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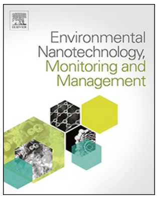

Physico-chemical and bacteriological quality assessment of surface water at Lake Tonga in Algeria

Karim Loucif[a,b,c], Souad Neffar[d], Taha Menasria[e], Mohamed Cherif Maazi[b], Moussa Houhamdi[c], Haroun Chenchouni[d,f,*]

[a] Department of Veterinary Sciences, University of Chadli Bendjedid, 36000 El Tarf, Algeria
[b] Department of Biology, Faculty of Natural and Life Sciences, University of Souk-Ahras, 41000 Souk-Ahras, Algeria
[c] Laboratoire Biologie, Eau et Environnement (LBEE), Faculté SNV–STU, Université 8 Mai 1945 Guelma. BP. 401, 24000, Guelma, Algeria
[d] Department of Natural and Life Sciences, Faculty of Exact Sciences and Natural and Life Sciences, Larbi Tebessi University, Tebessa, 12002, Algeria
[e] Department of Applied Biology, Faculty of Exact Sciences and Natural and Life Sciences, Larbi Tebessi University, Tebessa, 12002, Algeria
[f] Laboratory of Natural Resources and Management of Sensitive Environments 'RNAMS', University of Oum-El-Bouaghi, 04000, Oum-El-Bouaghi, Algeria

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ABSTRACT

Maintaining standard water quality of aquatic ecosystems requires continuous monitoring of water physicochemical and bacteriological characteristics. This study aimed at assessing water physicochemical and microbiological proprieties of Lake Tonga (northeastern Algeria). Water samples were collected monthly (January–June) from three different stations at different depths. Several physicochemical parameters (pH, electrical conductivity, turbidity, hardness, biological oxygen demand (BOD_5), concentrations of suspended solid materials, dry residuals, dissolved oxygen, phosphate, nitrites, nitrates, ammonium, calcium, magnesium, chloride, potassium and sulfur dioxide) and bacterial group sdensity (total heterotrophic bacteria, total coliforms, faecal coliforms and faecal Streptococci) were measured. Physicochemical analysis of Tonga Lake water revealed a slightly alkaline environment pH ($6.5 < pH < 8.5$), electrical conductivity < 1500 µS/cm, turbidity > 7.02 NTU, dry residues < 2000 mg/L, suspended solid materials (11.8 mg/L, < 30 mg/L), dissolved oxygen < 5 mg/L, phosphates > 5 mg/L, $BOD_5 < 5$ mg/L, nitrate < 50 mg/L, nitrite > 0.1 mg/L, and $NH_4^+ > 0.5$ mg/L, $Ca^{2+} < 200$ mg/L, $Mg^{2+} < 150$ mg/L, $Cl^- > 500$ mg/L, $K^+ > 20$ mg/L and sulfates < 200 mg/L. In addition, microbiological results indicated the presence of different groups of faecal bacteria with an average of 32.3×10^3 CFU/100 mL for total heterotrophic bacteria, 24×10^3 CFU/100 mL for total and faecal coliforms, and 37×10^3 CFU/100 mL for faecal Streptococci. Tonga Lake is currently in an eutrophication state and further severe ecosystem degradations may occur if the appropriate management measures are not taken in short term.

1. Introduction

Water covers about 71% of the earth surface in the form of rivers, lakes, seas, oceans, glaciers and ice caps. Due to different anthropogenic activities, most aquatic ecosystems (rivers, lakes, streams and ponds) are of poor quality because such types of waterbodies receive untreated wastewater from industries, households, municipal farms, breeding farms, etc. (Mutlu et al., 2018; Kumar et al., 2018; Belhouchet et al., 2019), leading to habitat pollution and eutrophication (Wu and Yang, 2015; Fang et al., 2019). Watershed managment and land-use practices affect the lands surrounding wetland waterbody and thus determine the quality of wetlands (Chenchouni, 2007; Aliat et al., 2016).

The functioning and balance of an aquatic ecosystem depends on the physicochemical and microbiological quality of its water, which undergoes spatiotemporal variations controlled mainly by anthropogenic activities and/or climatic conditions (Palamuleni and Akoth,

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Abbreviation: AIC, Akaike information criterion; ANOVA, analysis of variance; BOD_5, 5-day biological oxygen demand; CFU, colony-forming units; DO, dissolved oxygen; Dry.res, dry residues; EC, electrical conductivity; FC, faecal coliforms; FS, faecal Streptococci; THB, total heterotrophic bacteria; GLM, generalized linear model; MH, magnesium hazard; SD, standard deviation; SSM, Suspended solid material; TC, total coliforms; WHO, World Health Organization

[*] Corresponding author at: Department of Natural and Life Sciences, Faculty of Exact Sciences and Natural and Life Sciences, Larbi Tebessi University, Tebessa, 12002, Algeria.

E-mail addresses: loucifkarim9@gmail.com (K. Loucif), souad.neffar@univ-tebessa.dz (S. Neffar), tahamenasria@hotmail.com (T. Menasria), cherifmaazi@yahoo.fr (M.C. Maazi), houhamdimoussa@yahoo.fr (M. Houhamdi), chenchouni@gmail.com (H. Chenchouni).

