

## Article

# Physicochemical Characterization and Assessment of Magnitude of Pollution to Contribute to Water Sustainability

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**Abstract:** As in many countries worldwide, deterioration of quality of water in Morocco's natural reserves continues, such that an inventory of qualities of these reserves has become necessary. Based on statistical analyses of the data collected by measuring nineteen physicochemical variables, and applying an index, the comprehensive pollution index, to those data, the quality of the waters of Lake Dayat Roumi, Morocco, were assessed. Waters of the lake are currently characterized by a salinity of 921.7 mg Cl<sup>-</sup>/L and 124.2 mg sulfates/L. The concentration of chloride exceeds the value indicated in the standard norms. This can affect the composition of the sediment, overlying water, and specific composition of biota in the lake. Status and trends of values of other parameters also indicate deterioration of water quality in this lake. Multivariate statistical analysis made it possible to differentiate four clusters of samples according to their physicochemical characteristics. These groups are due to inputs from three sources of materials: leaching of rocks from the watershed and plantations, discharge of domestic wastewater and runoff water. Samples taken from deeper parts of the lake indicate a depression of concentrations of dissolved oxygen during the hot season. The analysis results demonstrate the heterogeneous degradation of the water quality in the peripheral areas and deep parts of the lake, favored by the leaching of soils by rainwater, which, when sufficiently severe, can cause repeated mortalities of fishes. This situation requires regular water quality monitoring to develop a management plan for restoration of water quality in the lake to preserve valued ecological services.

**Keywords:** water; pollution; Lake Dayat Roumi; sustainability

## 1. Introduction

Wetlands can harbor a wide variety of plant and animal species that provide important services to humans, which in addition to the obvious sources of water for drinking, irrigation and foods include regulation of hydrological inputs and acting as filters by storing

nutrients and purifying water [1]. Indeed, these areas retain heavy rains and prevent possible downstream flooding; they are also sources of groundwater recharge [2]. They also provide products that can be exploited sustainably and make it possible to enhance the economic value of territory through educational, recreational and tourist activities [3]. However, these environments are threatened by human activities, such as intensive agricultural practices, inappropriate hydraulic installations, strong urban growth, extensions of agricultural activities, construction of roads, and pollution due to discharges of solid and liquid waste, as well as excessive and invasive hunting, and overexploitation of resources [4]. Knowledge of the physicochemical and biological characteristics of the biotope of these wetlands is essential for any scientific study of the environment.

As is the case for many countries, Morocco is faced with degradation of the quality of its wetlands. Data from the Mediterranean Wetlands Outlook 2 (MWO2) report shows that unsustainable human activities are the main causes [5]. Likewise, this degradation is accentuated by changes in climate, including periods of drought. Thus, faced with this situation, it is necessary to actively manage these environments by implementing an integrated and sustainable development policy to safeguard this environment.

In Morocco, several water reserves are exposed to a degradation of their quality; the “Dayat Roumi” lake, located in the Khemisset region, is one of the natural resources in the process of degradation, as evidenced by the proliferation of vegetation in the coastal areas of the lake and the mortality of fish. Such disturbances indicate that eutrophication of the lake is in progress [6]. This eutrophication has already been identified by Ministry of Habitat, Urbanism and Spatial Planning (MHUAE) [7]. Likewise, organic and bacterial contamination of lake water has been reported previously [8]. Our present work is a follow-up to the work that has been interested in assessing the physicochemical quality of the waters of this lake and determining the main factors of their degradation.

## 2. Material and Methods

### 2.1. Description of the Study Site

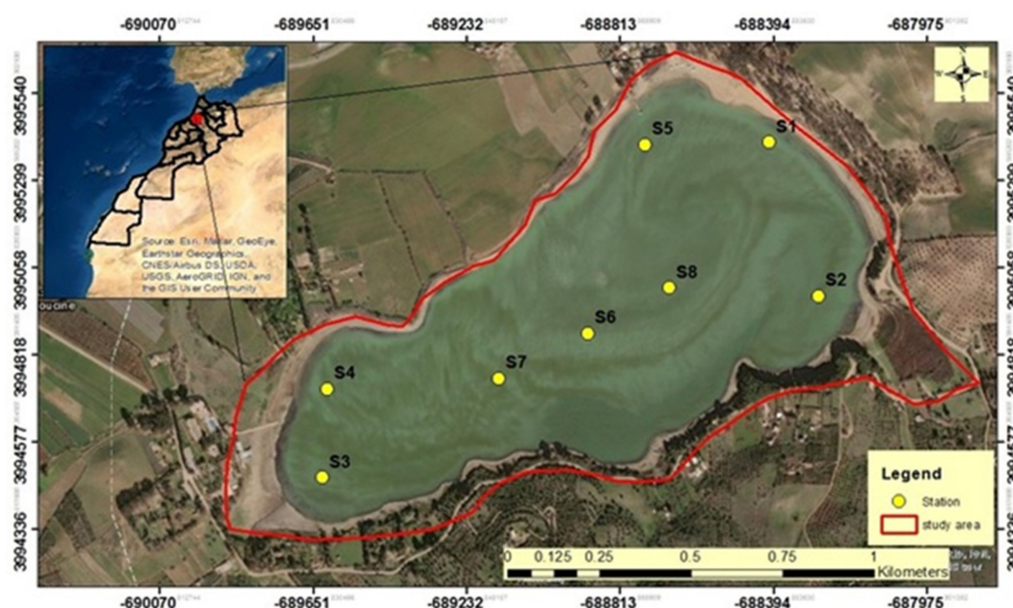
Dayat Roumi Lake (Figure 1) is located at 33°45' N–06°12' W, about 90 km east of the capital of Morocco. Its area is approximately 96 ha. Its depth can reach 11 m and it is located at an altitude of 350 m. It is located in the Triassic basin of Khemisset, which is dominated by silt-evaporitic facies [9]. This lacustrine environment, of elongated shape and oriented S.SW–N.NE, occupies a region made up of Mio-Pliocene marl hills covered with recent alluvium [10] and gets its water supply in the rainy season by underground waters and the leaching water of its watershed. The lake connects through its northwestern part with the Rho River and its northeastern part with the drainage channel of a wet depression. The bottom of the lake consists of a very fine, black and viscous mud which is rich in organic substances. The climate is of the geographical area in the Mediterranean, that is, temperate, and the average annual precipitation is 500 to 600 mm. The average monthly air temperature is between 8.9–26.5 °C (2009–2010) [7]. Around the lake, human activity is dominated by cereal agriculture and breeding of sheep and cattle, and, in the absence of a drainage system, the primary sanitation method is septic tanks. The lake area is subject to several pressures, including cultivation on the edges and hills overlooking the lake, overgrazing of meadows, watershed erosion, domestic waste, pollution caused by water sports equipment and fishing.

### 2.2. Choice of Stations to Study and Water Sampling

Taking into account tributaries and anthropogenic inputs, in summer (SU), autumn (AU), winter (WI) and spring (SP) during the period 2017–2018, surface water samples were taken in eight stations (Figure 1):

- Station 1 (S1): 33°45'06.4" N 06°11'06.3" W, a bathing area where a stream emerges draining from a marshy depression located 1–2 km from the lake, depth 0–0.5 m, presence of macrophytes.

