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Anthropogenic Activities Impact on the Physicochemical and Bacteriological Quality of Water in Dayat Roumi Lake, Morocco

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ABSTRACT

Dayat Roumi Lake, a vast body of permanent and shallow water in Morocco, is exposed to urban, tourist, and agricultural constraints. This human intervention can lead to microbial pollution of the lake ecosystem, hence the need to assess this contamination. For this reason, we undertook in this study an evaluation of the microbiological quality of the lake's water. Thus, seasonal water samples were taken at eight selected stations, taking into account the reception sites of the tributaries and anthropic activities. The parameters determined were: temperature, pH, dissolved oxygen (DO), electrical conductivity, biological oxygen demand (BOD), chemical oxygen demand (COD), ammonium, nitrates, orthophosphates, total phosphate, total coliforms, fecal coliforms and fecal streptococci. The results reveal: (1) A high water conductivity exceeding the admissible value recommended by the Moroccan standard; (2) A significant presence of coliforms and fecal streptococci, in dry periods, exceeding the standards set by the WHO, which could be attributed to a summer temperature favorable to the development of coliforms. This fecal contamination leads to an increased consumption of dissolved oxygen (high BOD and low DO values) explaining the fish mortality in this period of the year; (3) The principal component analysis identified the sources of water quality degradation as domestic sewage, agricultural run-off, domestic waste, and human and animal excreta; (4) The hierarchical analysis divided the sampling stations into three different clusters. The results of the microbiological quality index classified the waters from not to highly polluted. Station 4 was classified as the most polluted site. The results of the COD/BOD ratio showed a spatial and temporal heterogeneity of the biodegradability of the oxidizable matter present in the lake waters.

Keywords: bacteriological quality, Dayat Roumi Lake, physicochemical parameters, organic pollution, water, fecal contamination.

INTRODUCTION

Water is an essential element for living organisms, provided it is available in sufficient quantity and quality. It allows the dissolution and transport of many molecules and is involved in various physical and chemical reactions (including maintaining a constant temperature and producing energy). It protects the body by acting as a lubricant in the joints and the digestive system [Riveros-Perez et al., 2018].

Furthermore, living organisms draw their water needs from natural reserves: lakes, rivers, groundwater, ice, and the marine environment, and their health depend on the quality of this water. However, due to industrial activities, domestic wastewater discharges, solid waste discharges, leaching from agricultural land and pastures, and products of natural processes (drought), this water can be damaged, leading to a degradation of its quality by contaminating it with pollutants. This dysfunction can threaten the health of the biocenosis and even that of human beings [Lutz et al. 2016].

The factors of water degradation are numerous and diverse. Therefore it is essential to diagnose the causes of water pollution in the environment. Coliforms and fecal streptococci are bacteria that live in the intestinal tract of humans, certain vertebrates, and other warm-blooded animals [Zaghloul et al., 2020] and are deposited by the fecal waste in the aquatic environment. Thus, these bacteria are bio-indicators that indicate contamination of animal or human fecal origin [Silva et al., 2010]. It should be noted that these fecal bacteria can cause infectious diseases such as gastroenteritis, eye infections, ear infections, and dermatitis following the use of contaminated water [Fazlzadeh et al., 2015].

Thus, the objective of the present work is to evaluate the degree of the seasonal evolution of contamination by fecal bacteria in the waters of Lake Dayat Roumi. It is one of the Moroccan aquatic ecosystems in the process of degradation. Indeed, a field survey carried out in the lake area showed a regression of the water quality manifested by the massive mortality of fish, the decline of certain piscicultural species, the proliferation of plants on the banks of the lake, and the appearance of certain sanitary disorders among the users of Dayat. Until today, few bacteriological studies have been carried out on Dayat Roumi lake [Khyri et al., 2013]. The results of this work showed fecal contamination of the lake water.

MATERIALS AND METHODS

Study environment

Lake Dayat Roumi is located in the Rabat-Salé region, Khemissat province (Fig. 1). It covers an area of 96 ha and has a maximum depth of around 14 m in the center of the lake decreasing towards the shore. It is a vast natural depression flanked by hills of Mio-Pliocene marl, covered by recent alluvium. The lake is fed by groundwater and tributary waters. The study area is subject to a temperate Mediterranean climate, with a monthly temperature of 8.9 to 26.5°C and an average annual rainfall of around 600 mm. This natural environment is characterized by dense and varied vegetation, while its faunal population is small compared to