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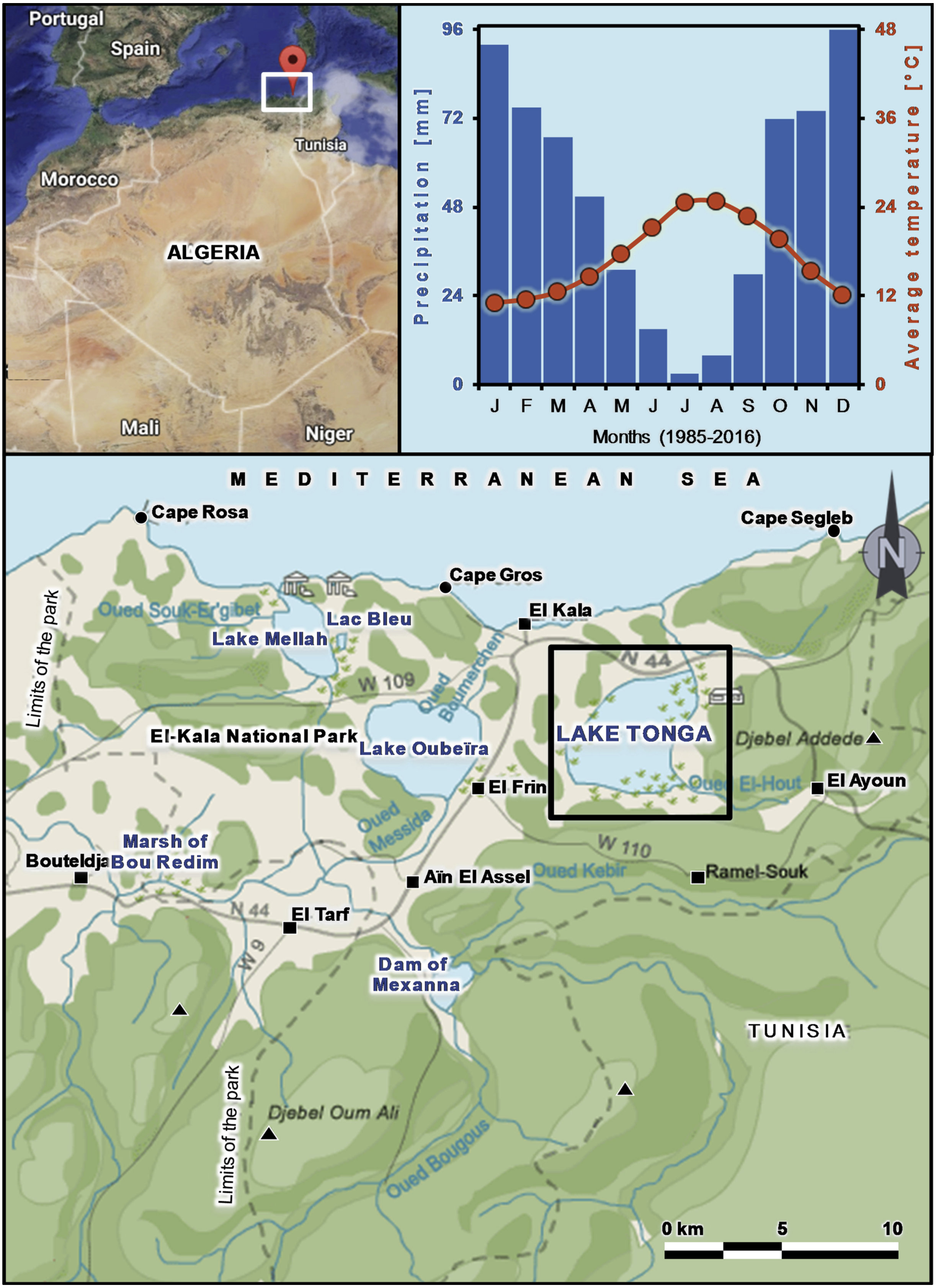

Fig. 1. Location of Lake Tonga within the Biosphere Reserve of El-Kala National Park at northeastern Algeria. The top right plot represents the ombrothermic diagram of Gaussen and Bagnouls of the region, where mean precipitation and air temperature are monthly averages of the period 1990–2012. Lake Tonga (study area) is indicated in the lower map by a solid black square.

2015; Belabed et al., 2017) or through emergent macrophytes, whose density limits the circulation of water and increases the decomposition rate of organic matter (Caraco et al., 2006). Moreover, because of their large metabolic diversity and ability to react quickly to environmental changes, bacteria are ideal indicators of surface water pollution (Kavka et al., 2006; Guemmaz et al., 2020), can act as sources and large reservoirs for faecal indicator bacteria detectable at high concentrations even in the absence of obvious faecal sources, with negative impacts on water quality (Monticelli et al., 2019), and consequently human health (Kagalou et al., 2002).

The El Kala National Park (Far Eastern Algeria) is an ecocomplex with many lakes of international importance (Ramsar sites and important bird areas) including, Lake Mellah (lagoon with salt water, 860 ha), Lake Tonga (brackish water, 2400 ha) and Lake Oubeïra (fresh water, 2200 ha) (Fig. 1). These wetlands are located on the migratory pathway of thousands of waterbirds migrating between Eurasia and Africa and represent the most important ornithological wintering sites in the Mediterranean basin (Benyacoub et al., 2011; Elafri, 2017). Tonga Lake has attracted the attention of many studies, the most recent of which have focused on vegetation (Boulemtafes and Hamel, 2018), waterbirds (Elafri, 2017), hydracarians (Bendali-Saoudi et al., 2014) and macroinvertebrates (Khedimallah and Tadjine, 2016). However, the data on the physicochemical and bacteriological properties of water of this ecosystem remain little known (Belabed et al., 2013), knowing that eutrophication in particular, accelerated by man activities may lead to the disappearance of this lake (Benyacoub et al., 2011). The main objective of this study is to determine the current status of water quality of Tonga Lake by assessing its physicochemical and microbiological proprieties. It investigates the relationships between water physicochemical variables and how these are affecting changes in bacterial loads in water. Determining water quality of lake Tonga and understanding its spatiotemporal changes is the keystone in order to take the necessary measures to preserve this ecosystem of international importance.

