.2. Data Treatment

The water quality dataset was subjected to multivariate analyses consequently to explore the relationships between physicochemical and biological variables and their influence on the hydrological system over time and space. Pearson's correlation, CA, PCA, and RDA were used for the analyses, with IBM SPSS 20, Microsoft Excel 2016 software, and RStudio version 3.3.0+ employed for the statistical calculations.

The CA analysis was utilized to investigate the similarity and dissimilarity between different classes based on their characteristics [32]. Hierarchical agglomerative clustering (HCA) is the most commonly used method to group objects into clusters based on their similarity [44]. In this study, the (HCA/CA) was conducted using Euclidean square distances as a measure of similarity.

PCA was employed to analyze the link between various water quality variables, with the aim of identifying the most meaningful parameters while keeping the existing variability in the dataset as much as possible [45]. PCA was performed on normalized data to categorize the absolute factor loading values of each component in this study [46].

In order to characterize the association between environmental variables and species abundance and to determine which variables are best able to reflect the distribution of groups [37], RDA was applied to the normalized data. It is regarded as a "raw-data approach" that identifies environmental factors or gradients that could considerably explain variations in phytoplankton communities in complex systems [27,47].

To assess eutrophication in a waterbody, the standards used take into account the examination of nutrient levels, the quantities of Chlorophyll-a (Chl-a) and total phosphorus (TP), and the degree of transparency (SD) [48]. The trophic state of the reservoir was calculated by applying different methods: OCDE [26] and the Trophic State Index (TSI) [49], which are based on the parameters of Chlorophyll-a, Total phosphorus, and Secchi disk transparency. The CTSI scale ranges from 0 to 100, with a CTSI score of 0–30 indicating oligotrophic conditions, a score of 30–50 indicating mesotrophic conditions, a score of 50–70 indicating eutrophic conditions, and a score of 70–100 indicating hypertrophic conditions. To calculate the CTSI score, mathematical equations outlined in Equations (1)–(4) are utilized [49].

$$\mathrm{TSI}(\mathrm{Chl}-\mathrm{a}) = 9.81\ln(\mathrm{Chl}-\mathrm{a}) + 30.6 \tag{1}$$

$$\mathrm{TSI}(\mathrm{TP}) = 14.42\ln(\mathrm{TP}) + 4.15 \tag{2}$$

$$\mathrm{TSI}(\mathrm{SD}) = 60 - 4.41\ln(\mathrm{SD}) \tag{3}$$

$$\mathrm{TSI\ CARLSON} = \frac{\mathrm{TSI}(\mathrm{Chl}-\mathrm{a}) + \mathrm{TSI}(\mathrm{TP}) + \mathrm{TSI}(\mathrm{SD})}{3} \tag{4}$$

The relationship TSI (Chl-a) − TSI (SD) and TSI (Chl-a) − TSI (TP) were used to define the TSID in two dimensions. The CTSI and TSID were used to quantify the degree of water eutrophication.

3. Results

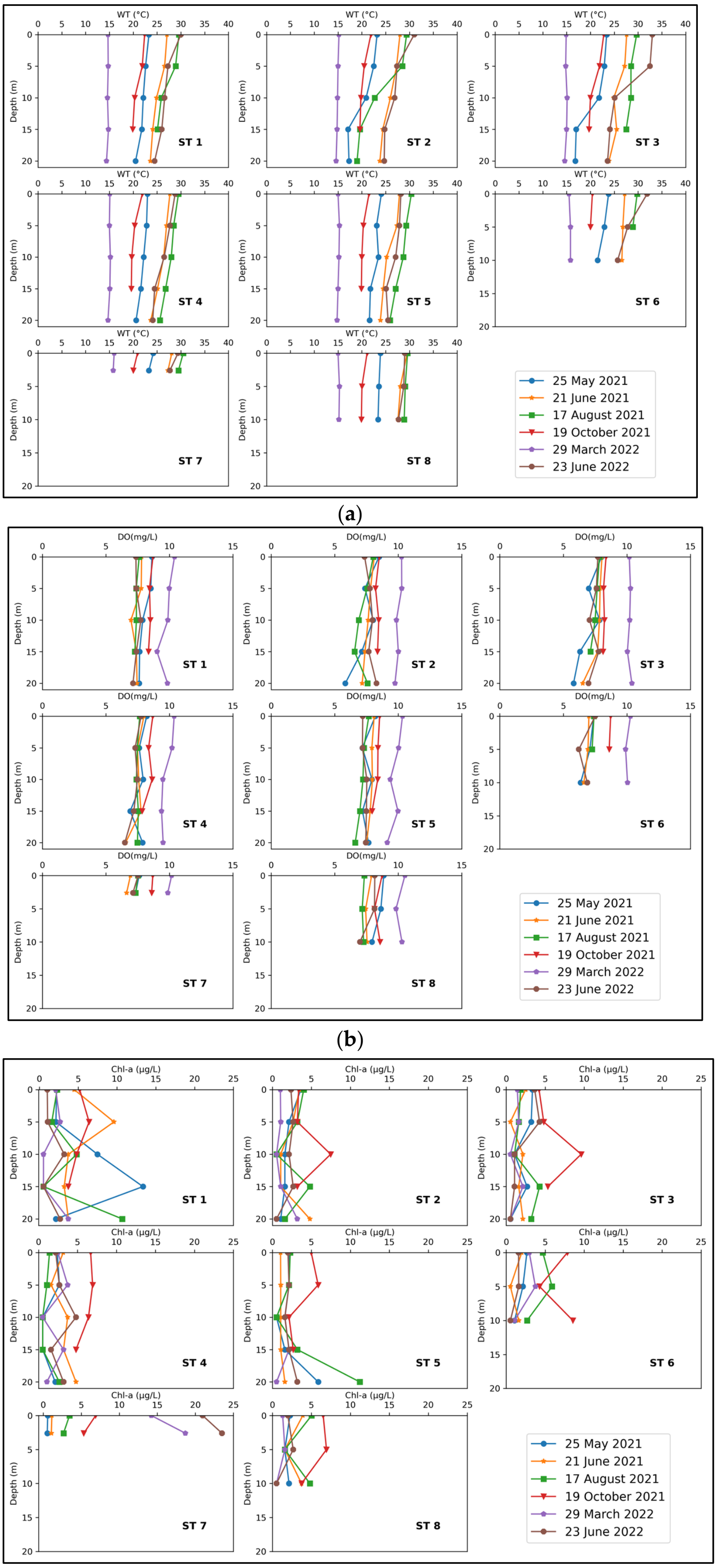
3.1. Trophic Status and Physicochemical Factors of the Joumine Reservoir