- Station 2 (S2): 33°44'49.5'' N 06°10'52.6'' W, fed by a small stream coming from the SE, depth 0–0.5 m, the abundance of macrophytes.
- Station 3 (S3): 33°44'38.0'' N 06°11'48.6'' W, located next to the Dar Eddaya hotel, abundance of macrophytes, depth 0–0.5 m.
- Station 4 (S4): 33°44'45.2'' N 06°11'46.6'' W, the area where the Rho river emerges, depth 0–0.5 m, abundance of macrophytes.
- Station 5 (S5): 33°45'07.5'' N 06°11'13.6'' W, campsite area, depth 0–0.5 m, presence of macrophytes.
- Station 6 (S6): 33°44'48.9'' N 06°11'18.6'' W, the center of the lake, depth 1 m, no macrophytes.
- Station 7 (S7): 33°44'45.38'' N 06°11'27.28'' W, the center of the lake, depth 5 m, no macrophytes.
- Station 8 (S8): 33°44'50.28'' N 06°11'14.34'' W, the center of the lake, depth 9 m, no macrophytes.



**Figure 1.** Map of the study area and surface water quality monitoring stations in Lake Dayat Roumi (Morocco).

Water samples were collected at the eight stations once per season: during summer and autumn (2017) and winter and spring (2018). Three replicates were collected for each sampling station. In total, 96 samples were collected during this study. Water samples were collected in the morning from 8 a.m. to 1 p.m., then stored in 2 L polyethylene bottles and kept in a cooler containing ice and delivered the same day to the laboratory and stored at 4 °C until processing and analyses. Samples of water were analyzed within 48 h of collection. Water quality parameters were measured using standard methods established for monitoring surface water in Morocco [11] in the National Laboratory of Studies and Monitoring of Pollution, Rabat, Morocco. The temperature (T), pH, electrical conductivity (EC), and dissolved oxygen (DO) of each water sample were measured in situ using a suitable portable multi-parameter HACH, model HQ40d. The total hardness (TH) and the calcium hardness (CH) were measured using the EDTA titrimetric method. The indicators are, respectively, EBT (Eriochrome Black T) and calcon. Total alkalinity (TA) and calcium alkalinity (CA) were determined by acid titration using, respectively, phenolphthaleine and helionthine as indicators, and chloride ( $\text{Cl}^-$ ) by titration of silver nitrate ( $\text{AgNO}_3$ ) in using potassium chromate solution ( $\text{K}_2\text{CrO}_4$ ) as an indicator. The sulfate ( $\text{SO}_4^{2-}$ ) was determined by spectrophotometry by the barium sulfate turbidity method; the nitrate nitrogen ( $\text{NO}_3\text{-N}$ ) and nitrite nitrogen ( $\text{NO}_2\text{-N}$ ) were analyzed by the photometric method in an acidic medium. Total phosphate (TP-P) and orthophosphate

(PO<sub>4</sub>-P) were measured by the phosphomolybdic complex photometric method. To measure ammonium ions (NH<sub>4</sub><sup>+</sup>), samples were developed with hypochlorite ions and salicylate and then measured spectrophotometrically. Total suspended solids (TSS) were measured by filtration at 0.45 μm. After mineralization with selenium, Kjeldahl nitrogen (TKN) was measured by the Kjeldahl method. BOD was determined by the respiratory method using a BOD meter and COD by the acid titration method.

### 2.3. Statistical Analysis of the Results

All mathematical and statistical calculations were performed using Microsoft Office Excel 2007 and SPSS Statistics 23.0. A one-way ANOVA was performed for each water quality parameter to determine significant differences between group means at the 5% significance level. The normality of the data distribution was tested using the Shapiro–Wilk test, and the assumption of homogeneity of variance was assessed using the Levene test. The relationships between the physicochemical parameters were examined by Pearson correlation analysis. In addition, the data were processed using principal component analysis (PCA) to reduce the number of variables and to identify potential factors or sources affecting water quality. The Kaiser–Meyer–Olkin (KMO) index and Bartlett’s test of sphericity were applied to measure sampling adequacy. PCA, based on the standardized sampling matrix (12 samples × 8 stations × 19 variables), was performed to identify the crucial parameters that characterize the water quality of the lake studied. The water quality was assessed using a calculated index, the comprehensive pollution index (P) [12,13] expressed by:

$$P = \frac{1}{n} \sum_{i=1}^n C_i/S_i \quad (1)$$

where  $C_i$  symbolizes the concentration of the pollutant  $i$  assessed,  $n$  signifies the total number of chosen contaminants, and  $S_i$  is the corresponding limit value authorized by the Moroccan standard for surface water quality [11]. Note that  $C_i$  and  $S_i$  have the same units so  $P$  (as  $C_i/S_i$ ) is dimensionless.

It should be noted that to compute the comprehensive pollution index, the dissolved oxygen deficit concentration  $C$  (OD) has been considered instead of the measured dissolved oxygen concentration  $C$  (DO) since this parameter is not considered a pollutant. Thus, the dissolved oxygen deficit pollution index  $P$  (OD) is calculated using the following equations:

$$C \text{ (OD)} = C \text{ (Sat DO)} - C \text{ (DO)} \quad (2)$$

$$P \text{ (OD)} = C \text{ (OD)}/S \text{ (OD)} \quad (3)$$

where  $C$  (Sat DO) is the dissolved oxygen concentration at the saturation point calculated for each station and each season and  $S$  (OD) represents the maximum limit admissible for the dissolved oxygen deficit.

The maximum admissible value of the DO deficit concentration  $S$  (OD) is calculated by:

$$S \text{ (OD)} = C \text{ (Sat DO)} - S \text{ (DO)} \quad (4)$$

$S$  (DO) is the minimum permissible dissolved oxygen value. In the Moroccan standard, it is fixed at 3 mg/L (cf. Table 1).

**Table 1.** Interval (R), the mean (M) and standard deviation (Sd.) of water quality parameters in the eight sampling stations of Lake Dayat Roumi.