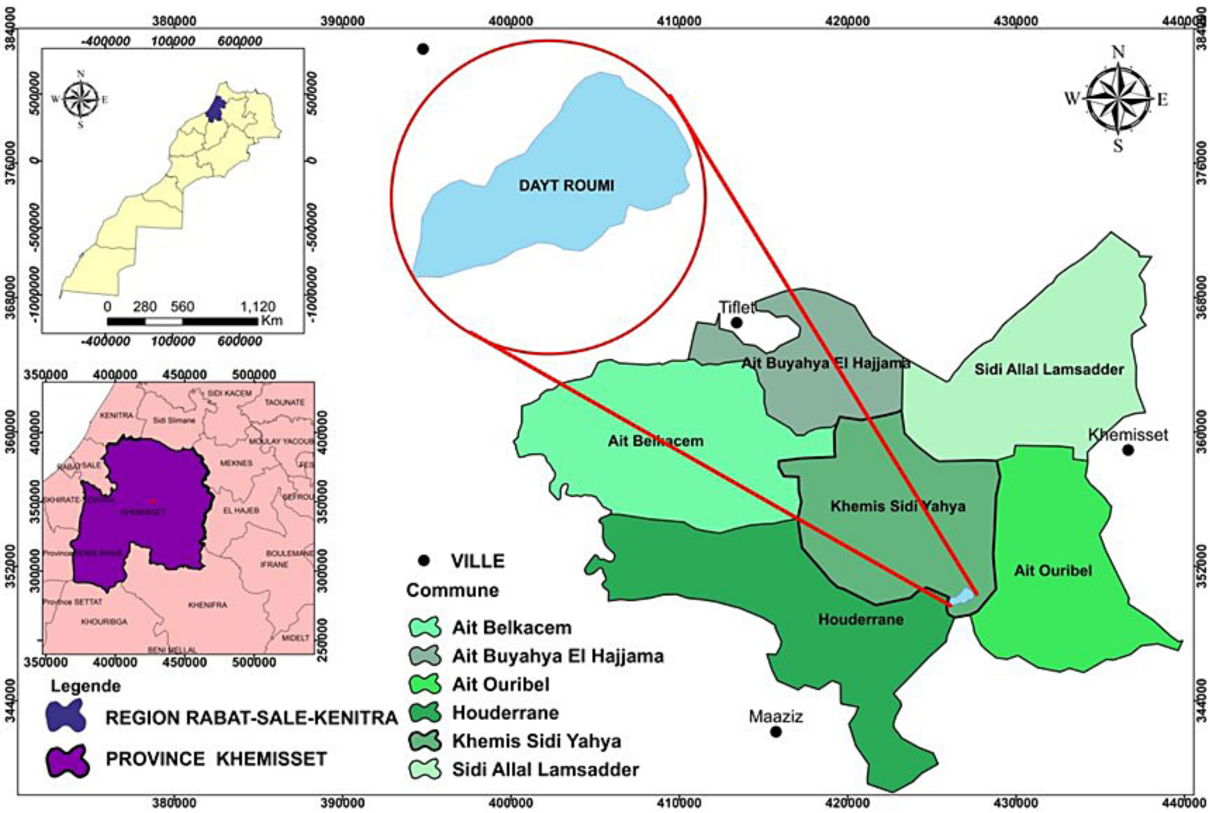


Figure 1. Situation map of the Dayat Roumi lake study area (Morocco)

other continental lakes in Morocco. The main activities of the region's inhabitants are agriculture, livestock breeding, and small-scale trade. In recent years, numerous constructions have been built on the land surrounding the lake. Moreover, domestic wastewater is evacuated in septic tanks by default of the sewerage system. Lake Dayat Roumi is subject to several types of nuisance, whether it be the urban wastewater tributaries that crown the lake area, the solid waste dumped on its banks or the runoff water carried directly into its waters and favoring the leaching of the surrounding soil.

Sampling

Eight water sampling stations were selected taking into account the position of the tributaries and the various human activities in the study area that may harm the health of the lake (Table 1).

Water samples were collected seasonally: in summer (SU) and autumn (AU) during 2017 and in winter (WI) and spring (SP) during 2018. Water samples destined for physicochemical characterization of water were taken, in duplicate, in plastic bottles previously rinsed with water from the station. At each sampling, the temperature (T), electrical conductivity (EC), pH, and dissolved oxygen (DO) were measured in situ by a HACH model HQ40d multiparameter apparatus. Then, the water samples were kept at 4°C until the determination of other physicochemical parameters, namely: the biological oxygen demand for 5 days (BOD) and the chemical oxygen demand (COD) by volumetric method, the total suspended solids (TSS) by filtration at 0.45 µm, the ions ammonium (NH_4^+), the nitrates (NO_3^-), the total phosphate (TP) and the orthophosphate (OP) by a photometric method. The physicochemical parameters are measured at the National Laboratory of Studies and Monitoring of Pollution, Morocco.

For bacteriology, samples were collected in sterile glass bottles and stored in a cooler before being transported to the laboratory for analysis. The water bacteriological study focused on the enumeration of bacteria indicative of fecal contamination: total coliforms (TC), fecal coliforms (FC), and fecal streptococci (FS). The quantitative evaluation of the bacteria studied was done according to the French standard method [AFNOR, 1985]. The results are expressed as colony-forming units per 100 ml of sample.

Statistical study

Statistical analyses were carried out using SPSS 23.0 statistical software. The spatiotemporal variation of physicochemical and microbiological parameters was studied using ANOVA at a significance level of 5%. The results of the physicochemical analysis and the bacteriological analysis were compared to the Moroccan surface water quality standards [NMQES, 2002] and to the WHO microbiological guidelines for drinking water [WHO, 2006]. Relationships between fecal pollution indicators (TC, FC, and FS) and physicochemical variables (T, pH, EC, COD, BOD, TSS, NH_4^+, NO_3^-, TP, and OP) were examined by Pearson correlation analysis. The data were also processed using principal component analysis (PCA) and cluster analysis to examine observations for similarity or dissimilarity to determine a typology.

Similarly, two indices were used, namely, the microbiological quality index (MQI) [Bovesse and Depelchin, 1980], calculated from the results of the bacteriological enumeration, to determine the level of water quality, and the biodegradability

Table 1. Locations of sampling sites on the Dayat Roumi Lake

Stations	Altitude (m)	Description	Latitude and longitude
S1	342	Swimming area	33°45′06.4″ N 06°11′06.3″ W
		The area where a stream emerges from a marshy depression located 1-2 km from the lake	
S2	341	The area that receives water from a small stream coming from the SE side. The area located near a meadow.	33°44′49.5″ N 06°10′52.6″ W
S3	344	Station located next to the Dar Eddaya hotel	33°44′38.0″ N 06°11′48.6″ W
S4	343	It receives the waters of a river "Rho" crossing agricultural lands and a local village	33°44′45.2″ N 06°11′46.6″ W
S5	343	Camping and nautical activities area	33°45′07.5″ N 06°11′13.6″ W
S6	343	Lake center (depth 1 m)	33°44′48.9″ N 06°11′18.6″ W
S7	343	Lake center (depth 5 m)	33°44′48.8″ N 06°11′18.5″ W
S8	343	Lake center (depth 9 m)	33°44′50.2″ N 06°11′14.3″ W

index [Rodier et al., 2009] to indicate the importance of biodegradable pollutants. The MQI classifies the fecal contamination of the water as very high if 1 < MQI ≤ 1.8, high if 1.9 < MQI ≤ 2.6, moderate if 2.7 < P ≤ 3.4, low if 3.5 < P ≤ 4.2), and null if 4.3 < MQI ≤ 5.0.