Except for Chlorophyll-a, Nitrite, and Ammonium, the variability of statistical data for sixteen measured variables at eight sampling stations in the Joumine reservoir was observed at different depths and dates. Table 1 did not demonstrate significant spatial variations among the stations ($p < 0.05$). However, the observed spatial differences for Chlorophyll-a, Nitrite, and Ammonium indicate the impact of human activities on the reservoir's water quality. Specifically, Chlorophyll-a concentration was notably higher at ST7 compared to other stations. ST7 is located at the downstream narrow part of the reservoir with a depth of only 5 m, receiving inputs from nearby agricultural areas and where the growth of vegetation can be observed. During the study period in the Joumine reservoir, the pH value ranged from 7.7 to 10.8, indicating the alkalinity of the water. However, there were significant fluctuations in pH values at different depths, particularly during August, with variations of up to 0.9 pH units. This can be attributed to higher algal activity in the epilimnion as reported in previous studies [21,40]. The decrease in pH at the bottom of the reservoir could be explained by the decomposition of algae and the oxidation reaction of organic matter [50]. Nevertheless, no significant spatial variations of pH were observed between stations. The stability of the alkalinity in the Joumine reservoir was caused by the water's hardness due to the carbonate elements found in the river bed/water shed bed rocks [6,12,40]. The Joumine reservoir is considered well-oxygenated, as the oxygenation levels in the reservoir range from 5.80 mg/L to 10.53 mg/L. These results are consistent with previous studies such as Bel Haj Zekri et al. [51] in Fathalli et al. [21]. They are similar to the oxygenation levels found in other Tunisian reservoirs like Lebna (5.71 mg/L; 11.56 mg/L) [52] and Kasseb (7.5 mg/L; 11.30 mg/L) [53] in [19]. However, it should be noted that the rate of dissolved oxygen decreases towards the bottom of the reservoir, which has been reported in many studies [21,52] to be potentially harmful to aquatic life [54]. These averages fit the criteria established by the WHO [29] in Figure 2.

Table 1. Mean, minimum, and maximum values of water quality parameters at different sampling stations (for all depths and dates) in the Joumine reservoir.