Z		S1	S2	S3	S4	S5	S6	S7	S8	Guideline Value *
T (°C)	R	15.20–25.00	14.90–24.20	15.70–23.70	16.30–25.90	16.30–25.90	17.00–27.80	16.20–25.30	16.50–23.10	30
	M ± Sd.	20.53 ± 4.87	19.3 ± 4.30	19.55 ± 4.24	20.88 ± 4.69	20.73 ± 4.50	22.00 ± 5.60	20.63 ± 4.59	19.55 ± 3.21	
pH	R	8.41–8.85	8.25–8.74	8.41–9.20	8.05–8.83	8.40–8.78	8.43–8.91	8.27–8.75	7.86–8.38	6.5–9.2
	M ± Sd.	8.68 ± 0.20	8.59 ± 0.23	8.83 ± 0.35	8.51 ± 0.34	8.62 ± 0.16	8.72 ± 0.21	8.46 ± 0.20	8.10 ± 0.25	
EC (mS/cm)	R	2.95–3.08	3.00–3.06	2.95–3.05	2.94–3.03	2.97–3.01	2.94–3.02	2.83–3.03	2.72–3.04	2.7
	M ± Sd.	3.00 ± 0.06	3.03 ± 0.03	3.00 ± 0.04	3.00 ± 0.04	3.00 ± 0.02	2.96 ± 0.04	2.94 ± 0.09	2.89 ± 0.13	
TSS (mg/L)	R	2–100	2–123	2–196	6–186	2–10	2–5	4–30	2–10	1000
	M ± Sd.	27.5 ± 48.37	55 ± 51.17	66.25 ± 91.45	58.25 ± 85.52	6.5 ± 3.42	3.5 ± 1.29	12.5 ± 11.93	6.25 ± 3.5	
Cl <sup>-</sup> (mg/L)	R	829.53–914.61	875.62–921.70	850.80–911.07	836.62–900.43	831.30–886.25	825.99–889.80	836.62–886.25	786.99–889.80	750
	M ± Sd.	885.36 ± 39.30	902.20 ± 19.74	886.25 ± 25.40	877.39 ± 29.30	869.85 ± 25.86	872.07 ± 30.77	871.18 ± 23.22	862.32 ± 50.25	
SO <sub>4</sub> <sup>2-</sup> (mg/L)	R	80.80–124.20	69.80–103.30	69.00–109.20	59.40–104.70	70.20–119.20	67.70–109.50	62.30–106.20	60.90–100.10	250
	M ± Sd.	105.10 ± 21.61	86.16 ± 16.91	86.82 ± 17.99	81.35 ± 24.77	94.29 ± 20.10	91.66 ± 17.73	84.35 ± 19.61	79.59 ± 17.55	
TA (mg/L)	R	10.00–25.00	0.00–25.00	10.00–25.00	10.00–20.00	10.00–20.00	10.00–20.00	10.00–17.50	0.00–15.00	-
	M ± Sd.	20.00 ± 7.07	13.75 ± 11.09	16.25 ± 7.50	16.88 ± 4.73	17.50 ± 5.00	16.25 ± 4.79	13.13 ± 3.75	6.25 ± 7.50	
CA (mg/L)	R	95.00–130.00	100.00–160.00	85.00–120.00	90.00–120.00	90.00–125.00	85.00–120.00	85.00–125.00	100.00–135.00	-
	M ± Sd.	111.25 ± 16.52	123.75 ± 25.62	106.25 ± 17.01	108.75 ± 14.36	107.00 ± 14.58	108.13 ± 15.99	111.25 ± 17.97	117.50 ± 14.43	
TH (mg/L)	R	250.00–480.00	250.00–440.00	270.00–420.00	290.00–440.00	250.00–440.00	250.00–440.00	180.00–440.00	240.00–440.00	-
	M ± Sd.	380.00 ± 95.57	382.50 ± 90.32	362.50 ± 66.52	380.00 ± 66.83	375.00 ± 89.63	375.00 ± 89.63	352.50 ± 118.71	365.00 ± 90.00	
CH (mg/L)	R	40.08–172.34	56.11–160.31	40.08–156.30	40.08–160.31	44.09–160.31	44.09–148.29	48.09–148.29	52.10–148.29	-
	M ± Sd.	85.17 ± 59.21	86.17 ± 49.57	83.16 ± 50.62	84.16 ± 52.56	78.15 ± 55.19	79.16 ± 46.90	81.16 ± 45.39	80.16 ± 45.70	
DO (mg/L)	R	7.42–10.41	2.32–11.25	2.60–9.88	2.76–11.60	2.50–11.88	6.98–11.40	5.65–9.20	4.83–8.02	3
	M ± Sd.	8.63 ± 1.30	7.17 ± 3.69	7.34 ± 3.26	7.55 ± 3.70	7.64 ± 3.89	8.72 ± 1.89	7.56 ± 1.47	6.52 ± 1.68	
NH <sub>4</sub> <sup>+</sup> (mg/L)	R	0.01–0.06	0.01–0.08	0.01–0.08	0.01–0.04	0.01–0.06	0.01–0.051	0.01–0.13	0.01–0.163	2
	M ± Sd.	0.02 ± 0.02	0.03 ± 0.03	0.02 ± 0.03	0.01 ± 0.01	0.02 ± 0.02	0.02 ± 0.02	0.07 ± 0.04	0.06 ± 0.07	
NO <sub>2</sub> -N (mg/L)	R	0.01–0.01	0.01–0.04	0.01–0.01	0.01–0.01	0.01–0.01	0.01–0.01	0.01–0.01	0.01–0.01	-
	M ± Sd.	0.01 ± 0	0.01 ± 0.01	0.01 ± 0	0.01 ± 0	0.01 ± 0	0.01 ± 0	0.01 ± 0	0.01 ± 0	
NO <sub>3</sub> -N (mg/L)	R	0.4–0.55	0.4–0.66	0.4–1.16	0.4–0.7	0.4–0.4	0.4–0.4	0.4–0.4	0.4–0.4	11.3
	M ± Sd.	0.43 ± 0.07	0.46 ± 0.13	0.59 ± 0.38	0.47 ± 0.15	0.4 ± 0	0.4 ± 0	0.4 ± 0	0.4 ± 0	
TKN (mg/L)	R	0.1–5.29	0.1–5.07	0.1–6.04	0.1–7.17	0.1–6.86	0.1–0.1	0.1–7.69	0.1–12.07	3
	M ± Sd.	2.18 ± 2.54	2.43 ± 2.04	2.31 ± 2.83	2.77 ± 3.39	2.53 ± 3.2	0.1 ± 0	2.41 ± 3.6	4.14 ± 5.49	
TP-P (mg/L)	R	0.03–0.3	0.03–0.3	0.03–0.11	0.3–0.3	0.03–0.3	0.3–0.3	0.03–0.3	0.03–0.4	0.5
	M ± Sd.	0.1 ± 0.13	0.09 ± 0.13	0.05 ± 0.04	0.3 ± 0	0.09 ± 0.13	0.3 ± 0	0.11 ± 0.13	0.12 ± 0.18	
PO <sub>4</sub> -P (mg/L)	R	0.03–0.06	0.03–0.03	0.03–0.03	0.03–0.03	0.03–0.06	0.03–0.03	0.03–0.03	0.03–0.06	0.326
	M ± Sd.	0.03 ± 0.01	0.03 ± 0	0.03 ± 0	0.03 ± 0	0.03 ± 0.01	0.03 ± 0	0.03 ± 0	0.03 ± 0.01	
BOD (mg/L)	R	1–14	1–8	1–3	1–2	1–8	1–2	1–5	1–6	10
	M ± Sd.	6.5 ± 5.8	3.75 ± 3.4	2 ± 0.81	1.25 ± 0.5	4.75 ± 3.77	1.5 ± 0.57	3 ± 1.63	3.75 ± 2.21	
COD (mg/L)	R	4.9–19.5	14.6–98.9	10–24.5	13.4–24.5	4.9–24.5	9.8–21.9	9.8–19	14.5–19.4	40
	M ± Sd.	13.47 ± 6.14	40.27 ± 39.35	16.47 ± 6.06	20.25 ± 5.34	14.6 ± 8	14 ± 5.71	12.8 ± 4.33	17.5 ± 2.37	

\* Guidelines values fixed by the Moroccan standard [11].

In this work, the comprehensive pollution index qualifies water as clean if  $P \leq 0.20$ , as sub-clean if  $0.20 < P \leq 0.40$ , as slightly polluted if  $0.4 < P \leq 1.00$ , as moderately polluted if  $1.00 < P \leq 2.0$  and severely polluted if  $P > 2.00$ .