The biodegradability index K is calculated by the formula (1):

$$K = COD/BOD \tag{1}$$

Coefficient k	Signification
k < 1.5	Easily biodegradable oxidizable materials
1.5 ≤ k < 2.5	Moderately biodegradable oxidizable materials
2.5 ≤ k < 3	Poorly biodegradable oxidizable materials
k ≥ 3	Hardly or not biodegradable oxidizable materials

RESULTS AND DISCUSSION

Spatial and temporal variations of the variables studied

Physicochemical parameters

The average, minimum, maximum values, and standard deviations of the physicochemical and bacteriological parameters studied in the waters of Lake Dayat Roumi are grouped in Table 2. The lake waters have a pH that varies between 7.8 and 9.02. The highest value was recorded in autumn and winter in S3 and the lowest in summer in S8 with an overall average of 8.62. It oscillates in the range 6.5–9.2 established by the Moroccan standard. Therefore, these values indicate that alkaline water conditions dominate the lake. This water alkalinity favors the life and optimal production of fish [Loucifa et al., 2020]. Similarly, the results show a significant difference between the pH of the stations ($p = 0.002$).

The temperature ranges from 14.96°C to 27.5°C, with an overall average of 20.58°C. The summer values are significantly higher ($p = 0.001$). The minimum temperature is measured in winter at S2 and the maximum value is recorded in summer at S6. In addition, a clear thermal stratification was recorded in the center of the lake (S6, S7, and S8) during the warm season (summer and spring).

Regarding EC, the values fluctuate between 2.3 mS/cm and 3.06 mS/cm, with an overall average of 2.96 mS/cm. Moreover, the values noted exceed the limit required by the Moroccan standard. In addition, the EC varies significantly ($p = 0.002$) according to the seasons indicating low values in summer and high values during autumn and spring. The enrichment of spring and autumn waters by leaching minerals may explain these high values.

DO concentrations ranged from 2.28 to 11.4 mg/l. The highest value was recorded in winter at S6 and the lowest value was measured in summer at S2, with an overall average of 7.51 mg/l. In addition, a significant difference between the seasonal values of the stations is noted ($p = 0.001$). The decrease in oxygen content in the water is attributed to the increase in water temperature and consequently the decrease in the degree of oxygen solubility in the water. On the other hand, the increase in temperature promotes the degradation of organic matter by microorganisms and consequently the consumption of dissolved oxygen [Al Afifi et al., 2018].

Table 2. Results of water quality parameters from eight sampling stations of Dayat Roumi Lake

Parameters	N	Minimum	Maximum	Mean	Std. Deviation
T	32.00	14.96	27.50	20.58	4.06
pH	32.00	7.80	9.02	8.62	0.28
DO	32.00	2.28	11.40	7.51	2.57
EC	32.00	2.30	3.06	2.96	0.14
BOD	32.00	1.00	14.00	4.97	3.84
COD	32.00	4.80	100.80	18.88	15.92
TC	32.00	0.00	3840.00	400.31	811.26
FC	32.00	0.00	960.00	57.31	169.30
FS	32.00	0.00	1800.00	102.06	321.01
TSS	32.00	2.00	186.00	29.78	49.25
NH_4^+	32.00	0.01	0.16	0.04	0.04
NO_3^-	32.00	0.01	1.30	0.35	0.25
OP	32.00	0.03	0.07	0.03	0.01
TP	32.00	0.03	0.45	0.10	0.13

COD values fluctuate between 4.8 and 100.8 mg/l. The lowest value was measured in winter at S1 and S5, while the highest value was recorded in autumn at S2, with an overall average of 18.88 mg/l. These values, therefore, vary significantly according to the season ($p = 0.016$). It should also be noted that the values recorded, except S2, remain below the threshold of the Moroccan standard. In addition, this high value 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.

BOD values vary between 1 and 14 mg/L. The high values (8–14 mg/L) and exceeding the limits required by the Moroccan standard are recorded in summer (S1, S2, S4, and S5), autumn (S4), and spring (S2, S3, and S5). The high amount of biodegradable organic matter present in the water is due to the local anthropic pollution produced by the visitors to the lake, the fishers, the breeding of sheep and cattle, as well as the discharge of domestic waste could be the origin of the high values of the BOD.

The TSS values vary between 2 and 186 mg/l with an overall average of 29.78 mg/l. The highest value was recorded in autumn in S3 while the lowest was in spring in stations S5, S6, and S8. The concentrations noted are lower than the maximum limit admitted by the Moroccan standard (1000 mg/l). No significant difference is recorded between the TSS values on a seasonal or spatial level.

NH_4^+ values vary between 0.01 and 0.16 mg/L, with an overall average of 0.04 mg/L. The minimum value is noted in all stations in different seasons and the maximum value is recorded in winter at S8. NH_4^+ values do not show any significant difference between stations or seasons.

Nitrate concentrations vary between 0.01 and 1.30 mg/l, with an overall average of 0.35 mg/l. The minimum value is noted in summer at S7 and S8 and the maximum value is recorded in autumn at S3. Seasonally, the nitrate values present a significant difference ($p = 0.001$). These values are lower than the concentration allowed by the Moroccan standard.

Orthophosphate concentrations fluctuate between 0.03 and 0.07 mg/l, with an overall average of 0.03 mg/l. The minimum value is noted in all stations at different seasons and the maximum value is recorded in summer at S5. Seasonally, the orthophosphate values show a significant difference ($p = 0.004$). These values are lower than the concentration allowed by the Moroccan standard.

Total Phosphate concentrations vary between 0.03 and 0.45 mg/l, with an overall average of 0.10 mg/l. The minimum value is noted in autumn, winter, and spring in all stations and the maximum value is recorded in summer at S8. Seasonally, the phosphate values show a significant difference ($p = 0.001$). These values are lower than the concentration allowed by the Moroccan standard.