		2020/2021–2021/2022															
		WT [1]	**pH**	**DO** [1]	**NO_3^-** [1]	**NO_2^-** [1]	**NH_4^+** [1]	**Chl-a** [1]	**CSS** [1]	**Na^+** [1]	**K^+** [1]	**Ca^{2+}** [1]	**Mg^{2+}** [1]	**Cl^-** [1]	**SO_4^{2-}** [1]	**SD** [1]	**Zeu** [1]
ST1	Mean	21.82	8.87	8.28	6.12	0.22	1.61	4.33	11.37	46.14	3.31	40.64	13.43	88.09	67.00	1.50	3.84
	Min	14.40	8.03	6.97	0.07	0.01	0.30	0.53	1.00	17.42	0.28	0.97	4.66	21.84	30.56	0.70	1.79
	Max	29.60	10.73	10.40	18.47	0.65	7.40	13.35	39.00	202.04	14.82	123.34	40.37	133.00	120.40	2.50	6.40
	+/−SD [1]	4.66	0.93	0.98	6.74	0.20	1.93	3.30	12.08	54.78	4.09	30.65	9.94	31.73	24.76	0.62	1.58
ST2	Mean	21.31	8.95	8.14	6.80	0.23	1.48	2.63	10.00	37.46	4.02	39.92	13.22	105.34	69.87	1.51	3.87
	Min	14.60	8.19	5.84	0.09	0.02	0.18	0.53	1.00	21.81	1.22	23.81	0.13	20.45	31.54	0.80	2.05
	Max	29.40	10.45	10.28	17.97	0.65	6.25	7.48	92.00	144.79	25.70	91.11	29.80	319.40	105.70	2.50	6.40
	+/−SD	4.67	0.71	1.18	6.92	0.23	1.59	1.69	18.72	29.97	5.56	23.18	7.08	55.97	21.74	0.63	1.60
ST3	Mean	21.78	8.80	8.13	5.94	0.23	1.50	2.63	12.22	30.58	2.62	41.47	12.38	87.02	63.90	1.54	3.94
	Min	14.60	7.69	5.80	0.03	0.00	0.36	0.53	1.00	18.30	0.81	17.96	8.76	18.13	28.70	0.90	2.31
	Max	29.70	10.39	10.39	16.62	0.69	7.10	9.61	83.00	58.09	6.94	91.14	22.20	124.40	93.90	2.50	6.40
	+/−SD	4.97	0.85	1.29	6.41	0.25	1.72	2.07	18.48	13.89	1.99	24.26	4.97	35.80	22.24	0.62	1.60
ST4	Mean	22.30	8.91	8.17	6.19	0.23	1.47	2.80	5.83	30.93	2.52	39.90	11.41	84.04	64.04	1.63	4.17
	Min	14.70	8.14	6.55	0.04	0.02	0.18	0.53	1.00	22.83	0.95	21.11	2.36	16.22	25.38	0.80	2.05
	Max	29.50	10.80	10.37	16.51	0.71	5.14	6.94	16.00	57.46	6.72	92.68	22.11	120.13	93.96	3.00	7.68
	+/−SD	4.75	0.77	0.99	6.43	0.23	1.50	2.04	5.65	12.00	1.87	21.82	4.62	36.38	22.86	0.80	2.04
ST5	Mean	22.56	8.77	8.15	5.92	0.25	1.76	2.59	7.07	30.75	2.50	41.48	12.49	88.07	62.48	1.50	3.84
	Min	14.80	8.08	6.62	0.10	0.01	0.44	0.53	1.00	21.26	1.11	24.38	8.02	14.43	23.27	0.80	2.05
	Max	30.40	10.20	10.34	16.76	1.46	8.24	11.21	22.00	60.48	7.02	94.40	22.63	140.80	91.97	2.50	6.40
	+/−SD	4.88	0.70	0.99	6.17	0.34	2.12	2.41	6.03	12.77	1.68	23.59	4.78	36.95	22.02	0.57	1.47
ST6	Mean	22.69	8.86	7.97	3.31	0.20	1.42	3.48	6.54	30.41	2.18	41.63	12.27	94.39	61.99	1.06	2.71
	Min	15.50	8.30	6.36	0.08	0.01	0.35	0.53	1.00	23.66	0.94	25.16	9.24	19.53	31.99	0.70	1.79
	Max	29.80	10.01	10.28	10.15	0.49	5.70	8.54	15.00	55.21	5.80	88.50	20.74	161.80	92.32	2.00	5.12
	+/−SD	5.03	0.66	1.37	4.01	0.17	1.86	2.51	5.51	11.26	1.48	22.06	4.06	46.04	24.56	0.49	1.26
ST7	Mean	23.56	8.79	8.07	3.07	0.23	1.40	4.49	23.17	30.47	2.10	39.14	12.55	86.22	66.43	0.62	1.59
	Min	15.80	8.15	6.63	0.08	0.01	0.53	0.53	5.00	24.61	1.32	24.27	9.47	21.81	36.22	0.50	1.28
	Max	30.50	9.93	10.17	10.40	0.69	6.07	18.69	73.00	56.20	4.30	90.43	21.31	119.25	91.89	0.70	1.79
	+/−SD	5.33	0.57	1.21	4.56	0.26	1.76	5.77	27.26	11.45	1.01	23.51	4.06	39.71	26.26	0.08	0.20
ST8	Mean	22.52	8.97	8.61	7.76	0.22	1.62	3.69	12.00	29.90	2.29	39.36	11.21	95.99	67.98	1.18	3.03
	Min	15.00	8.24	7.17	0.12	0.02	0.20	0.53	1.00	17.90	1.50	22.86	7.14	17.39	28.33	0.70	1.79
	Max	29.60	9.99	10.53	12.32	0.40	5.62	6.94	60.00	56.88	4.96	90.31	20.56	152.20	88.21	2.00	5.12
	+/−SD	6.01	0.66	1.19	4.72	0.16	1.96	2.17	17.43	13.88	1.38	27.18	4.36	46.72	24.38	0.60	1.53

Notes: [1] WT (°C), DO (mg/L), NO_3^- (mg/L), NO_2^- (mg/L), NH_4^+ (mg/L), Chl-a (µg/L), CSS (mg/L), Na^+ (mg/L), K^+ (mg/L), Ca^{2+} (mg/L), Mg^{2+} (mg/L), Cl^- (mg/L) SO_4^{2-} (mg/L) SD (m), Zeu (m) and +/−SD standard deviation.



(**a**)

(**b**)

(**c**)

Figure 2. Vertical profiles of water temperature (**a**), dissolved oxygen (**b**), and Chlorophyll-a (**c**) along the water column in the Joumine reservoir from ST1 to ST8.

The matrix of Pearson's correlation coefficients (r) reveals the potential linear relationships between each pair of environmental variables in Figure 3. In accordance with the correlation matrix carried out in our study, pH displayed a significant positive correlation value of 0.79 and 0.83, corresponding to Ca^{2+} and Mg^{2+}, respectively. In the correlation matrix, DO was negatively correlated to water temperature (−0.718) since oxygen becomes more soluble in colder water [7,45,55]. High and positive correlations can be observed between sulphate, chloride, calcium, magnesium, potassium, sodium, and CSS (r = 0.36 to 0.89), which are responsible for water mineralization. Similar results were observed in [7,45]. This analysis also shows a positive correlation (0.83) between NO_3^- and NO_2^-. The positive relationship between these variables indicates that their sources were similar. The reservoir's water clarity decreased with the increase in nitrate, nitrite, Chl-a, and the concentration of the suspended solid.