### 3. Results and Discussion

#### 3.1. Physicochemical Characteristics of the Water in Lake Dayat Roumi

Table 1 shows the interval of variation, arithmetic mean, and computed standard deviation of the measurements observed for each one of the 19 tested water quality parameters in each sampling station.

The surface temperature was higher in summer (21.5–27.8 °C) and lower in winter (14.9–17.7 °C). A significant difference between the seasonal values of the stations is noted ( $p$  value = 0.000). These thermal variations depend on the seasonal variability of the air temperature. In addition, the stations in the center of the lake (S6, S7 and S8) are characterized by thermal stratification during the warm period and water mixing during the cold season. According to the typology of Lewis and William [14], this water body has been classified as warm monomictic.

The lake water is slightly alkaline. The pH varied between 7.86 and 9.2. Therefore, this variation falls within the limit range of 6.5 to 9.2 authorized by Moroccan water quality standards [11]. The maximum values were observed in spring and summer. A value of 9.2 was observed at S3 in autumn. In addition, a significant variation between stations was detected ( $p$  value = 0.01). Furthermore, the pH of the bottom waters (S6, S7 and S8) showed a decrease with depth during the warm period. The slight decrease in pH at depth can be explained by the degradation of organic matter by bacteria with the release of carbon dioxide [15]. The high pH values of the lake water can be explained either by the dissolution of evaporite rocks, which constitute the geological substratum of the region, or by the photosynthetic activity of aquatic plants, favored by the increase in water temperature and light.

The electrical conductivity of the water ranged from 2.72 mS/cm to 3.08 mS/cm. Its values showed significant seasonal variability ( $p$  value = 0.002). The maximum values were observed in autumn (S5, S6, S7 and S8) and spring (S1, S2, S3 and S4). Thus, the values of this conductivity classify the lake water as highly mineralized. A large amount of ionizable salts in the water, responsible for this high value, seems to result from the leaching of the soils in the area by runoff.

Chloride concentrations ranged from 786.99 to 921.7 mg/L and showed a significant seasonal difference ( $p$  value = 0.000). The highest concentration was measured in summer at S2 whereas the lowest concentration was recorded in summer at the lake center (S8) at 9 m depth. The chloride values exceed the limits required by Moroccan standards. Chloride inputs to the water may be related to the chemical nature of the soil through which it flows and to animal waste [16]. The use of chloride in agriculture in some fertilizers and in cattle feed can also increase the chloride content in the lake water [17].

Sulfate concentrations ranged from 59.4 to 124.2 mg/L. The minimum concentration was observed in autumn at station S4, whereas the maximum concentration was observed in spring at station S1. Sulfate values showed a significant difference between seasons ( $p$  value = 0.000). The highest concentrations were observed in winter and the lowest in autumn. The sulfate concentrations observed during this study were higher than those measured by Khyri et al. (0.64 to 29.48 mg/L) during 2013–2014 [8]. This increase was caused by the fertilizer and pesticide application on the surrounding agricultural land of the lake [18] or leaching from evaporite rocks in the region [19]. Similarly, concentrations of  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  anions in the water can increase electrical conductivity [20].

Total suspended solids concentrations varied between sites, with concentrations ranging from 2 mg/L at sites S1, S2, S3, S5 and S6, to 196 mg/L at S3. The higher concentrations were probably related to runoff during the winter flood period, or due to intense phytoplankton production during the summer. No significant differences were revealed between stations ( $p$  value = 0.4) and seasons ( $p$  value = 0.56).

TA and CA concentrations ranged from 0 to 25 and 85 to 160 mg/L, respectively. CA concentrations measured in winter were significantly ( $p$  value = 0.000) higher than those observed in summer. Weathering of geological substrates, drainage of salts from fertilizers and wastewater, and urbanization are important sources of alkalization of freshwater [21].

Dissolved oxygen concentrations ranged from 2.32 to 11.88 mg/L. During the warm season, dissolved oxygen concentrations were significantly low ( $p$  value = 0.000) in stations with emergent aquatic plants (S2, S3, S4 and S5) and in the deeper layers (S7 and S8). This deoxygenation of the water is related to a significant degradation of organic matter. This phenomenon has been observed in other lake environments [22,23]. These results were consistent with previous studies [24] where an increase in temperature and salinity was observed in shallow lakes during dry periods, which resulted in plant growth and consequently changes in oxygenation. The increase in the nutrient load from anthropogenic sources (domestic and agricultural) causes a phytoplankton proliferation which is accompanied by large diurnal variations in DO levels. This variability influences aquatic life and can lead to mass fish kills. Such a phenomenon was observed in stations S1 (DO = 7.42 mg/L) and S3 (DO = 2.6 mg/L) with shallow water depths [25].

The COD values fluctuate between 4.8 and 100.8 mg/L. The lowest value was measured in winter at S1 and S5, whereas the highest value was recorded in summer at S2. No significant difference was observed between seasons or stations ( $p$ -value = 0.05). It should also be noted that the values recorded, except for S2, remain below the threshold of the Moroccan standard. In addition, the high value of COD recorded at S2 could be explained by contamination of the water by anthropic pollutants (domestic wastewater and agricultural waste) transported by the water of a small stream that feeds the lake.

The BOD values vary between 1 and 14 mg/L. The high values (8–14 mg/L), exceeding the limits required by the Moroccan standard, are recorded in summer in stations S1, S2 and S5. A significant difference between BOD values ( $p$ -value = 0.026) was observed between seasons. The high level of biodegradable organic matter in the water is due to the local anthropogenic pollution produced by lake visitors, sheep and cattle breeding, and domestic waste discharge.

The concentration range of total hardness (TH) and calcium hardness (CH) was 180–480 mg/L and 40.08–172.34 mg/L, respectively. The maximum value of TH was observed in spring at S1, and its minimum value was observed in autumn at S7 (5 m). The hardness values follow a significant seasonal variation ( $p$ -value = 0.000). They increase in winter and spring and decrease in summer and autumn. Note that the supersaturation of the water with alkaline earth (Ca, Mg) can be explained by dissolution of the calcareo-dolomitic substrate of the lake's catchment area [26].

The concentration range of ammonium, nitrate nitrogen, nitrite nitrogen and TKN was 0.01–0.163, 0.01–0.04, 0.4–1.16 and 0.1–12.07 mg/L, respectively. The concentrations of nitrogenous compounds were below the limit value set by the Moroccan standard, except for the TKN values. The TKN values were significantly higher in autumn and winter ( $p$  value = 0.04) in stations S1, S2, S3, S4, S5, S7 and S8. These higher concentrations might be linked to the reception of agricultural runoff and wastewater or water pollution by domestic waste and by livestock in the riparian areas of the lake.

In the whole water body, the concentrations of TP-P and PO<sub>4</sub>-P were low and did not exceed the standards set by the Moroccan norm. The recorded nutrient concentrations were lower than those measured by Khyri et al. [8]. This low level could be associated with the different actions undertaken by the water managers in the Dayat Roumi study area, as well as being explained by an abundance of phytoplankton [27].