Fecal bacteria

The microbiological indicators TC, FC, and FS were detected in the majority of the lake water samples. The highest values were recorded in summer at stations 1, 2, 3, 4, and 5, which are located at the edge of the lake. The TC concentrations varied from 0 to 3840 CFU/100 ml. A significant difference between the stations was recorded ($p = 0.02$). The minimum value was recorded in winter and spring (S7, S8) and the maximum value was recorded in summer (S4). The FC values ranged from 0 to 960 CFU/100 ml. The highest value was significantly ($p = 0.009$) detected in summer at S4 and the lowest in winter (S2, S4, and S8) and spring (S7 and S8). It is, therefore, noted that for both TC and FC, the concentrations noted are below the maximum limit allowed by the Moroccan standard (20000 CFU/100 ml) and exceed the values set by the World Health Organization [WHO, 2006]. For FS, the values vary from 2 to 1800 CFU/100 ml. A significant seasonal difference is recorded ($p = 0.01$). The highest values were recorded in summer (S4) and spring (S2). These values are higher than the WHO permissible limit for drinking water but remain lower than the Moroccan standard.

Furthermore, as reported by Sabae et al. [2014], the high concentrations of TC, FC, and FS in the summer period were attributed to the increase in water temperature which stimulates the enzymatic activity of bacteria allowing them to grow rapidly throughout this season. In addition, the increase in temperature leads to a decrease in water level, and consequently, an increase in the number of insoluble pollutants during the summer, and this phenomenon is accentuated by the discharge of domestic sewage and livestock defecation into the lake water. A similar result was reported by Ayenuddin Haque et al. [2018] in the water of the Padma river in Bangladesh. They also found high levels of fecal bacteria in the hot season. Regarding the high level of total coliforms in station 1, recorded in summer, it can be attributed to recreational activities of visitors as well as direct discharge of household waste into the lake. Similarly, the drainage of sewage and livestock excreta from rainfall can lead to increased numbers of TC and SF in S2 in spring. While the high level of fecal bacteria in S4 is associated with anthropogenic activities as this station collects wastewater from the local village and wastes from surrounding agricultural activities via Rho River.

Relationship between physicochemical and microbiological parameters

Table 3 shows the correlation results between microbiological and physicochemical variables studied for each season. In summer, temperature levels showed a positive correlation with DO levels (0.76), while they showed a negative correlation with COD levels (-0.75). Also, DO levels showed a negative correlation with COD levels (-0.91). In addition, NO_3^- concentrations were positively correlated with EC (0.71) and TSS (0.73). In addition, TC values showed a strong positive correlation with BOD (0.89), FC (0.88), and FS (0.88), and FC values showed a strong positive correlation with FS levels (0.99). In autumn, TSS values correlated positively with pH (0.81), DO (0.83), and NO_3^- (0.99). In addition, NO_3^- concentrations were positively correlated with pH (0.81) and DO (0.83). A positive correlation is revealed between NH_4^+ and EC levels (0.89). Furthermore, COD values showed a positive correlation with FC values (0.82) and a negative correlation with TP values (-0.72). BOD levels showed a positive correlation with TC (0.87) and FS (0.71). OP values correlated positively with TP (0.72) and negatively with CE (-0.78) and T (-0.71). Finally, a positive correlation is recorded between TC and FC (0.9).

In winter, NH_4^+ values showed a negative correlation with pH (-0.86) and DO (-0.84). In addition, a positive correlation is recorded between DO and EC (0.75) and between BOD and TC (0.87). TSS values showed a positive correlation with NO_3^- (0.73) and FS (0.78). In addition, a positive correlation is noted between NO_3^- and FS values (0.84). In spring, a positive correlation is recorded between T and pH values (0.94) and between T and DO values (0.93). In addition, pH values correlated positively with DO values (0.96). Also, positive correlations are recorded between TSS and NO_3^- (0.93), OP (0.75) and TP (0.93) concentrations. TP values presented a positive correlation with OP (0.8) and NO_3^- (0.99) and OP values showed a positive correlation with COD (0.71) and NO_3^- (0.8). As for TC, its values showed a positive correlation with those of FS (0.97) and FC (0.81). Finally, BOD values were positively correlated with TC (0.82), FC (0.77), and FS (0.77).

In conclusion, the results show correlations between certain physicochemical variables, and between physicochemical variables and fecal bacteria contents. Similarly, the same physicochemical factor can correlate with different factors depending on the season. pH is a good example. It should also be noted that TC values were higher than FC values and showed a strong positive correlation between them linked to the fact that TCs group all types of fecal bacteria, including fecal coliforms [Prescott et al., 1996]. Moreover, the relationship between biological and physicochemical parameters indicates fecal pollution in the water with consumption of dissolved oxygen, accentuated in dry periods. These hypoxic conditions could explain fish death at this time of year. In addition, the high level of fecal bacteria in the environment makes the water unfit for consumption and may be the cause of the symptoms that appear in users of the lake (dermatitis and conjunctivitis) [Mouchel et al., 2010].

Principal component analysis

Principal component analysis was applied to data from the eight sampling stations. The number of components to be extracted is determined on the basis of the Eigen value. The components with an Eigen value higher than or equal to 1 are retained. The results are summarized in Table 4. Figures 2 and 3 show the plots of variables and observations for the eight sampling points, respectively.

Five principal components (C1, C2, C3, C4, and C5) were retained, explaining together 77.5% of the total variance in the data set. The first component, representing 26.5% of the total variance, is positively correlated with parameters values for TC, FC, FS and BOD and negatively correlated with the DO values. This axis represents an increasing gradient, from negative to positive, of the degree of fecal contamination of the lake water. This factor shows that bacteriological pollution comes mainly from domestic sewage, household waste, and the leaching of agricultural land