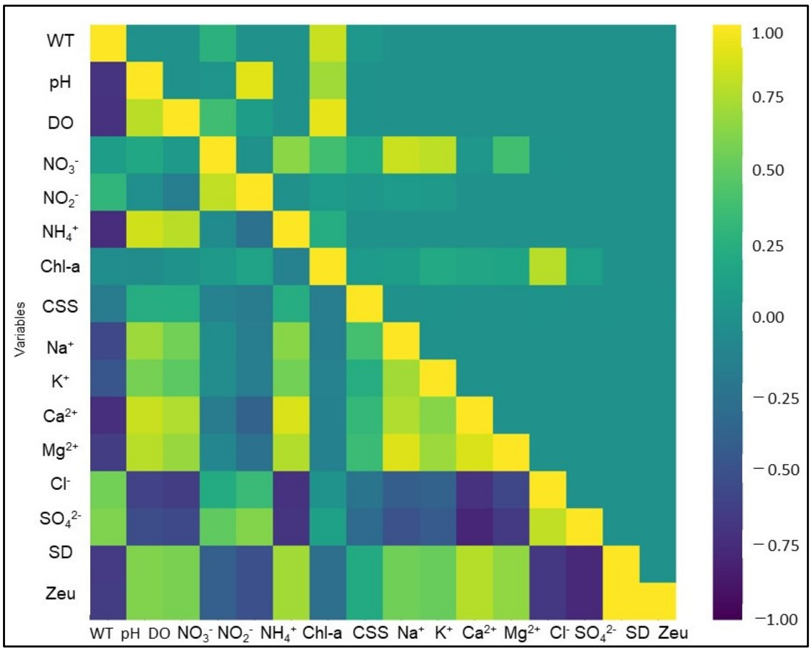
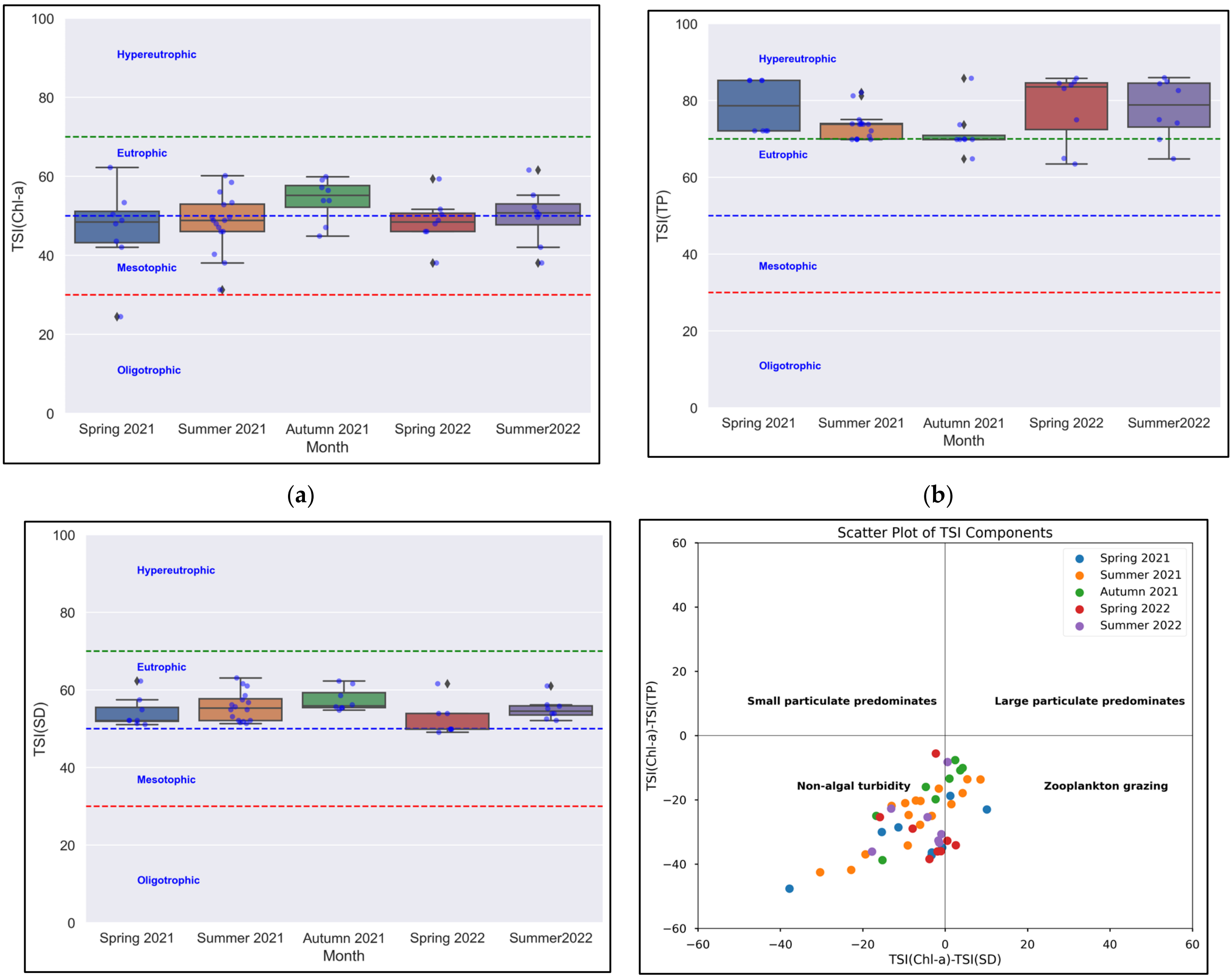


Figure 3. Correlation matrix between physicochemical parameters and Chlorophyll-a from the Joumine reservoir. Pearson correlation test values are represented as correlation coefficients (below diagonals and shown by color and intensity of shading) and *p*-values (above diagonal).

The Joumine reservoir's CTSI was determined using Secchi disk depth (SD), Chlorophyll-a concentration (Chl-a), and Total phosphorus (TP). Based on the average values obtained throughout the sampling period, the CTSI value was 59.9. Using the [56] classification, our findings indicate that the water body in the studied reservoir is eutrophic. On the other hand, according to OCDE, 1982 [26], and with reference to Chlorophyll-a, the reservoir reveals a mesotrophic status. This is not the case considering total phosphorus that indicates a hypereutrophic status. This could explain the development of phytoplankton [19].