2. Materials and methods

2.1. Study area

The study was conducted in a shallow brackish water lake named Tonga Lake, located in northeastern of Algeria (36°51'511 N, 8°30'100 E), with total area of 2400 ha (Fig. 1). The Tonga Lake is part of the wetland complex of El Kala National Park. It has been listed as Ramsar site since 1983 and also classified as a Biosphere Reserve and an Important Bird Area 'IBA' (Fishpool and Evans, 2001). The Lake is characterized by the existence of a significant alder carr (*Alnus glutinosa*), which is a centerpiece of the site, providing an important functional role for the avifauna by harboring several bird species (Benyacoub et al., 2011; Elafri, 2017). In fact, the bird diversity of Tonga Lake is largely determined by a complex mosaic plant community across the entire site area (Bakaria et al., 2009). Based on climatic data provided by El Kala station over a period of 23 years (1990–2012), the zone is characterized by a humid climate according to the De Martonne index ($I_{DM} = 24.7$) (De Martonne, 1925), while the Emberger quotient ($Q_2 = 112.7$) indicated that the zone had a warm subhumid bioclimate. The ombrothermal diagram of Bagnouls and Gaussen delineated a dry season that extended from mid-May to mid-September (Fig. 1).

2.2. Water sampling

This study was conducted in the northern part of Tonga Lake, while the north-west part is characterized by extension of cultivated agricultural surfaces and the presence of a set of rural dwellings in full spatial expansion with an increased wastewater discharge. Three stations, located along a depth gradient, were selected for sampling water of Lake Tonga during a period of six months from January to June 2018. The gradient of depths was selected to have a representation of all depths of the lake. The maximum depth at low water is about 2.00 m (the average depth is 1.30 m). Accordingly, three stations were sampled:

- **Station 1 (depth = 97 cm):** located in the north of the lake at the southern limit of the alder trees (*Alnus glutinosa*), it represents relatively shallow and surficial water.
- **Station 2 (depth = 145 cm):** Intermediate between the first and third stations towards the center of the lake. It is characterized by free surface of water and some hydrophytic vegetation formations especially during spring and summer. Samples of this station represent moderate depths of the lake.
- **Station 3 (depth = 190 cm)**: located near the center of the lake and slightly toward the western shores, it represents deep water of the lake.

For water physicochemical analysis, water samples were collected in clean polypropylene bottles of 1.5 L capacity. Whereas, bacteriological assays were conducted on waters samples collected in sterile glass vials of 250 mL capacity. All samples were labeled and immediately transported to the laboratory at 4 °C and processed within max 6 h from collection time.

2.3. Water physicochemical analyses

Water samples were analyzed following the standard methods of water analysis (APHA, 1999; Rodier et al., 2009). Water physicochemical parameters determined *in situ* using a multiparameter analyzer included pH, electrical conductivity (EC) and dissolved oxygen (DO); turbidity (in NTU) was measured using an optic turbidimeter; suspended solid matter (SSM) and dry residues concentration were analyzed using the filtration method, and total hardness was determined by direct colorimetric titration. The measurement of the 5-day biological oxygen demand (BOD_5) was evaluated by the respirometric method, which automatically tracks the evolution of the biochemical oxygen demand during the oxidation of organic matter that was carried out using a WTW type device "Oxitop System" and the BOD_5 was expressed in mg O_2/L. Ammonium, orthophosphate, calcium, potassium, magnesium, sulfates, nitrates and nitrites concentrations were determined using ionic spectrophotometry, while the chloride concentration was determined using the flow injection method and photometric detection. Magnesium hazard index 'MH in %' $MH = [Mg^{2+}/(Ca^{2+} + Mg^{2+})] \times 100$, was used as indicator of water quality, with $MH > 50\%$ indicating bad quality (Bouaroudj et al., 2019).

2.4. Bacteriological analysis

The microbiological analyses were carried out using the standard methods (APHA, 1999; Rodier et al., 2009). Heterotrophic bacterial counts were made by the pour plate method using Plate Count Agar. Counts of total coliforms and faecal coliforms were carried out with membrane filtration method according to standard method (APHA, 1999). This method utilizes an elevated temperature incubation to distinguish faecal coliforms from the total coliforms. For faecal streptococci group, the counts were made with filter membrane on Slanetz and Bartley Agar. The results were expressed as colonyforming units (CFU) per 100 mL of water and the reproducibility of the analysis was tested by means of triplicates.

2.5. Statistical analysis

In order to compare values of different variables (water physicochemical parameters and bacterial loads) between study sites, means ± standard deviations (SD) are computed based on monthly raw data that were considered replications per site. The spatiotemporal variation of water physicochemical parameters and bacterial load values of total heterotrophic bacteria (tagged hereafter as THB), total coliforms (tagged TC), faecal coliforms (tagged FC), and faecal Streptococci (tagged FS) between study sites and months were tested using two-way ANOVA at a significance level $P \leq 0.05$. When ANOVA test is significant ($P \leq 0.05$), Tukey's post hoc test was applied to distinguish heterogeneous site groups. Interrelationships between water physicochemical parameters were analyzed using Pearson's correlation tests. Using the R package "corrplot" (Taiyun and Viliam 2016), the obtained correlation matrix was visualized in a single plot, in which correlation coefficients (r) and P-values were included. Because the growth of one bacterial group can either reduce or inhibit the growth of other bacteria as it changes water characteristics (Hiraishi et al., 1984), inter-relationships between densities of bacterial groups (THB, TC, FC and FS) were investigated using linear regressions and correlation tests. The effects of measured water physicochemical parameters on the variation of bacterial loads of each of the four bacteria groups were tested using generalized linear model (GLM). Bacterial load data were fitted to a Poisson distribution error and log link function. For each group of bacteria, the initial full model included the effects of all water parameters on the the variation bacterial loads. Then a simplified model was obtained using 'backward/forward' stepwise selection procedure based on Akaike information criterion (AIC). The final model selected had the lowest AIC value. The free statistical software R (R Core Team, 2019) was used to conduct all statistical analyses of the current study.