Table 3. Correlations between physicochemical and bacteriological parameters

Summer	T	pH	DO	EC	BOD	COD	TC	FC	FS	TSS	NH_4^+	NO_3^-	OP	TP
T	1													
pH	0.706	1												
DO	**0.769***	0.409	1											
EC	-0.061	0.125	-.0444	1										
BOD	0.056	-0.002	-.0151	0.441	1									
COD	**-0.753***	-0.287	**-0.914****	0.326	0.353	1								
TC	0.062	-0.130	-0.201	0.409	**0.890****	0.323	1							
FC	-0.086	-0.335	-0.422	0.327	0.645	0.411	**0.886****	1						
FS	-0.092	-0.330	-0.422	0.333	0.622	0.408	**0.885****	**0.993****	1					
TSS	-0.456	-0.109	-0.389	0.230	0.125	0.460	-0.065	-0.061	-0.142	1				
NH_4^+	-0.342	0.175	-0.664	0.528	0.034	0.641	0.168	0.229	0.294	0.015	1			
NO_3^-	-0.287	0.017	-0.602	**0.710***	0.448	0.603	0.425	0.448	0.399	**0.736***	0.442	1		
OP	-0.085	-0.109	0.114	0.069	0.274	-0.043	-0.045	-0.303	-0.289	-0.201	-0.259	-0.362	1	
TP	-0.269	-0.185	0.250	-0.441	0.022	-0.037	-0.310	-0.546	-0.560	0.161	-0.473	-0.404	0.704	1
Autumn	T	pH	DO	EC	BOD	COD	TC	FC	FS	TSS	NH_4^+	NO_3^-	OP	TP
T	1													
pH	-0.214	1												
DO	-0.194	0.491	1											
EC	0.657	-0.499	-0.335	1										
BOD	-0.494	-0.264	-0.203	0.031	1									
COD	0.312	0.254	-0.251	0.414	0.271	1								
TC	-0.357	0.102	-0.181	0.016	**0.874****	0.648	1							
FC	-0.179	0.188	-0.280	0.015	0.640	**0.821***	**0.901****	1						
FS	-0.641	0.075	0.195	-0.258	**0.719***	-0.109	0.584	0.216	1					
TSS	-0.180	**0.811***	**0.839****	-0.415	-0.365	-0.151	-0.198	-0.272	0.200	1				
NH_4^+	0.492	-0.404	-0.316	**0.890****	-0.096	0.391	-0.082	0.028	-0.465	-0.406	1			
NO_3^-	-0.128	**0.813***	**0.837****	-0.395	-0.423	-0.141	-0.244	-0.292	0.123	**0.997****	-0.370	1		
OP	**-.0717***	0.213	-0.235	**-0.785***	0.190	-0.328	0.129	0.119	0.244	-0.047	-0.635	-0.073	1	
TP	-0.476	-0.159	-0.069	-0.682	-0.174	**-0.723***	-0.404	-0.350	-0.110	-0.143	-0.476	-0.143	**0.727***	1
Winter	T	pH	DO	EC	BOD	COD	TC	FC	FS	TSS	NH_4^+	NO_3^-	OP	TP
T	1													
pH	-0.187	1												
DO	0.226	0.544	1											
EC	-0.049	0.402	**0.753***	1										
BOD	0.490	0.261	0.060	-0.254	1									
COD	-0.081	-0.522	-0.615	-0.495	0.135	1								
TC	0.191	0.496	0.219	-0.121	**0.875****	-0.185	1							
FC	-0.069	-0.266	-0.445	-0.312	0.295	0.441	0.110	1						
FS	-0.357	-0.252	-0.150	-0.366	-0.185	-0.212	0.124	0.024	1					
TSS	-0.647	-0.033	0.158	0.167	-0.333	-0.220	0.055	-0.031	**0.780***	1				
NH_4^+	0.004	**-0.867****	**-0.841****	-0.523	-0.192	0.532	-0.400	0.439	0.197	-0.060	1			
NO_3^-	-0.235	-0.013	0.208	0.066	-0.318	-0.673	0.069	-0.214	**0.846****	**0.731***	-0.054	1		
OP	0.435	0.176	0.569	0.335	0.569	0.000	0.544	-0.312	-0.219	-0.008	-0.427	-0.184	1	
TP	-0.253	-0.288	-0.429	-0.377	0.181	0.284	0.160	**0.916****	0.416	0.317	0.433	0.156	-0.372	1
Spring	T	pH	DO	EC	BOD	COD	TC	FC	FS	TSS	NH_4^+	NO_3^-	OP	TP
T	1													
pH	**0.948****	1												
DO	**0.938****	**0.954****	1											
EC	0.448	0.658	0.613	1										
BOD	-0.007	0.095	0.139	0.604	1									
COD	0.283	0.220	0.349	0.068	0.227	1								
TC	0.156	0.225	0.186	0.545	**0.823***	0.511	1							
FC	0.098	0.297	0.256	0.688	**0.770***	0.364	**0.816***	1						
FS	0.189	0.202	0.166	0.451	**0.777***	0.510	**0.979****	0.686	1					
TSS	0.218	0.254	0.313	0.329	-0.158	0.300	0.012	0.109	-0.031	1				
NH_4^+	-0.193	-0.211	-0.460	-0.320	-0.433	-0.589	-0.205	-0.284	-0.154	-0.188	1			
NO_3^-	0.251	0.198	0.280	0.132	-0.342	0.243	-0.176	-0.223	-0.154	**0.931****	-0.143	1		
OP	0.470	0.364	0.443	0.106	-0.171	**0.713***	0.202	-0.005	0.250	**0.750***	-0.267	**0.802***	1	
TP	0.254	0.201	0.284	0.134	-0.338	0.247	-0.171	-0.218	-0.149	**0.932****	-0.145	**0.990****	**0.804***	1

polluted by livestock defecation. Moreover, the leaching of soil contaminated by animal excreta and domestic sewage contribute to high levels of TC and FC in surface waters [Raji et al., 2015]. The 2nd component, representing 19.51% of the total variance, shows a positive correlation with parameters TP, OP and T and negative with EC. It defines an increasing gradient from negative to positive side of nutrient pollutants. The 3rd component, explaining 11.75% of the total variance, is positively correlated with pH values and negatively with NH_4^+ values. This component defines an increasing gradient, from negative to positive, of the alkalinity of the waters. The positive loading for pH is attributed to the consumption of CO_2 by autotrophic organisms during their photosynthetic activity. The 4th component, representing 11.26% of the total variance, is positively correlated with the variables TSS and NO_3^-. This axis indicates an increasing load from the negative to the positive side of nitrogenous organic matter. Indeed, the increase in nutrient content in the water is responsible for the growth of phytoplankton. Thus, this component represents organic pollution and eutrophication of the lake waters associated with wastewater discharge. The 5th component, explaining 8.48% of the total variance, is positively correlated with COD levels. This parameter reflects an increasing load of oxidizable matter in the water from the negative to the positive side of the axis.