Information on algal Chlorophyll growth, nutritional variability, and many other reservoir factors can be found by analyzing TSI and TSID in Figure 4a–d. In the Joumine reservoir, TSI and TSID were estimated based on Chl-a, TP, and SD, and their values displayed seasonal and spatial variation. Seasonally and over the entire sampling sites, the mean TSI (Chl-a), TSI (TP), and TSI (SD) values imply a mesotrophic, hypereutrophic, and eutrophic state, respectively.



(**a**) (**b**)

(**c**) (**d**)

Figure 4. Seasonal Trophic State Index (**a**–**c**) and (**d**) its deviation.

According to Carlson and Havens [57], TSID has been used to calculate the degree of eutrophication and identify nutrient limitations in reservoirs. Additionally, according to Carlson (1983), variations of the TSI (Chl-a) from the TSI (TP) generally represent levels of P limitation, whereas deviations of the TSI (Chl-a) from the TSI (SD) represent levels of light penetration in relation to the quantity and size of sediment particles. Non-algal turbidity is indicated if TSI (TP) and TSI (SD) both vary from TSI (Chl-a) but are associated with each other.

Based on the links between TSI (Chl-a) with TSI (TP) and TSI (SD), and according to Carlson and Havens [57], there was no algal turbidity in the reservoir over the whole sample period in Figure 4d. This graph allows for the simultaneous visualization of the deviations of all three indices by plotting the deviations of the Total Suspended Solids Index TSI (SD) onto the graph of the other deviations. By examining the spatial position of the data points representing the reservoir, it becomes possible to infer potential relationships between the three indices. In Figure 4d, it is explained that around 87% of the observations are classified as having a predominance of small particulates based on the relationships between "TSI (Chl-a) − TSI (SD)" and "TSI (Chl-a) − TSI (TP)" across all periods. Additionally, Figure 4d provides evidence of a non-algal turbidity effect observed in most observations. Despite the role of TP in the Joumine reservoir in controlling algal production, the productivity of plankton is also influenced by low-light conditions primarily caused by non-algal turbidity. The reservoir has a few zooplankton that were found to be grazing.

Temporal CA generated a dendrogram that grouped the six months into three statistically significant clusters at (Dlink/Dmax) × 100 < 30. Cluster one included August and October 2021 and June 2022, closely corresponding to summer and autumn. Cluster two included May and June 2021, closely corresponding to late spring and summer. The third cluster included March 2022, corresponding to spring. The study area receives approximately 96% of its annual precipitation from October to April. Indeed, the temporal variation of surface water quality showed significant sensitivity to seasons (spring, summer, and autumn) and hydrological conditions during different periods. These natural factors play a crucial role in shaping the fluctuations and characteristics of water quality.

Figure 5 displays the scree plot depicting the relationship between component numbers and their respective eigenvalues. Notably, there is a significant change in slope at the third eigenvalue. As a result, three principal components, namely PC1, PC2, and PC3, were retained for further analysis, as detailed in Table 2.

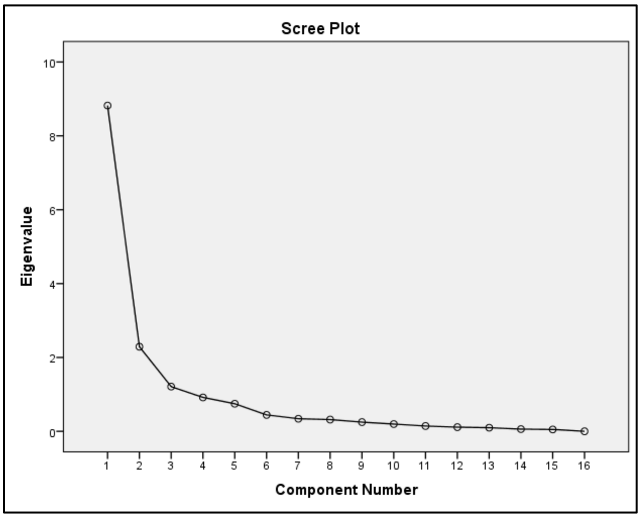


Figure 5. Scree plot of the eigenvalues.

Table 2. Loadings of experimental variables (16) on principal components for the whole datasets of the Joumine reservoir.

	Components		
	PC1	**PC2**	**PC3**
WT	−0.79	−0.09	0.25
pH	0.83	0.44	−0.81
DO	0.79	0.30	−0.21
NO_2^-	−0.25	0.89	0.42
NO_3^-	−0.44	0.79	0.04
NH_4^+	0.89	0.19	−0.12
Chl-a	−0.17	0.21	−0.72
CSS	0.37	−0.02	0.49
Na^+	0.78	0.28	0.32
K^+	0.68	0.23	0.27
Ca^{2+}	0.96	0.08	−0.02
Mg^{2+}	0.89	0.20	0.15
Cl^-	0.77	0.10	0.30
SO_4^{2-}	0.84	0.37	0.13
SD	0.87	−0.27	0.03
Zeu	0.87	−0.27	0.03

Based on the Kaiser Normalization criterion, which involves retaining eigenvalues greater than 1, the analysis yielded three principal components. These three components explained approximately 77% of the total variance of the water quality variables.