3. Results

3.1. Spatiotemporal patterns of water physicochemical parameters

Spatial and monthly values (means ± SD) of water physicochemical parameters sampled at Tonga Lake are presented in Fig. 2 and Table 1.

Lake Station 1 (S1) has an average pH of 7.2 ± 0.2 (range: 7.02–7.66), turbidity of 9.6 ± 1.5 NTU (range: 8.62–12.33), DO content of 0.70 ± 0.15 mg/L (range: 0.42–0.86), an EC of 1747.3 ± 595.9 µS/cm (range: 1024–2354) and SSM of 12.2 ± 0.6 mg/L (range: 11.45–13). Dry residues averaged 1183.6 ± 83.2 mg/L (range: 1087.7–1324.6), with an NO_3^- content of 17.5 ± 8.8 mg/L (range: 9.77–33), NO_2^- of 0.89 ± 0.22 mg/L (range: 0.55–1.20), NH_4^+ of 2.25 ± 1.21 mg/L (range: 1.20–4.50), PO_4^{3-} of 3.2 ± 2.6 mg/L (range: 1.30–6.66), Ca^{2+}: 82.0 ± 3.9 mg/L (range: 78.02–86.77), Mg^{2+} of 111.8 ± 70.9 mg/L (range: 39.87–192.25), MH: 52.6 ± 16.9% (range: 31.5–71), Cl^- of 688.7 ± 565.9 mg/L (range: 182–1425), K^+: 71.7 ± 16.1 mg/L (range: 51–8), SO_2^{2-}: 144.0 ± 34.9 mg/L (range: 110–210), BOD_5 of 3.8 ± 0.4 mg O_2/L (range: 3.3–4.3) and hardness: 59.9 ± 6.6 °F (range: 54.66–68.66) (Fig. 2).

At the second lake station (S2), the water recorded the following values: pH of 7.1 ± 0.1 (range: 7.03–7.21), mean turbidity of 8.2 ± 0.9 NTU (range: 7.02–8.96), DO: 0.63 ± 0.09 mg/L (range: 0.53–0.77), an EC of 1207.6 ± 58.3 µS/cm (range: 1132.55–1266.74), SSM of 11.8 ± 0.8 mg/L (range: 10.52–12.33), dry residues of 1198.6 ± 57.5 mg/L (range: 1113.4–1238.4), NO_3^- of 13.3 ± 0.6 mg/L (range: 12.22–14.01), NO_2^- of 0.83 ± 0.39 mg/L (range: 0.33–1.52), NH_4^+ of 3.08 ± 0.46 mg/L (range: 2.40–3.50), PO_4^{3-}: 7.2 ± 0.9 mg/L (range: 6.30–8.66), Ca^{2+} of 77.9 ± 11.1 mg/L (range: 56.88–87.52), Mg^{2+} of 99.8 ± 66.1 mg/L (range: 46.25–193.33), MH of 52.0 ± 14.1% (range: 36.86–71.09), Cl^-: 561.8 ± 447.9 mg/L (range: 154–1021), K^+: 81.3 ± 3.7 mg/L (range: 78–88), SO_2^{2-}: 144.0 ± 46.1 mg/L (range: 102–220), BOD_5: 4.6 ± 0.8 mg O_2/L (range: 3.5–5.3) and a hardness of 54.8 ± 9.3 °F (45.55–69.75) (Fig. 2).

Finally, the values of water parameters characterizing the third station (S3) were: pH: 7.3 ± 0.3 (range: 7.05–7.66), turbidity: 10.9 ± 0.8 NTU (range: 10.22–12.34), DO: 0.76 ± 0.08 mg/L (range: 0.60–0.82), EC: 1184.4 ± 78.4 µS/cm (range: 1064.22–1266.89), SSM: 11.4 ± 0.5 mg/L (range: 10.66–12.03), dry residues: 1119.2 ± 39.6 mg/L (range: 1082.7–1175.7), NO_3^-: 12.4 ± 1.1 mg/L (range: 11.38–14.33), NO_2^-: 0.74 ± 0.05 mg/L (range: 0.67–0.81), NH_4^+: 2.53 ± 0.26 mg/L (range: 2.33–3.02), PO_4^{3-}: 7.0 ± 0.2 mg/L (range: 6.84–7.24), Ca^{2+}: 67.3 ± 6.6 mg/L (range: 60.54–75.55), Mg^{2+}: 109.8 ± 36.1 mg/L (range: 84.65–165.55), MH: 61.0 ± 5.7% (range: 55–69.92), Cl^-: 591.7 ± 371.3 mg/L (range: 185–998), K^+: 81.5 ± 2.6 mg/L (range: 78–85), SO_2^{2-}: 158.2 ± 26.3 mg/L (range: 133–194), BOD_5: 4.6 ± 0.8 mg O_2/L (range: 3.5–5.3) and hardness: 60.3 ± 6.5 °F (range: 54.33–68.22) (Fig. 2).

Despite the temporal variations observed in the physicochemical parameters of the lake, the difference remains statistically non-significant ($P > 0.05$), except for chlorides ($P < 0.001$), dry residues ($P = 0.029$) and organic matter content ($P = 0.017$) (Table 1). On the other hand, the factor station affected only the following parameters: turbidity ($P = 0.002$), EC ($P = 0.021$), dry residues ($P = 0.025$), PO_4^{3-} ($P = 0.003$), Ca^{2+} ($P = 0.0143$) and BOD_5 ($P = 0.013$). The combined effect (Station + Month) was exclusively observed on dry residues ($P = 0.017$), PO_4^{3-} ($P = 0.042$), Cl^- ($P < 0.001$) and BOD_5 ($P = 0.009$) (Table 2).