Table 4. Correlation coefficients between variables and components, Eigen values, % of the variance, and cumulative % of the variance

Parameters	Components				
	1	2	3	4	5
FC	**0.945**	-0.012	-0.192	-0.031	-0.030
TC	**0.944**	0.112	0.090	-0.046	0.083
FS	**0.939**	-0.003	-0.203	-0.046	-0.044
BOD	**0.754**	0.157	0.296	-0.095	0.172
TP	0.015	**0.960**	-0.003	0.139	-0.026
OP	0.076	**0.774**	0.062	-0.059	0.108
EC	0.222	**-0.544**	0.194	0.235	0.399
T	0.324	**0.524**	0.431	-0.212	0.021
DO	**-0.454**	-0.516	0.359	0.137	-0.247
pH	-0.147	-0.129	**0.783**	0.135	0.149
NH_4	-0.036	-0.116	**-0.683**	-0.103	0.376
TSS	-0.019	0.073	0.109	**0.961**	-0.031
NO_3	-0.289	-0.540	0.132	**0.682**	-0.037
COD	0.051	0.092	-0.074	-0.052	**0.866**
Eigen values	4.371	2.396	1.826	1.163	1.095
% of variance	26.500	19.515	11.750	11.259	69.024
Cumulative %	26.500	46.015	57.765	69.024	77.506

Station projection in F1 and F2 plane

According to axis 1, the stations located in the positive part have high TC, FC, FS and BOD concentrations. The Stations S4 “SU” and S2 “SP” are an example and have a high bacterial load. S4 is influenced by discharges from Rho River, wastewater discharges from the local village, and leaching from agricultural fields. The fecal charge, recorded in S2, is associated with agricultural runoff and its proximity to a meadow, and contamination by the excrement of animals grazing in this area. The stations, located in the negative part of axis 1, have low TC, FC, FS, and BOD values. Stations located in the center of the lake and far away from wastewater collection areas and water samples from the cold seasons (autumn and winter) have a low bacterial load. According to axis 2, stations such as S1 “SU”, S4 “SP”, S5 “SU”, S7 “SU” and S8 “SU”, located in the positive part of the axis, have high TP, OP, and T values and low EC values, while cold season stations such as S2 “WI”, S3 “WI” and S5 “WI, located in the negative part of this axis, have low TP, OP and T values and high EC values. Thus, relative to both axis 1 and 2, the proliferation of fecal bacteria is accompanied by high values of BOD, and EC and low values of TP, OP, OD, and T (Figure 2).

Station projection in F1 and F3 plane

According to axis 3, stations such as S1 “SU”, S1 “SP”, S2 “SP” and S5 “SP”, located on the positive side of this axis, have high pH and low NH_4^+ values whereas stations such as S7 “WI”, S8 “SU” and S8 “WI”, located on the negative side, have low pH and high NH_4^+ values. In alkaline waters pH ≥ 8, ammonium ions react with hydroxide ions and produce ammonia NH_3, a gas harmful to aquatic species. Relative to both axis 1 and 3, the growth of fecal bacteria is associated with high NH_4^+ and low pH values.

Station projection in F1 and F4 plane

According to axis 4, stations such as S1 “WI”, S3 “AU” and S4 “SP”, located on the positive side of the axis, have high TSS and NO_3^- concentrations while those located on the negative side, the case of S6 “SU” and S7 “SU” have low TSS and

NO_3^- values. The stations S2 "SP", S1 "SU" and S4 "SU", with a high bacterial load, have moderate values of TSS and NO_3^-. Therefore, for both axis 1 and 4, the conditions that accompany high levels of fecal bacteria are intermediate values of TSS and NO_3^- (Figure 3).

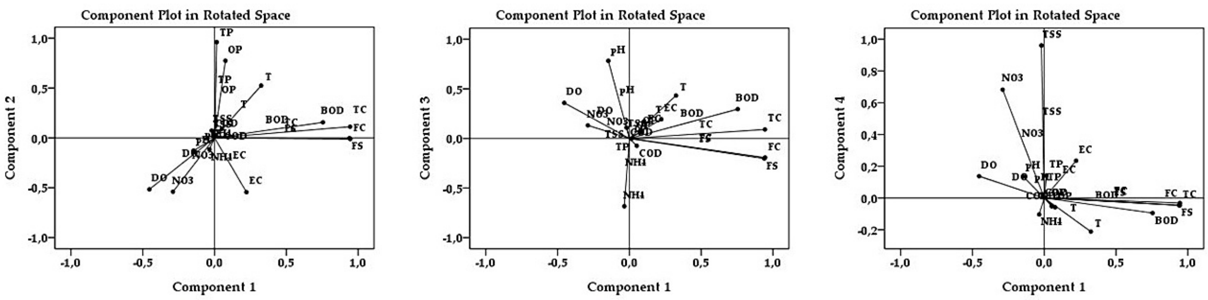
Finally, the PCA revealed organic pollution of the water due to domestic wastewater discharges and agricultural land leaching. In addition, the water samples taken during the cold season (autumn and winter) show a low bacterial load. In the stations with a high fecal load (S4 "SU"), the growth of bacteria is associated with high values of BOD, EC, and NH_4^+, TSS and NO_3^- moderate values, and low values of pH, DO, T, TP, and OP.

Hierarchical analysis

Hierarchical analysis was performed in this study on the normalized data using Ward's method, using squared Euclidean distances as a measure of similarity (Figure 4). The microbiological quality index MQI and the biodegradability index COD/BOD were applied to rank the station clusters obtained from the hierarchical analysis.