The first principal component (PC1) exhibited high positive loadings pH, DO, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, and SD, explaining 55.128% of the total variance. PC1 reflects the process of mineralization influenced by a range of hydrogeochemical mechanisms, including the dissolution of limestone and marl soils [7,58], as well as human activities such as intensive agriculture, farming, and the release of domestic wastewater [59]. Water temperature contributes negatively to this factor, which can be explained by considering the dissolution processes of dissolved minerals increasing with temperature. The second factor, PC2 (14.314%), shows a very strong positive association with NO_3^- and NO_2^-. They could be derived from agricultural areas in the region (the use of fertilizers) and domestic wastewater. The third factor PC3, explaining the lowest total variance, 7.567%, had a negative loading on Chl-a, which is an indicator of algae and phytoplankton levels.

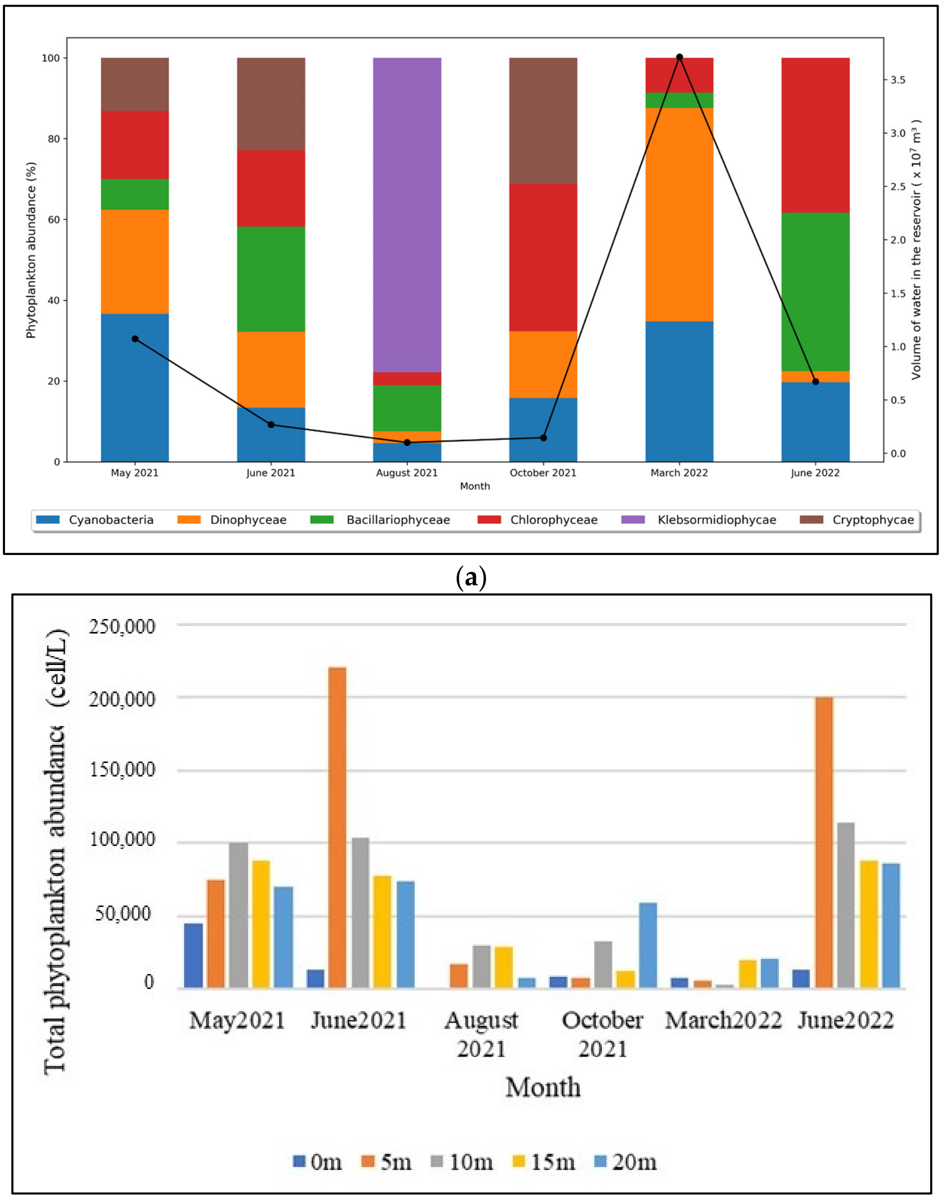
Overall, the water quality parameters, represented by the principal components obtained from PCA, provide clear evidence of the impact of human activities upstream from the reservoir.

3.2. Joumine Reservoir's Phytoplankton Community

In the Joumine reservoir, twenty-five phytoplankton taxa were recorded, belonging to seven classes. Figure 6a shows the distribution of phytoplankton groups during the sampling months (during 4 monthly campaigns). In Figure 6b, *Chlorophyceae* is the most abundant cluster, comprising 44% of the total identified species. This class is represented by eleven species where the dominant genera is *Coelastrum* sp. Much less diversified, the *Cyanobacteria* represent about 24% of the total phytoplankton abundance, with the dominance of *Chroococus turgidus*. *Bacillariophyceae* and *Euglenophyceae* represent respectively 12% and 8% of all identified taxa. The first one is dominated by the presence of *Cyclotella* sp. and the second one is represented by *Trachelomonas*. *Dinophyceae*, *Klebsormidiophycae*, and *Cryptophycae* appear very irregularly. These three classes are not important in terms of richness, where each one represents 4% of the total phytoplankton abundance. There were differences in the contributions of all the groups during both late spring-summer and late summer-autumn, with *Klebsormidiophycae* and *Chlorophyceae* showing higher densities during late summer-autumn and *Cyanobacteria*, *Bacillariophyceae*, *Chlorophycae*, and *Cryptophycae* during late spring-summer.