3.2. Relationships between water physicochemical parameters

The relationships between the physicochemical parameters of Tonga Lake water revealed many significant positive and negative correlations at the $P \leq 0.05$, $P < 0.01$ and $P < 0.001$ levels (Fig. 3). Positive correlations included the following pairs: pH—NO_3^- ($P = 0.015$); pH—Cl^- ($P = 0.024$), EC—SSM ($P = 0.009$), EC—dry residues ($P = 0.026$), EC—NO_3^- ($P = 0.001$), EC—Cl^- ($P = 0.019$), SSM—dry residues ($P = 0.022$), SSM—Cl^- ($P = 0.019$), dry residues—NO_3^- ($P = 0.042$), dry residues—Cl^- ($P = 0.002$), NO_3^-—Mg^{2+} ($P = 0.043$), NO_3^-—Cl^- ($P = 0.002$), PO_4^{3-}—K^+($P = 0.000$), Mg^{2+}—MH ($P < 0.001$), Mg^{2+}—SO_2^{2-} ($P = 0.009$), Mg^{2+}—hardness ($P < 0.001$), MH—hardness ($P = 0.002$), MH—SO_2^{2-} ($P = 0.017$) and SO_2^{2-}—hardness ($P < 0.001$). In contrast, the negative correlations affected: Turbidity—dry residues ($P = 0.002$), Turbidity—NH_4^+ ($P = 0.024$), DO—dry residues ($P = 0.043$), Ca^{2+}—BOD_5 ($P = 0.033$), Mg^{2+}—BOD_5 ($P = 0.010$) and BOD_5—hardness ($P = 0.019$) (Fig. 3).

3.3. Spatiotemporal variations of bacterial load

The variations of the bacterial load in the studied Lake are showed in Fig. 4. The first station (S1) contains a total heterotrophic bacteria load of 276.2 × 10^3 ± 59.9 × 10^3 CFU/100 mL (Range: 230 × 10^3–368 × 10^3), in total coliforms: 248.3 × 10^3 ± 55.6 × 10^3 CFU/100 mL (Range: 210 × 10^3–320 × 10^3), faecal coliforms 198.3 × 10^3 ± 67.1 × 10^3 CFU/100 mL (Range: 120 × 10^3–280 × 10^3) and in faecal streptococci: 28.2 × 10^3 ± 7.6 × 10^3 CFU/100 mL (Range: 21 × 10^3–38 × 10^3). The second station (S2) revealed a total microbial load of 347.7 × 10^3 ± 97.1 × 10^3 CFU/100 mL (Range: 251 × 10^3–455 × 10^3); TC: 263.3 × 10^3 ± 54.3 × 10^3 CFU/100 mL (Range: 210 × 10^3–320 × 10^3); FC: 231.3 × 10^3 ± 44.4 × 10^3 CFU/100 mL (Range: 188 × 10^3–290 × 10^3) and of FS: 39.8 × 10^3 ± 5.19 × 10^3 CFU/100 mL (Range: 33 × 10^3–45 × 10^3). The third station (S3) was characterized by a bacterial load of 347.7 × 10^3 ± 127 × 10^3 CFU/100 mL (Range: 215 × 10^3–489 × 10^3), of TC: 231.8 × 10^3 ± 90.5 × 10^3 CFU/100 mL (Range: 140–368), FC: 185 × 10^3 ± 63.5 × 10^3 CFU/100 mL (Range: 110 × 10^3–260 × 10^3) and FS: 44.7 × 10^3 ± 1.8 × 10^3 CFU/100 mL (Range: 42 × 10^3–47 × 10^3) (Fig. 4).

As for the temporal variation (Fig. 4), despite the monthly fluctuations between different groups of bacteria, the minimums are recorded in January and the maximums in May or June. For total heterotrophic bacteria: 241.3 × 10^3 ± 25.1 × 10^3 CFU/100 mL in January (Range: 215 × 10^3–265 × 10^3), and 426.7 × 10^3 ± 80.3 × 10^3 CFU/100 mL in May (Range: 368 × 10^3–447 × 10^3). TC showed minimal load in January with 189 × 10^3 ± 38.1 × 10^3CFU/100 mL (Range: 145 × 10^3–212 × 10^3) and a maximum in May with 312 × 10^3 ± 6.9 × 10^3 CFU/100 mL (Range: 308 × 10^3–320 × 10^3). The FC revealed a minimum in February: 160 × 10^3 ± 43.6 × 10^3 CFU/100 mL (Range:

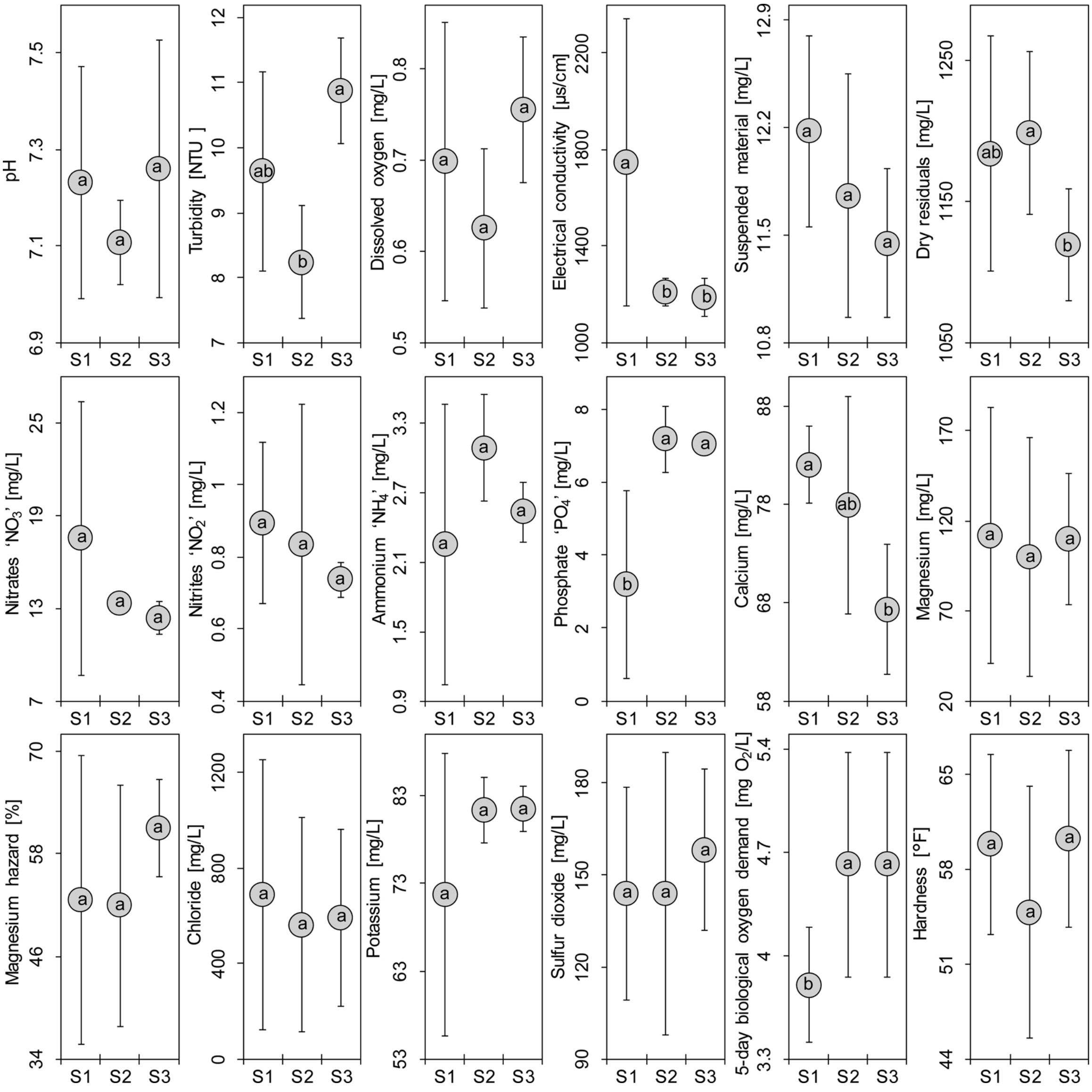

Fig. 2. Spatial variation of the physicochemical parameters of water collected at a depth gradient in Lake Tonga water, northeastern Algeria. The values displayed are the mean (solid grey circle) ± standard deviation (vertical bars). (S1: shallow water near shore, S2: intermediate sampling site between S1 and S3, S3: deep water near lake center).

110 × 10^3–190 × 10^3), and a maximum in May: 270 × 10^3 ± 10 × 10^3 CFU/100 mL (Range: 260 × 10^3–280 × 10^3). Finally, the minimum load of the FS is observed in January with 36.7 × 10^3 ± 10.2 × 10^3 CFU/100 mL (Range: 25 × 10^3–44 × 10^3) and a maximum in May 38 × 10^3 ± 4 × 10^3 CFU/100 mL (Range: 34 × 10^3–42 × 10^3) and in June 38 × 10^3 ± 5.6 × 10^3 CFU/100 mL (Range: 33 × 10^3–44 × 10^3). However, a part of FS which present a significant effect of site factor ($P = 0.004$), ANOVAs revealed a non–significant site effect on other tested groups ($P > 0.05$) (Table 3). In addition, a significant time effect is observed on the total loads ($P = 0.002$), TC ($P = 0.030$) and the FC ($P = 0.034$). The combined effect (Months + Sites) was not significant on the variation of FS and TC ($P > 0.05$), but statistically significant on changes of THB ($P = 0.003$) and FC ($P = 0.044$).

3.4. Interrelationships between bacterial groups

The growth of THB was correlated positively with TC (linear regression: THB = 1.2595 × TC + 11.6963), FC (linear regression: THB = 1.3233FC + 52.7013) and FS (linear regression: THB = (3.111 × FS) + 206.992). The density of TC was positively associated to the increase of FC and FS loads (TC = (1.0129 × FC) + 40.2954, TC = (0.5566 × FS) + 226.9313). The same is for FC, where a positive correlation was observed associated to the increase of FS (linear regression: FC = (1.122 × FS) + 162.744). The positive correlations were revealed between TC and THB ($r = 0.84$, $P < 0.001$), FC–THB ($r = 0.79$, $P < 0.001$), FCT−C ($r = 0.91$, $P < 0.001$), but non-significant ($P > 0.05$) between FS and other groups (Fig. 5).

3.5. Effects of water characteristics on bacterial loads

The GLM revealed that bacteria respond differently to the physicochemical parameters of Tonga Lake (Table 4). The decrease in pH, NH_4^+, Ca^{2+} and hardness caused a significant increase ($P < 0.001$) of THB, whereas DO, EC, SSM, dry residues, NO_3^-, NO_2^-, PO_4^{3-}, Mg^{2+}, $C1^-$, SO_2^{2-} are positively correlated ($P \leq 0.05$ and $P < 0.001$). For CT, the correlations are negatively significant with pH ($P < 0.001$), turbidity ($P = 0.004$), dry residues ($P < 0.001$), NH_4^+ ($P < 0.001$), Ca^{2+} ($P < 0.001$), BOD_5 ($P = 0.014$) and hardness ($P < 0.001$), but positively correlated ($P < 0.001$) with DO, EC, SSM, NO_3^-, NO_2^-, Mg^{2+}, $C1^-$ and SO_2^{2-}. In addition, for FC group, the increase was

Table 1

Descriptive statistics (mean ± SD and range [min–max]) of water physico-chemical parameters measured at Lake Tonga, northeastern Algeria. Subscript letter associated to means epitomize HSD Tukey tests (different letters are significantly different at $P \leq 0.05$).