### 3.2. Correlations between Variables

The matrix of pair-wise correlations between the 19 measured parameters (Table 2) shows links between the various physicochemical parameters evaluated. Indeed, the pH values correlate positively with the concentrations of DO (0.61) and those of TA (0.66). It is known that pH is a parameter affected by changes in the physicochemical and biological

conditions of the aquatic environment. A high rate of photosynthetic activity and the uptake of carbon dioxide to synthesize organic matter increase the pH and the rate of dissolved oxygen in the water. Also, during the hot season, decomposition of organic matter by microorganisms reduces the amount of oxygen and increases the amount of CO<sub>2</sub> in the water, which leads to a decrease in pH [28]. BOD values showed a positive correlation with PO<sub>4</sub>-P (0.53) and TP-P (0.5). Positive correlations are observed between the values of TP-P and those of PO<sub>4</sub>-P (0.77), and negative correlations are noted between the values of EC and those of TP-P (−0.58). There is also a positive correlation between the DO contents and those of TA (0.51) and a negative correlation between the values of T and those of CH (−0.58). The concentrations of Cl<sup>−</sup> correlate positively with those of EC (0.60) and negatively with those of PO<sub>4</sub>-P (−0.67) and TP-P (−0.60). The CH values correlate negatively with those of TH (−0.84), T (−0.58) and SO<sub>4</sub><sup>2−</sup> (−0.51), whereas the levels of TH correlate positively with those of SO<sub>4</sub><sup>2−</sup> (0.51). Positive correlations between CE, Cl<sup>−</sup>, SO<sub>4</sub><sup>2−</sup> and TH indicate water mineralization [29]. A similar observation between SO<sub>4</sub><sup>2−</sup> and TH was reported in the Angoori reservoir [30], and a high value of alkalinity and chlorides was confirmed in Lake Anchar [31] due to anthropogenic pressures, including agricultural activities, land use in the lake watershed and urbanization. Finally, a positive correlation between the total suspended solids (TSS) values and NO<sub>3</sub>-N (0.87) values is observed. Indeed, the increase in the content of nutrients in the water causes the growth of phytoplankton and, consequently, an increase in TSS concentration.

### 3.3. Principal Component Analysis

Factor analysis was performed on 19 variables and 8 sampling stations to determine the variation in water quality. The values of the factor loads and the explained variance of the water quality parameters of Lake Dayat Roumi are given (Table 3). Graphical representation of the factor loads of the principal components is also shown (Figure 2). The factor loads have been classified at levels of >0.75, 0.75 to 0.5 and 0.50 to 0.30 as strong, moderate and weak, respectively, based on absolute load values [32].

Three components of the multivariate analysis cumulate 52.86% of the variance of the data set. This low inertia accumulated by the first three axes C1, C2 and C3 is explained by the intervention of a high number of studied variables. Component 1, representing 24.36% of the total variance, is correlated with the parameters TP-P, Cl<sup>−</sup>, PO<sub>4</sub>-P, DO, T, TA, EC, BOD and CA. This axis, therefore, corresponds to a concentration gradient increasing from the negative side to the positive side for Cl<sup>−</sup>, DO, TA, EC and CA and decreasing for TP-P, PO<sub>4</sub>-P, T and BOD. The stations located on the right side of this axis have high concentrations of Cl<sup>−</sup>, DO, TA, EC and CA and low concentrations of TP-P, PO<sub>4</sub>-P, T and BOD, whereas the stations located on the left side of this axis have low levels of Cl<sup>−</sup>, DO, TA, EC and CA and high concentrations of TP-P, PO<sub>4</sub>-P, T and BOD. The strong positive load on Cl<sup>−</sup> and TA indicates the mineralization of the lake water. The high concentration of salts in the water could be due to the leaching of sedimentary rocks in the catchment area and the dissolution of evaporated rocks such as Halite, which could contribute to high chloride concentrations in the surface water [33]. In addition, contamination of water with mineral salts such as Cl<sup>−</sup> can also be of anthropogenic origin. Sources include wastewater effluents; chemical fertilizers and manures containing chlorine, used in agriculture, will increase the level of chlorides in drainage water from agricultural land [34]. In the study, the results of which are presented here, the second hypothesis is very probable since concentrations of chlorides in the lake were relatively great and exceed the quality standards for surface waters in Morocco. The negative loading on the T is attributed to the seasonal change [35], which results in warm water during summer and spring and cold water during autumn and winter. The positive loading on DO is attributed to strong photosynthetic activity. The negative loading on PO<sub>4</sub>-P and TP-P is attributed to the strong uptake of phosphorus by autotrophs during photosynthetic reactions.



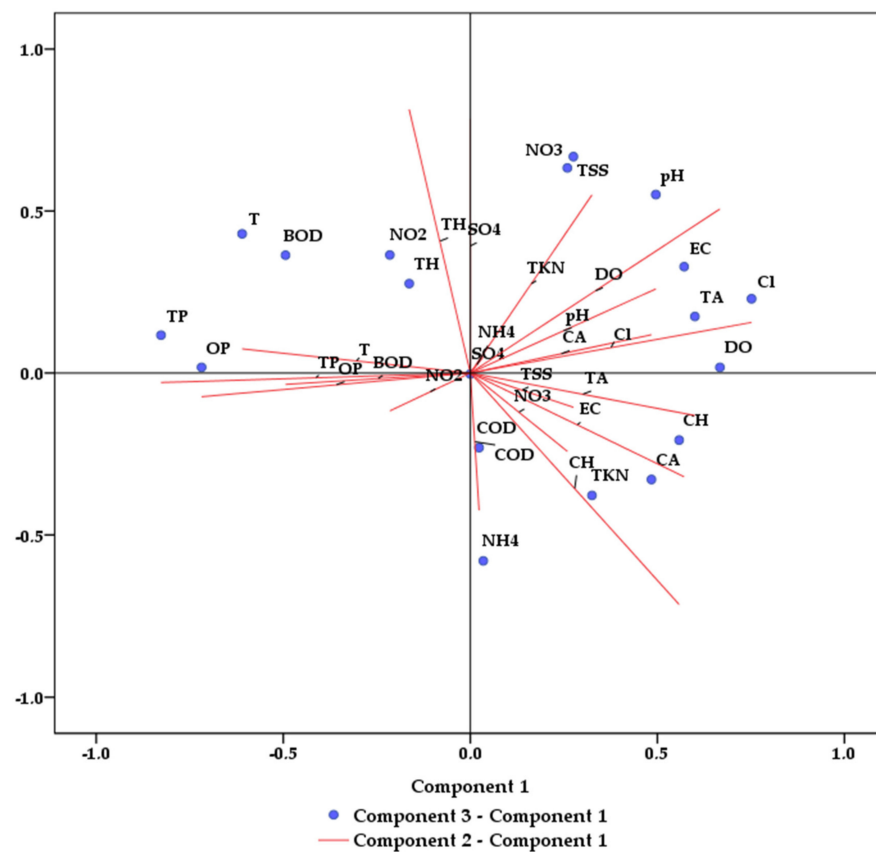
**Table 2.** Correlation matrix of the nineteen estimated parameters.