In the Joumine reservoir, the total of phytoplankton abundance varied from 1.2×10^3 cells/L in August 2021 at a depth of 0m to 2200×10^3 cells/L in June 2021 at a depth of 5 m in Figure 6b.

The composition and the density of phytoplankton were influenced by the reservoir volume. During late summer and autumn (August 2021, October 2021, and March 2022), the largest contribution of *Chlorophyceae*, *Dinophyceae*, and *Cyanobacteria* is related to the increase in water volume, which explains the mesotrophic state of the reservoir during this period, according to TSI (Chl-a). The occurrence of these groups can be explained either by the transportation of microorganisms from rivers to the reservoir or by the augmentation of nutrient concentration in this period since the area is agricultural land. During late spring and summer (May 2021, June 2021, and June 2022), there is a lower discharge volume in the reservoir. Phytoplankton reflect this variation with a decrease in the density of *Cyanobacteria*, *Dinoflagellate*, and *Chlorophyceae* [60,61], which explains the mesotrophic state of the reservoir during this period according to TSI (Chl-a) (Figure 4). RDA was applied to evaluate the interactions between phytoplankton variation and environmental variables. The RDA ordination figure, including 16 environmental parameters and 11 phytoplankton groups, is presented in Figure 7.



(**a**)

(**b**)

Figure 6. (**a**) Cells density rate of the phytoplankton species classes identified in the Joumine reservoir during the study period and (black line) the variation in water volume from the reservoir during the study period; (**b**) Depth (average values at the eight sampling stations) and temporal distribution of total phytoplankton in the Joumine reservoir.

The community composition and distribution are significantly impacted by the temperature of the water, which is the most influential factor. The RDA ordination clearly shows that the phytoplankton community experienced changes. These changes are related to many variables, including WT, DO, pH, Nitrate, Nitrite, Ammonium, Na^+, Cl^-, SO_4^{2-}, Chl-a, Mg^{2+}, Ca^{2+}, CSS, K^+, Na^+, SD, and water flow. The analyzed results found that *Ceratium* sp., *Aphanocapsa* sp., and *Oocystis* sp. were positively correlated with WT. *Staurastrum* sp1, *Navicula* sp., and *Pseudoanabaena* sp. were negatively correlated to WT. *Coelastrum* sp. is negatively and significantly correlated with pH and NO_3^-. *Staurastrum* sp1 and *Navicula* sp. show a preference for high DO. These preferences were reported by Reynolds [62]. Cyanobacteria are associated with water flow.

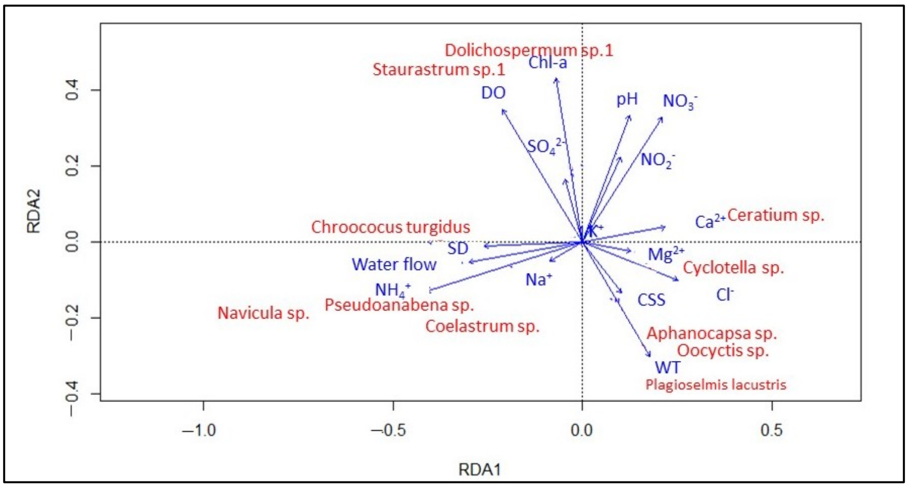


Figure 7. RDA ordination figure of the prevailing phytoplankton groups and environmental variables (WT, water temperature; SD, water transparency; DO, dissolved oxygen; Chl-a, Chlorophyll-a; CSS, concentration of the suspended solid; NO_3^-, nitrate; NO_2^-, nitrite; Cl^-, chloride; NH_4^+, ammonium; Ca^{2+}, calcium; Mg^{2+}, magnesium; SO_4^{2-}, sulphate; Na^+, sodium and K^+, potassium, water flow).

4. Discussion

In this survey, environmental parameters and the composition of the phytoplankton community in the Joumine reservoir in Tunisia were studied. The results showed that the Joumine reservoir has a eutrophic status according to the Carlson and Sampson Index. This is probably due to the enrichment caused by domestic and intensive agriculture [11]. The study area is mostly an agricultural area with numerous cultures using chemical fertilizers. One of the key factors controlling the abiotic and biotic variability in reservoirs is freshwater flow. According to Domingues et al. [63], the fluctuation of flow may have an impact on the phytoplankton dynamic due to changes in nutrient and light availability [64,65] and water residence time [66]. Therefore, the measures that could be taken for managing eutrophication would involve the following approaches: (i) enhancing the control of water flow and domestic sewage, (ii) reducing nitrogen and/or phosphorus inputs into aquatic systems, and (iii) biomanipulation measures [67–69].

The concentrations of major ions in the Joumine reservoir are acceptable compared to the quality standards required by the WHO [29] for drinking and irrigation water. Comparing the obtained value to other Tunisian reservoirs, the Joumine reservoir is characterized by low water transparency, which confirms its turbidity, as mentioned in Limam [40]. This could be explained by allochthone particles inputs from the watershed by tributaries [40]. The Joumine reservoir was found to have an oligotrophic status based on Chlorophyll-a levels, as confirmed by Limam [40] using the OCDE [26] method. However, this is not the case considering the width of Secchi depth which indicates a eutrophic status [40].