Water Parameters	Months: Mean ± SD [min–max]						
	January	February	March	April	May	June	Overall
pH	7.11 ± 0.09 ^{a} [7.03–7.21]	7.15 ± 0.06 ^{a} [7.11–7.21]	7.06 ± 0.06 ^{a} [7.02–7.12]	7.07 ± 0.06 ^{a} [7.03–7.14]	7.41 ± 0.33 ^{a} [7.04–7.66]	7.4 ± 0.23 ^{a} [7.21–7.66]	7.2 ± 0.21 [7.02–7.66]
Turbidity [NTU]	10.54 ± 1.69 ^{a} [8.96–12.33]	10.62 ± 1.74 ^{a} [8.87–12.34]	9.17 ± 0.91 ^{a} [8.62–10.22]	9.37 ± 1.1 ^{a} [8.67–10.64]	8.77 ± 1.61 ^{a} [7.22–10.44]	9.04 ± 2.17 ^{a} [7.02–11.33]	9.58 ± 1.53 [7.02–12.34]
Dissolved oxygen [mg/L]	0.73 ± 0.09 ^{a} [0.63–0.78]	0.7 ± 0.06 ^{a} [0.66–0.77]	0.66 ± 0.17 ^{a} [0.53–0.86]	0.68 ± 0.14 ^{a} [0.54–0.81]	0.71 ± 0.08 ^{a} [0.62–0.77]	0.67 ± 0.22 ^{a} [0.42–0.82]	0.69 ± 0.12 [0.42–0.86]
Electrical conductivity [µs/cm]	1106 ± 109 ^{a} [1024–1230]	1097 ± 56 ^{a} [1033–1135]	1459 ± 361 ^{a} [1235–1876]	1428 ± 378 ^{a} [1177–1863]	1604 ± 632 ^{a} [1237–2334]	1584 ± 670 ^{a} [1133–2354]	1380 ± 423 [1024–2354]
Suspended material [mg/L]	11.4 ± 0.69 ^{a} [10.66–12.02]	11.23 ± 0.23 ^{a} [11–11.45]	11.7 ± 1.05 ^{a} [10.52–12.54]	12.07 ± 0.65 ^{a} [11.33–12.55]	12.04 ± 0.28 ^{a} [11.78–12.33]	12.32 ± 0.68 ^{a} [11.64–13]	11.79 ± 0.68 [10.52–13]
Dry residuals [mg/L]	1095 ± 17 ^{b} [1083–1113]	1160 ± 68 ^{ab} [1102–1235]	1121 ± 28 ^{ab} [1089–1137]	1199 ± 31 ^{ab} [1176–1234]	1207 ± 39 ^{ab} [1162–1235]	1222 ± 111 ^{a} [1104–1325]	1167 ± 69 [1083–1325]
Nitrates 'NO_3^-' [mg/L]	12.4 ± 0.8 ^{a} [11.55–13.2]	12.7 ± 0.7 ^{a} [12.22–13.44]	12.4 ± 2.4 ^{a} [9.77–14.33]	13 ± 1.4 ^{a} [11.38–14.01]	19.6 ± 11.6 ^{a} [12.09–33]	16.5 ± 5.7 ^{a} [12.66–23]	14.4 ± 5.3 [9.77–33]
Nitrites 'NO_2^-' [mg/L]	0.77 ± 0.18 ^{a} [0.66–0.97]	0.86 ± 0.16 ^{a} [0.71–1.02]	1.04 ± 0.42 ^{a} [0.74–1.52]	0.61 ± 0.24 ^{a} [0.33–0.77]	0.94 ± 0.23 ^{a} [0.77–1.2]	0.72 ± 0.14 ^{a} [0.55–0.81]	0.82 ± 0.25 [0.33–1.52]
Ammonium 'NH_4^+' [mg/L]	2.42 ± 1.16 ^{a} [1.2–3.5]	2.31 ± 1 ^{a} [1.3–3.3]	2.25 ± 0.39 ^{a} [1.8–2.54]	3.37 ± 1 ^{a} [2.6–4.5]	2.64 ± 0.57 ^{a} [2.3–3.3]	2.74 ± 0.57 ^{a} [2.4–3.4]	2.62 ± 0.8 [1.2–4.5]
Phosphate 'PO_4^{3-}' [mg/L]	5.29 ± 2.77 ^{a} [2.1–7.03]	5.5 ± 3.48 ^{a} [1.5–7.88]	5.61 ± 3.84 ^{a} [1.3–8.66]	5.05 ± 3.25 ^{a} [1.3–7]	6.76 ± 0.32 ^{a} [6.5–7.12]	6.62 ± 0.53 ^{a} [6.3–7.24]	5.81 ± 2.41 [1.3–8.66]
Calcium [mg/L]	81.8 ± 9.2 ^{a} [71.2–87.5]	77.9 ± 2.1 ^{a} [75.6–79.6]	76.6 ± 3.5 ^{a} [72.6–79.2]	67 ± 13.8 ^{a} [56.9–82.8]	77.8 ± 15 ^{a} [60.5–86.6]	73.2 ± 9.3 ^{a} [62.5–78.7]	75.7 ± 9.7 [56.9–87.5]
Magnesium [mg/L]	127 ± 75.6 ^{a} [39.9–175.6]	130.1 ± 72.5 ^{a} [51–193.3]	64.4 ± 21.9 ^{a} [46.3–88.8]	94.5 ± 40.2 ^{a} [60.2–138.8]	111.6 ± 69.8 ^{a} [57.9–190.5]	115.1 ± 67.6 ^{a} [65.9–192.3]	107.1 ± 56.3 [39.9–193.3]
Magnesium hazard [%]	56 ± 21.3 ^{a} [31.5–69.9]	58.7 ± 17.2 ^{a} [39.1–71.1]	44.9 ± 9.2 ^{a} [36.9–55]	57.4 ± 5.6 ^{a} [51.4–62.6]	55.9 ± 14.6 ^{a} [40.1–68.8]	58.3 ± 12.7 ^{a} [45.6–71]	55.2 ± 13 [31.5–71.1]
Chloride [mg/L]	174 ± 16.5 ^{b} [155–185]	198 ± 49.1 ^{b} [154–251]	233 ± 107.8 ^{b} [155–356]	899.7 ± 123 ^{a} [778–1024]	1042.3 ± 73.4 ^{a} [982–1124]	1137.3 ± 249.2 ^{a} [989–1425]	614.1 ± 443.7 [154–1425]
Potassium [mg/L]	81 ± 2.6 ^{a} [78–83]	75 ± 8.9 ^{a} [65–82]	71.7 ± 12.7 ^{a} [57–79]	71.7 ± 17.9 ^{a} [51–83]	87 ± 1.7 ^{a} [85–88]	82.7 ± 4 ^{a} [79–87]	78.2 ± 10.2 [51–88]
Sulfur dioxide [mg/L]	160.3 ± 17.9 ^{a} [145–180]	183.3 ± 38.6 ^{a} [143–220]	139.7 ± 48.2 ^{a} [102–194]	128.7 ± 7.5 ^{a} [120–133]	125.7 ± 14 ^{a} [110–137]	154.7 ± 50.2 ^{a} [112–210]	148.7 ± 35.1 [102–220]
BOD_5 [mg O_2/L]	3.6 ± 0.2 ^{b} [3.5–3.8]	4 ± 0.2 ^{ab} [3.7–4.1]	4.9 ± 0.6 ^{a} [4.2–5.3]	4.9 ± 0.5 ^{a} [4.3–5.2]	4.6 ± 1.2 ^{ab} [3.3–5.3]	4 ± 0.5 ^{ab} [3.5–4.3]	4.3 ± 0.7 [3.3–5.3]
Hardness [°F]	59.3 ± 2.6 ^{a} [56.3–61.2]	64.6 ± 7.7 ^{a} [55.8–69.8]	56 ± 11.2 ^{a} [45.6–67.9]	51.9 ± 5.4 ^{a} [45.8–55.6]	58.4 ± 9 ^{a} [51.8–68.7]	59.8 ± 7.2 ^{a} [55.2–68.1]	58.3 ± 7.6 [45.6–69.8]