-	PH	EC	DO	T	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	TH	CH	TA	CA	TSS	NO <sub>3</sub> -N	NH <sub>4</sub> <sup>+</sup>	NO <sub>2</sub> -N	TKN	PO <sub>4</sub> -P	TP-P	COD	BOD	
pH	1																			
EC	0.320	1																		
DO	<b>0.609 **</b>	0.074	1																	
T	0.035	-0.107	-0.399 *	1																
Cl <sup>-</sup>	0.304	<b>0.601 **</b>	0.414 *	-0.426 *	1															
SO <sub>4</sub> <sup>2-</sup>	0.239	-0.116	0.323	-0.070	0.131	1														
TH	0.164	-0.179	0.198	0.392 *	0.182	<b>0.512 **</b>	1													
CH	0.024	0.406 *	0.104	-0.583 **	0.231	-0.514 **	<b>-0.840 **</b>	1												
TA	<b>0.663 **</b>	0.482 **	<b>0.505 **</b>	-0.162	0.251	-0.041	-0.214	0.450 **	1											
CA	-0.035	0.112	0.410 *	-0.419 *	0.465 **	-0.039	0.164	0.153	0.114	1										
TSS	0.318	0.205	0.109	-0.074	0.364 *	-0.152	0.066	0.053	0.005	0.039	1									
NO <sub>3</sub> -N	0.349	0.144	0.035	-0.112	0.223	-0.181	-0.123	0.200	0.135	-0.089	<b>0.876 **</b>	1								
NH <sub>4</sub> <sup>+</sup>	-0.363 *	-0.083	-0.131	0.304	0.014	0.150	-0.124	0.025	-0.167	0.202	-0.144	-0.134	1							
NO <sub>2</sub> -N	-0.187	0.088	-0.378 *	0.049	0.260	0.089	0.065	-0.106	-0.382 *	-0.131	0.332	0.261	0.019	1						
TKN	0.134	-0.261	0.481 **	-0.492 **	0.221	0.430 *	0.176	-0.029	0.004	0.211	-0.013	-0.041	0.412 *	-0.141	1					
PO <sub>4</sub> -P	-0.206	-0.443 *	-0.302	0.264	-0.669 **	-0.039	0.007	-0.268	-0.152	-0.235	-0.145	-0.100	-0.080	-0.058	-0.227	1				
TP-P	-0.273	<b>-0.582 **</b>	-0.457 **	0.333	-0.599 **	0.034	0.036	-0.359 *	-0.434 *	-0.380 *	-0.014	-0.001	-0.062	0.374 *	-0.110	<b>0.771 **</b>	1			
COD	-0.067	0.130	-0.278	-0.023	-0.109	-0.226	-0.236	0.235	0.142	0.377 *	-0.073	-0.047	0.194	0.083	-0.128	0.051	0.035	1		
BOD	-0.028	0.080	-0.273	0.398 *	-0.149	0.056	0.140	-0.254	-0.044	-0.243	-0.064	-0.037	-0.088	0.278	-0.273	<b>0.534 **</b>	<b>0.503 **</b>	-0.020	1	

\*\* . Correlation is significant at the 0.01 level (2-tailed). \* . Correlation is significant at the 0.05 level (2-tailed).

**Table 3.** Factor loading values and explained variance of water quality parameters of Lake Dayat Roumi.

Parameters	Component		
	1	2	3
TP-P	0.827	−0.029	0.117
Cl <sup>−</sup>	0.752	0.156	0.229
PO <sub>4</sub> -P	−0.718	−0.073	0.017
DO	0.667	0.506	0.017
T	−0.610	0.074	0.430
TA	0.600	−0.131	0.174
EC	0.572	−0.321	0.328
BOD	−0.494	−0.035	0.364
CA	0.484	0.118	−0.329
TH	−0.163	0.814	0.276
SO <sub>4</sub> <sup>2−</sup>	0.000	0.784	−0.003
CH	0.558	−0.715	−0.207
TKN	0.325	0.550	−0.378
COD	0.023	−0.424	−0.230
TSS	0.276	−0.106	0.668
NO <sub>3</sub> -N	0.259	−0.242	0.633
NH <sub>4</sub> <sup>+</sup>	0.035	0.049	−0.580
pH	0.496	0.260	0.551
NO <sub>2</sub> -N	−0.215	−0.117	0.364
Eigen values	4.62	2.85	2.56
Total variance (%)	24.36	15.01	13.49
Cumulative variance (%)	24.36	39.36	52.86