The density of phytoplankton varied significantly across different seasons, with higher levels observed during spring and summer, and lower levels in autumn. This fluctuation exhibited a strong correlation with water quality that could be attributed to the important nutrient concentrations in spring/summer compared to autumn. This study also revealed that the phytoplankton community and distribution were mainly influenced by Nitrate.

Furthermore, water temperature (WT) emerged as a key driving factor impacting the succession of phytoplankton. Earlier research in Nansi Lake demonstrated that WT played a significant role in shaping changes in phytoplankton community composition [27]. The density of phytoplankton tended to increase with rising water temperatures [27]. The results of the RDA analysis indicated a positive correlation between WT and Cyanophyceae and Chlorophyceae, leading to increased phytoplankton abundance during summer, as these species thrived in higher temperatures. Consequently, the number of phytoplankton species was higher in spring and summer, but lower in autumn, which can be attributed to the temperature variations. The Joumine reservoir is a warm lake, characteristic of the

Mediterranean climate [70]. Therefore, air temperature is high, and daylight duration is longer between spring and mid-autumn [19]. As a result, ephemeral stratification is observed in the Joumine reservoir [19]. The aforementioned result corroborates the results of Limam [40] in the same reservoir. The stratification is influenced by wind and frequent water withdrawal during summer [19].

The pH of the Joumine reservoir was above 8, indicating that it was alkaline water conducive to the growth and reproduction of Cyanophyceae and Diatoms. The RDA results further confirmed that a significant majority of Cyanophyceae, particularly *Aphanocapsa* sp., exhibited a positive correlation with pH, underlining their preference for alkaline conditions [62,71].

Within the RDA analysis, cyanobacteria were significantly and negatively correlated with water flow. This indicates that water flow is an important regulator of phytoplankton community dynamics [63].

Based on microscope analyses, 25 phytoplankton species were identified, classified according to seven classes, including the *Chlorophyceae*, *Cyanobacteria*, and *Diatomophyceae*. The *Chlorophyceae* group is the most diversified group since it represents 44% of the species richness. The results revealed that *Chlorophyceae* dominated the phytoplankton community, a finding which aligns with the results described in other Tunisian reservoirs under temperate climates [52,53]. In the Joumine reservoir, the authors of Limam [40] recorded 63 taxa of phytoplankton represented by *Chlorophyceae*, *Bacillariophyceae*, *Dinophyceae*, *Cryptophyte*, *Charophyceae*, *Euglenophycin*, and *Cyanobacteria*. Furthermore, compared to the 63 taxa identified by the Limam [40] survey, our examined reservoir has a eutrophic status and fewer phytoplankton species (25 taxa) than it had in the Limam [40] study. As a result, the investigated reservoir appears to be less nutrient-rich than it was in 2003. According to the water quality criteria of Rao et al. [72], the seasonal appearance of *Coelsatrum* sp. and *Staurastrum* sp1 with low abundance during May, June, and October is an indicator of good water quality in the Joumine reservoir. However, the presence of these genera is also characteristic of eutrophic reservoirs, as noted by Parakkandi et al. [73]. The seasonal variation in phytoplankton cell density is characterized by the highest abundance value during late spring-summer and the lowest abundance value during late summer-autumn. The lower values of phytoplankton communities during late summer-autumn are in tune with the results of El Herry [52] in the Lebna reservoir, which could be due to the limitation of Nitrate [64]. Thus, the increase in the density of the cyanobacteria could be explained by the internal storage capacity of nutrients of these species [52]. The negative correlation between nutrients and phytoplankton density in the Joumine reservoir suggests that low phytoplankton density results in low consumption of nutrients [74], leading to high nutrient concentration and a negative correlation. This could be attributed to the limitation of the rate of inorganic carbon and the low water turbulence, as suggested by Klemer et al. and Steinberg et al. [75,76], respectively. Added to that, it could be due to the high frequency of dry years [18] and low reservoir water levels (below 50% capacity) [77]. Indeed, cell advection is reduced during periods of low river flow, whether naturally occurring or caused intentionally by the operation of dams [61]. Added to that, even the high concentration of Chlorophyll-a at sampling sites 1, 3, 5, and 7 in water may not always correspond to the density of algal cells present. According to some reports, the measurement of Chlorophyll-a may not accurately represent the total biomass of algae due to various factors such as the type of species, physiological state of the algae, and time of sampling, that can all affect the pigment content. Therefore, it cannot be assumed that the ratio of Chlorophyll-a to carbon content remains constant [40]. Despite being in eutrophication conditions, the phytoplankton density is relatively low. This could be explained by grazing because zooplankton consumption of phytoplankton affects its density and composition [78].

5. Conclusions

During the study period, the Joumine reservoir's seasonal changes in the phytoplankton community and environmental parameters were examined. The results of the chemical analysis of the reservoir water reveal that it is in a eutrophic state, most likely as a result of the discharge of industrial, domestic, and particularly agricultural effluents. The Joumine reservoir exhibits temporal phytoplankton succession. The water flow is a crucial regulator of abiotic and biotic variables, especially for cyanobacteria. Cyanophyceae were the most prevalent algae during the spring, summer, and fall seasons. Chlorophyceae were in great abundance in early autumn. Physical variables, particularly water flow and those immediately related to water fluxes (water temperature, dissolved oxygen, pH), were the most important forcing factors in the Joumine reservoir. They had a significant impact on phytoplankton species.

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