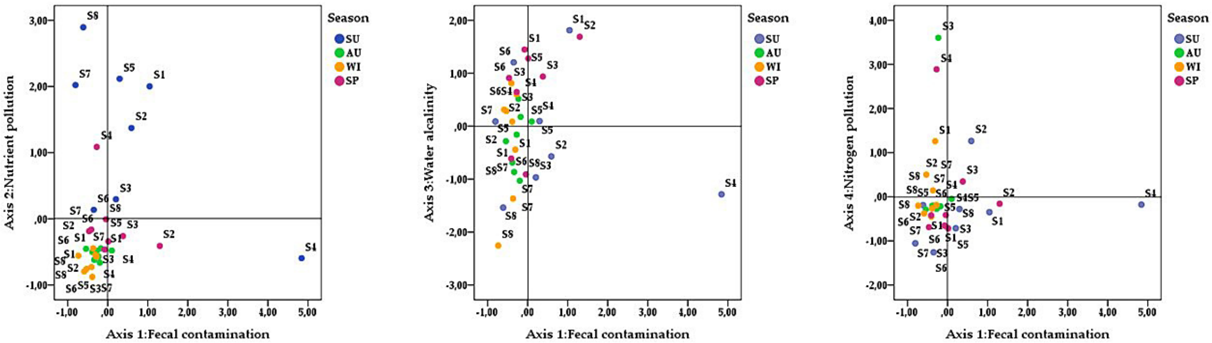
The sampling stations were divided into 3 clusters. Cluster 1, including S4 "SU", is considered the most polluted cluster recording an MQI of 2.67, and these pollutants are moderately biodegradable (its COD/BOD ratio is less than 2.5). This station is located in the southwestern sector of the lake. It receives discharges from Rho River, wastewater discharges from the local village, and leaching from agricultural fields polluted by livestock defecation. Its FC/FS report showed animal fecal contamination.

Cluster 2 included stations S1 "SU", S2 "SU", S3 "SU", S5 "SU", S7 "SU" and S8 "SU". The MQI value ranged from 3.33 to 5 and classified the waters as not to moderate polluted. The biodegradability index ranges from 1.37 to 12 indicating that these waters contain easily to poorly biodegradable oxidizable materials. The water quality of S1 "SU" is influenced by the recreational activities of visitors to the lake at this time of year. Its COD/BOD ratio is less than 1.5, showing it collects domestic sewage charged with easily biodegradable materials such as food waste and feces. Stations S2 "SU", S3 "SU" and S5 "SU", located on the shore of the lake, have an MQI of 3.67, thus classifying these waters as slightly polluted. In addition, the oxidizable substances are poorly to hardly biodegradable. Samples from the autumn, winter and spring seasons and the S6 "SU" constitute cluster



2a 2b 2c

Figure 2. Individual plots in the C1xC2 (2a), C1xC3 (2b), and C1xC4 (2c) planes



3a 3b 3c

Figure 3. Variable plots in the C1xC2 (3a), C1xC3 (3b), and C1xC4 (3c) planes

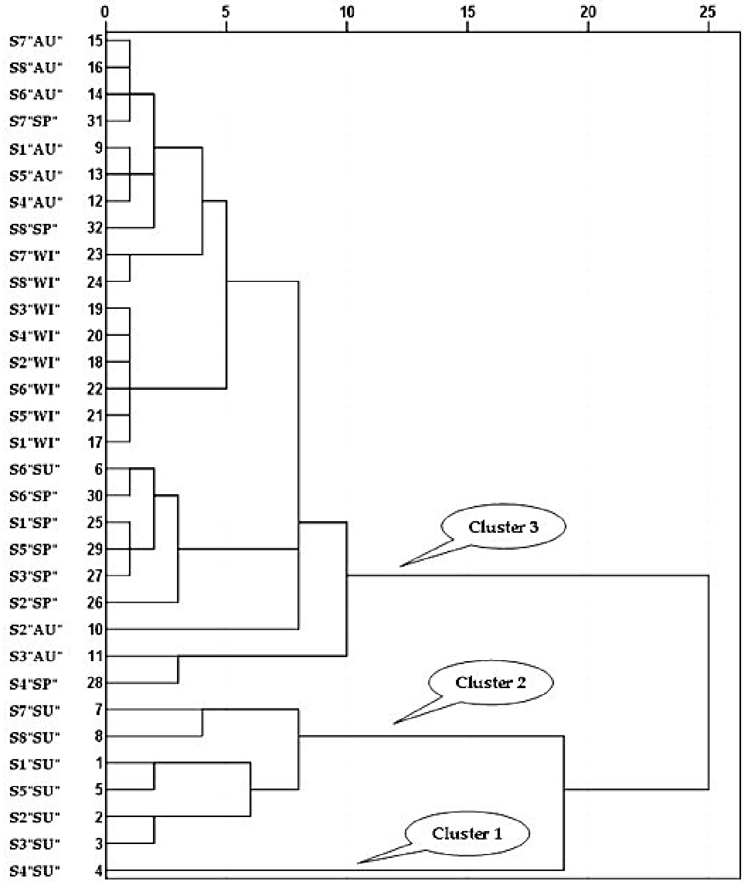


Figure 4. Cluster analysis dendrogram for the 32 samples from Dayat Roumi Lake

3. The MQI values range from 3.67 to 5, placing these waters in the non-polluted to slightly polluted categories. The biodegradability index values range from 1.2 to 21.6 and indicate that the waters are loaded with easily to poorly biodegradable oxidizable materials. The bacterial contamination of S4 "AU" is due to domestic wastewater from the local village and runoff from agricultural land. Its FC/FS ratio indicates fecal pollution of animal origin. Station S2 "SP" showed an MQI of 3.67 classifying this water as low pollution. Its FC/FS ratio indicates animal fecal pollution related with its proximity to a meadow and its contamination by the excrement of animals grazing in this area. The results of the COD/BOD ratio of stations S1 "SP", S2 "SP", S3 "SP", S5 "SP", S3 "WI", S4 "WI", and S5 "WI" show that these waters are loaded with the moderately biodegradable oxidizable matter. They result from domestic sewage, discharges from lake visitors, and livestock waste. The low biodegradability, characterized by a high COD/BOD ratio, recorded in the other stations can be attributed to high levels of oxidizable inorganic pollutants (metals, plant protection products) originating from agricultural land leaching.