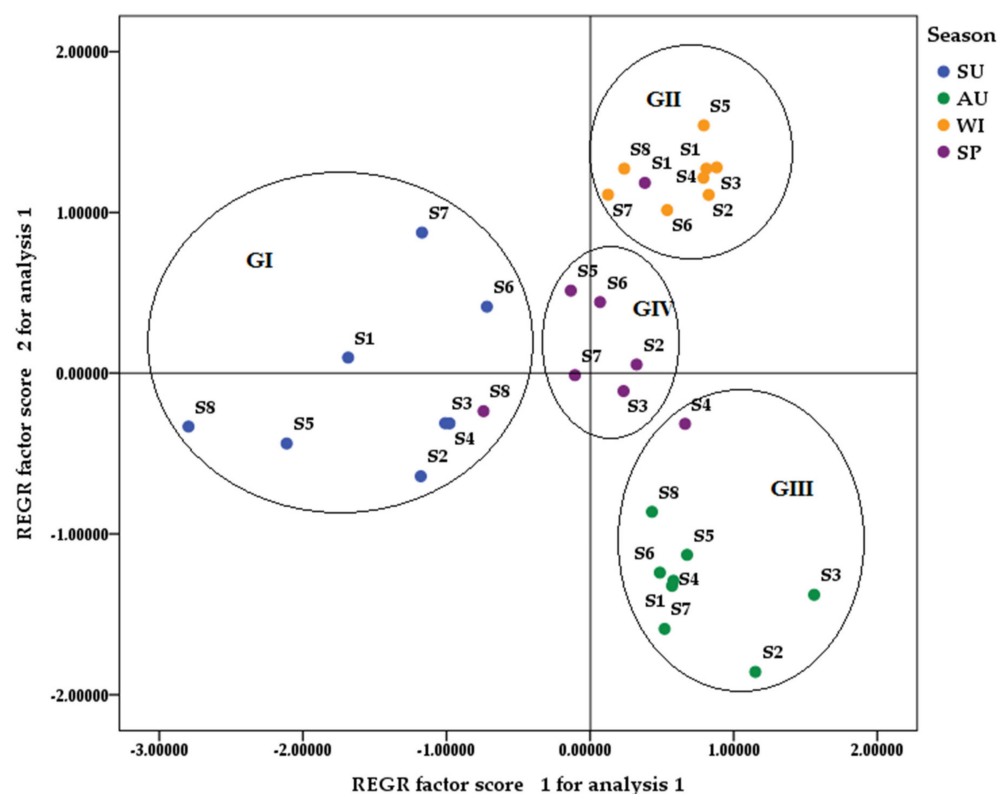


**Figure 2.** Graphic representation of the factor loads of the principal components C1, C2 and C3.

The second component, representing 15.01% of the total variance, included TH,  $\text{SO}_4^{2-}$ , CH, TKN and COD. This axis, therefore, corresponds to a concentration gradient of the elements evaluated, increasing from the negative side to the positive side for  $\text{SO}_4^{2-}$ , TH and TKN and decreasing for CH and COD. Stations on the positive side of axis 2 have higher values for  $\text{SO}_4^{2-}$ , TH and TKN and low values for CH and COD, whereas those on the negative side of the axis have high values for CH and COD and low values for  $\text{SO}_4^{2-}$ , TH and TKN. Positive loadings on TH and  $\text{SO}_4^{2-}$  indicate mineralization of the lake waters. Since these elements are part of the composition of fertilizers used in agriculture or domestic wastewater effluents, increased loads of mineral salts, including  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , and  $\text{SO}_4^{2-}$ , might be of natural origin, resulting from the leaching of sedimentary rocks entering into the composition of the region or an agricultural runoff [33]. The third component, representing 13.49% of the total measured variance, was positively correlated with TSS,  $\text{NO}_3\text{-N}$ , pH and  $\text{NO}_2\text{-N}$  parameters, and negatively with  $\text{NH}_4^+$ . A positive loading on  $\text{NO}_3\text{-N}$  indicates enrichment of the medium in nutrients from agricultural runoff [36]. This nutrient factor reflects the degree of eutrophication of the lake waters.

### 3.4. Segmentation of Sampling Stations

Global analysis of the graph of individuals made it possible to identify a specific classification by distinguishing four groups of stations: GI, GII, GIII and GIV (Figure 3). A comprehensive pollution index (P) was applied to qualify the state of the water at each station (Table 4).



**Figure 3.** Graphic of the distribution of the analyzed water samples and the C1 × C2 plane stations.

**Table 4.** Weights of physicochemical parameters, values of the comprehensive pollution index, and quality class of surface water of Lake Dayat Roumi.

Stations	P OD	P Cl <sup>-</sup>	P SO <sub>4</sub> <sup>2-</sup>	P TSS	P NO <sub>3</sub> -N	P NH <sub>4</sub> <sup>+</sup>	P TKN	P PO <sub>4</sub> -P	P TP-P	P BOD	P COD	ΣPi	P	Quality Class
S1 SU	0.00	1.106	0.372	0.006	0.035	0.015	0.033	0.2	0.600	1.40	0.49	4.26	0.387	sub cleanness
S1 AU	0.30	1.182	0.323	0.002	0.035	0.005	0.033	0.1	0.060	0.30	0.38	2.71	0.246	sub-cleanness
S1 WI	0.00	1.215	0.490	0.100	0.049	0.028	1.763	0.1	0.100	0.10	0.12	4.07	0.370	sub cleanness
S1 SP	0.00	1.219	0.497	0.002	0.035	0.005	1.080	0.1	0.060	0.80	0.36	4.16	0.378	sub cleanness
S2 SU	1.12	1.229	0.392	0.123	0.058	0.020	0.033	0.1	0.600	0.80	0.65	5.12	0.465	slight pollution
S2 AU	0.36	1.167	0.294	0.002	0.035	0.038	0.673	0.1	0.060	0.10	2.47	5.31	0.483	slight pollution
S2 WI	0.00	1.215	0.413	0.060	0.035	0.005	1.690	0.1	0.060	0.10	0.37	4.04	0.368	sub cleanness
S2 SP	0.02	1.201	0.279	0.035	0.035	0.005	0.853	0.1	0.060	0.50	0.55	3.64	0.331	sub-cleanness
S3 SU	1.08	1.134	0.372	0.002	0.035	0.040	0.033	0.1	0.220	0.20	0.61	3.83	0.348	sub cleanness
S3 AU	0.09	1.186	0.276	0.196	0.103	0.005	1.003	0.1	0.060	0.20	0.36	3.58	0.325	sub-cleanness
S3 WI	0.00	1.215	0.437	0.002	0.035	0.005	2.013	0.1	0.060	0.10	0.25	4.22	0.383	sub cleanness
S3 SP	0.08	1.191	0.304	0.065	0.035	0.005	0.033	0.1	0.060	0.30	0.42	2.60	0.236	sub-cleanness
S4 SU	1.05	1.115	0.403	0.006	0.035	0.020	0.033	0.1	0.060	0.10	0.61	3.53	0.321	sub-cleanness
S4 AU	0.38	1.167	0.238	0.016	0.035	0.005	1.237	0.1	0.060	0.10	0.61	3.95	0.359	sub cleanness
S4 WI	0.00	1.196	0.419	0.025	0.035	0.005	2.390	0.1	0.060	0.10	0.34	4.67	0.424	slight pollution
S4 SP	0.00	1.201	0.242	0.186	0.062	0.005	0.033	0.1	0.060	0.20	0.47	2.55	0.232	sub-cleanness
S5 SU	1.10	1.108	0.385	0.006	0.035	0.020	0.033	0.2	0.600	0.80	0.61	4.90	0.445	slight pollution
S5 AU	0.31	1.177	0.281	0.008	0.035	0.005	1.023	0.1	0.060	0.20	0.36	3.56	0.324	sub-cleanness
S5 WI	0.00	1.172	0.477	0.010	0.035	0.028	2.287	0.1	0.060	0.10	0.12	4.39	0.399	sub cleanness
S5 SP	0.00	1.182	0.366	0.002	0.035	0.005	0.033	0.1	0.060	0.80	0.36	2.95	0.268	sub-cleanness
S6 SU	0.00	1.101	0.395	0.003	0.035	0.005	0.033	0.1	0.060	0.20	0.36	2.30	0.209	sub-cleanness
S6 AU	0.37	1.182	0.271	0.004	0.035	0.026	0.033	0.1	0.060	0.20	0.25	2.53	0.230	sub-cleanness
S6 WI	0.00	1.186	0.438	0.005	0.035	0.005	0.033	0.1	0.060	0.10	0.25	2.21	0.200	cleanness
S6 SP	0.00	1.182	0.363	0.002	0.035	0.005	0.033	0.1	0.060	0.10	0.55	2.43	0.221	sub-cleanness
S7 SU	0.03	1.115	0.377	0.006	0.035	0.005	2.500	0.1	0.600	0.30	0.25	5.31	0.483	slight pollution
S7 AU	0.23	1.177	0.249	0.004	0.035	0.040	0.033	0.1	0.060	0.30	0.25	2.47	0.225	sub-cleanness
S7 WI	0.03	1.172	0.425	0.030	0.035	0.063	2.563	0.1	0.156	0.50	0.48	5.55	0.504	slight pollution
S7 SP	0.48	1.182	0.299	0.010	0.035	0.036	0.033	0.1	0.060	0.10	0.32	2.65	0.241	sub-cleanness
S8 SU	0.56	1.049	0.280	0.008	0.035	0.005	0.277	0.2	0.800	0.30	0.49	4.00	0.363	sub cleanness
S8 AU	0.23	1.182	0.350	0.005	0.035	0.032	1.187	0.1	0.060	0.50	0.36	4.04	0.368	sub cleanness
S8 WI	0.21	1.186	0.400	0.010	0.035	0.082	4.023	0.1	0.060	0.10	0.49	6.69	0.608	slight pollution
S8 SP	0.67	1.182	0.244	0.002	0.035	0.005	0.033	0.1	0.060	0.60	0.42	3.35	0.305	sub-cleanness

Group I includes stations S1“SU”, S2“SU”, S3“SU”, S4“SU”, S5“SU”, S6“SU”, S7“SU”, S8“SU” and S8“SP”, which are characterized by lower values of  $\text{Cl}^-$ , DO, TA, EC and CA and moderate to high values of TP-P,  $\text{PO}_4\text{-P}$ , T and BOD. The comprehensive pollution index values range from 0.21 to 0.48, classifying the waters in S1, S3, S4, S6 and S8 as sub-clean, and the waters in S2, S5 and S7 as slightly polluted. Stations S1, S2, S3, S4 and S5 receive organic waste and wastewater from lake visitors in the summer period. In addition, the increase in temperature in dry periods favors the decomposition of organic matter by microorganisms. In deep waters, hypoxic conditions accentuate this phenomenon, which leads to the degradation of water quality. Group II includes stations S1“WI”, S2“WI”, S3“WI”, S4“WI”, S5“WI”, S6“WI”, S7“WI”, S8“WI” and S1“SP”, characterized by moderate to high values of  $\text{Cl}^-$ , DO, TA, EC and CA and low values of TP-P,  $\text{PO}_4\text{-P}$ , T and BOD. Furthermore, it is characterized by high values of  $\text{SO}_4^{2-}$ , TH and TKN and lower values of CH and COD. The pollution index values for group II range from 0.2 to 0.6. The water quality varies regressively from clean (S6) to sub-clean (S1, S2, S3 and S5) to slightly polluted (S4, S7 and S8). During the wet season, the enrichment of the water with mineral salts and organic matter is related to the leaching of rocks and plantations by rainwater and the input of domestic wastewater and runoff. Group III includes stations S1“AU”, S2“AU”, S3“AU”, S4“AU”, S5“AU”, S6“AU”, S7“AU”, S8“AU” and S4“SP”; all of them are characterized by high to medium values of DO, T, TA, EC, BOD and CA and low values of TP-P,  $\text{PO}_4\text{-P}$ , T and BOD. Similarly, they are characterized by moderate to high values of CH and COD and low values of  $\text{SO}_4^{2-}$ , TH and TKN. The comprehensive pollution index values range from 0.22 to 0.48 which indicates sub-clean to slightly polluted water quality. This group includes station S2“AU”, characterized by slightly polluted water. This station is located in the southeast sector and receives water from a stream and domestic wastewater tributaries. Group IV includes stations S2“SP”, S3“SP”, S5“SP”, S6“SP” and S7“SP”, which are close to the center of gravity and therefore play little role in explaining the physicochemical typology of the environment. Thus, for the parameters characterizing the C1 and C2 axis, the seasonal effect is notable and significant.

Concerning the variables constituting the C3 axis, the stations can be divided into three groups (Figure 4): Group A includes stations S1“SU”, S2“SU”, S3“AU” and S4“SP”, characterized by high concentrations of TSS,  $\text{NO}_3\text{-N}$ , pH and  $\text{NO}_2\text{-N}$  but low concentrations of  $\text{NH}_4^+$ . These stations are located on the lakeshore and therefore receive direct runoff and leaching from agricultural fields and are more exposed to tourism and pastoral activity, unlike group C, which includes stations S7“WI”, S8“WI”, S8“AU” and S2“AU”, all characterized by high  $\text{NH}_4^+$  concentrations and low TSS,  $\text{NO}_3\text{-N}$ , pH and  $\text{NO}_2\text{-N}$  values. This group consists mainly of samples from the lake’s center and therefore less exposed to riparian influences. Group B includes surveys carried out in different seasons and stations located at different positions around the lake’s center. Intermediate levels of TSS,  $\text{NO}_3\text{-N}$ , pH,  $\text{NO}_2\text{-N}$  and  $\text{NH}_4^+$  characterize these stations. It should be noted that the season factor does not play a role in the differentiation of these last three groups.

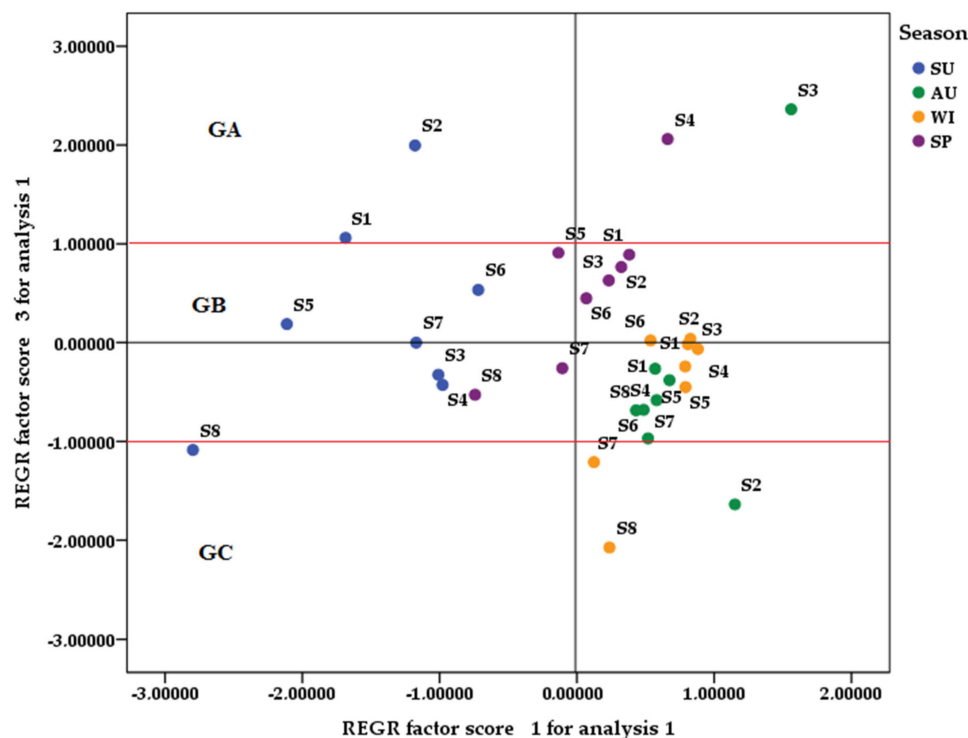


Figure 4. Graphic of the distribution of the analyzed water samples and the C1 × C3 plane stations.

#### 4. Conclusions

Chloride and electrical conductivity values vary from area to area within the lake and exceed the Moroccan surface water standard. DO, BOD and TKN levels also vary from area to area, but concentrations are within the norms except in stations with degrading plant matter and in the deep layers. These anoxic conditions can affect the life of the biocenosis and lead to the death of certain species, such as the death of fish in summer. The other physicochemical parameters vary from one station to another but remain below the Moroccan norm. According to the multivariate analysis, three sources of pollution are responsible for the degradation of water quality, namely the leaching of rocks from the catchment area and plantations, domestic wastewater, and runoff. The PCA also allowed distinguishing several clusters of surveys differing in their degree of mineralization, the extent of their sulfate contamination, and their degree of eutrophication. Similarly, the comprehensive pollution index (P) showed degradation of water quality, in the peripheral areas of the lake and the deep parts, favored by soil leaching and the entrainment of agricultural residues into the lake water. Based on the results of this study, it is therefore concluded that to develop an effective management plan for the lake's water resources, regular monitoring of the water quality assessment is necessary.

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