CONCLUSIONS

Based on the above results, it is concluded that the lake waters are contaminated by organic matter. Fecal bacteria levels are higher in the summer period and on the edges of the lake (S1, S2, S3, S4, and S5). Indeed, in the hot season, this fecal contamination, leads to increased consumption of DO, explaining the fish death in this period of year. The EC values are quite high, indicating the richness of the water in mineral salts caused by the leaching of the soil by rainwater and wastewater. Moreover, the high level of mineral salts in the water can explain the proliferation of macrophytes on the lakeshore following the increase in photosynthetic activity in spring (positive correlation between pH, DO, and T). The principal component analysis revealed that the lake water is contaminated by domestic sewage, agricultural runoff, household waste, and human and animal excrement. The PCA also revealed that at stations with high fecal load, bacterial growth is accompanied by high values of BOD, EC, and NH_4^+, moderate values of TSS and NO_3^- and low values of pH, DO, T, TP and OP. The hierarchical analysis based on the PCA results grouped the sampling stations of similar quality into three different classes. The MQI classified the lake waters into four categories unpolluted, slightly polluted, moderately polluted, and heavily polluted. Station 4 was qualified as the most polluted group. It receives wastewater from the local village and leachate from agricultural land via the Rho River, which requires continuous monitoring of the River discharge. Results of the DOC/BOD ratio showed a spatial and temporal heterogeneity of the biodegradability of oxidizable matter in the lake water. Thus, measures must be taken to reduce the discharge of wastewater and domestic waste into this water body and to provide fish species with a suitable living environment.

REFERENCES

1. AFNOR, 1985. Essais des eaux - Recherche et dénombrement des coliformes et des coliformes thermotolérants - Méthode générale par filtration sur membrane, NF T90-414. Available: https://www.boutique.afnor.org/norme/nf-t90-414/essais-des-eaux-recherche-et-denombrement-des-coliformes-et-des-coliformes-thermotolerants-methode-generale-par-filtration-sur m/article/863604/fa033276
2. Al-Afify A.D.G., Tahoun U.M., Abdo M.H., 2018. Water Quality Index and Microbial Assessment of Lake Qarun, El-Batts and El-Wadi Drains, Fayoum Province, Egypt. Egyptian Journal of Aquatic Biology and Fisheries, 23(1), 341-357.
3. Ayenuddin Haque Md., Abu Sayed Jewel Md., Papia Sultana Mst., 2018. Assessment of physicochemical and bacteriological parameters in surface water of Padma River, Bangladesh. Applied Water Science, 9(1), 10.
4. Bovesse M., Depelchin A., 1980. Cartographie de la pollution des cours d'eau de la province de Namur: analyses bactériologiques. Rapport final (1979–1980), 25p.
5. Fazlzadeh M., Sadeghi H., Bagheri P., Poureshg Y., Rostami R., 2015. Microbial quality and physical–chemical characteristics of thermal springs. Environmental Geochemistry and Health, 38(2), 413-422.
6. Khyri M., Chahlaoui A., Samih M., 2013. Etude Bactériologique De L'eau De L'écosystème Aquatique Dayet Er Roumi (Khemisset, Maroc). ScienceLib Editions Mersenne, 5 (131111).
7. Loucifa K., Neffar S., Menasria T., Maazi M.C., Houhamdi M., Chenchounid H., 2020. Physicochemical and bacteriological quality assessment of surface water at Lake Tonga in Algeria. Environmental Nanotechnology, Monitoring & Management, 13, 100284.
8. Lutz S.R., Mallucci S., Diamantini E., Majone B., Bellin A., Merz R., 2016. Hydroclimatic and water quality trends across three Mediterranean river basins. Science of The Total Environment, 571, 1392-1406.
9. Mouchel J.M., Lucas F.S., Moulin L., Wurtzer S., Euzen A., Haghe J.P., Rocher V., Azimi S., Servais P., 2010. Bathing Activities and Microbiological River Water Quality in the Paris Area: A Long-Term Perspective. The Seine River Basin, 90, 323-353.
10. NMQES, 2002. Norme Marocaine Qualité des Eaux. Arrêté conjoint du Ministre de l'équipement et du Ministre chargé de l'aménagement du territoire, de l'urbanisme, de l'habitat et de l'environnement n°1275-02 du Chaabane 1423 (17-10-2002) définissant la grille de qualité des eaux de surface. Bulletin Officiel Maroc, 5 décembre 2002.
11. OMS, 2006. Guidelines for drinking water quality. Volume 1. Recommendations. First addendum to 3rd edition. Geneva: World Health Organization; 2006. p. 121
12. Prescott L, Harley J, Klein D, 1996. Microbiology, 3rd edn. WCB Publishers, Chicago.
13. Raji M.I.O., Ibrahim Y.K.E., Tytler B.A., Ehinmidu J.O., 2015. Faecal Coliforms (FC) and Faecal Streptococci (FS) Ratio as Tool for Assessment of Water Contamination: A Case Study of River Sokoto, Northwestern Nigeria. The Asia Journal of Applied Microbiology, 2(3), 27-34.
14. Riveros-Pereza E., Riveros R., 2018.Water in the human body: An anesthesiologist's perspective on the connection between physicochemical properties of water and physiologic relevance. Annals of Medicine and Surgery, 26, 1-8.
15. Rodier J., Legube B., Merlet N., Coll. (2009). L'analyse de l'eau. 9éme Edition, Dunod, Paris, 1579 p.
16. Sabae Z.S., El-Sheekh M.M., Khalil A.M., El-Fattah A.W., Badr M.H., 2014. Seasonal and regional variation of physicochemical and bacteriological parameters of surface water in El-Bahr El Pherony, Menoufia, Egypt. World J Fish Marine Sci, 6(4), 328–335.
17. Silva A.M., Vieira H., Martins N., Granja A.T.S., Vale M.J., Vale F.F., 2010. Viral and bacterial contamination in recreational waters: a case study in the Lisbon bay area. Journal of Applied Microbiology, 108(3), 1023-1031.
18. Zaghloul A., Saber M., Gadow S. and Awad F., 2020. Biological indicators for pollution detection in terrestrial and aquatic ecosystems. Bulletin of the National Research Centre, 44(1), 127.