Table 2

Two-way analyses of variance (ANOVA) testing the spatiotemporal variations of water physicochemical parameters of Lake Tonga, northeastern Algeria.

Variables	Model (Site + Month)			Site		Month	
	R^2	*F*	*P*-value	*F*	*P*-value	*F*	*P*-value
pH	0.631	2.44	0.097	1.42	0.287	2.85	0.075
Turbidity	0.765	4.66	0.015	11.24	0.003	2.03	0.160
DO	0.259	0.50	0.815	1.45	0.281	0.12	0.984
EC	0.652	2.68	0.077	5.76	0.022	1.45	0.288
SSM	0.549	1.74	0.207	2.27	0.154	1.52	0.268
Dry.res	0.755	4.40	0.018	5.43	0.025	3.99	0.030
NO_3^-	0.456	1.20	0.384	1.69	0.234	1.00	0.464
NO_2-	0.403	0.96	0.505	0.57	0.581	1.12	0.410
NH_4^+	0.436	1.11	0.428	1.76	0.221	0.84	0.549
PO_4^{3-}	0.699	3.31	0.043	10.31	0.004	0.52	0.759
Ca^{2+}	0.677	2.99	0.057	6.70	0.014	1.51	0.270
Mg^{2+}	0.175	0.30	0.937	0.06	0.947	0.40	0.837
MH	0.244	0.46	0.841	0.70	0.522	0.37	0.859
Cl^-	0.958	32.46	< 0.001	1.87	0.204	44.70	< 0.001
K^+	0.553	1.76	0.200	2.39	0.142	1.51	0.269
SO_2^{2-}	0.379	0.87	0.558	0.31	0.741	1.10	0.419
BOD_5	0.789	5.35	0.009	6.88	0.013	4.74	0.018
Hardness	0.385	0.89	0.545	0.91	0.432	0.89	0.524

negatively correlated with the decrease of pH, turbidity, PO_4^{3-}, Ca^{2+} ($P < 0.001$) and BOD_5 ($P = 0.004$), but no correlation was noted with SO_2^{2-} ($P = 0.157$) and hardness ($P = 0.013$). However, a positive correlation was observed between FC and EC, SSM, NO_2^-, $Mg^{2+}$and K^+ ($P < 0.001$). As shown in Table 4, the FS population increases with the increase of PO_4^{3-} concentrations ($P < 0.001$), with a non-significant correlation with turbidity ($P = 0.097$).

4. Discussion

4.1. Physicochemical proprieties of lake waters

The spatiotemporal trends of almost all the measured physicochemical parameters in the water of Tonga Lake revealed insignificant variations as well for the "Station" and "Time" factors. However, an exception was reported for turbidity, EC, dry residues, PO_4^{3-}, Calcium and BOD_5 among the sampling stations, as well as chlorides concentration, dry residues and BOD_5 for the months.

The majority of surface waters have a pH that ranges between 6.5 and 9 (Journal Officiel de la République Algérienne JORA, 2011), which due to the buffer system developed by carbonates and bicarbonates (Rodier et al., 2009). The results report that the pH of Tonga Lake is on averages of 7.2, within the range of (6.5–8.5) established by WHO (2017), reflecting a neutral to slightly alkaline environment. This allows to the development of an optimal aquaculture and supports fish life (Rodier et al., 2009; Mutlu and Uncumusaoğlu, 2016). In addition, with a slightly alkaline pH, the toxicity of heavy metals is immobilized since the acidity of the medium promotes and increases their solubility and mobility in water, respectively (Ouma et al., 2016), allowing the metals to adsorb to algae and other plants within the aquatic trophic chain (Kobielska et al., 2018).

The EC, which is a function of temperature and proportional to the

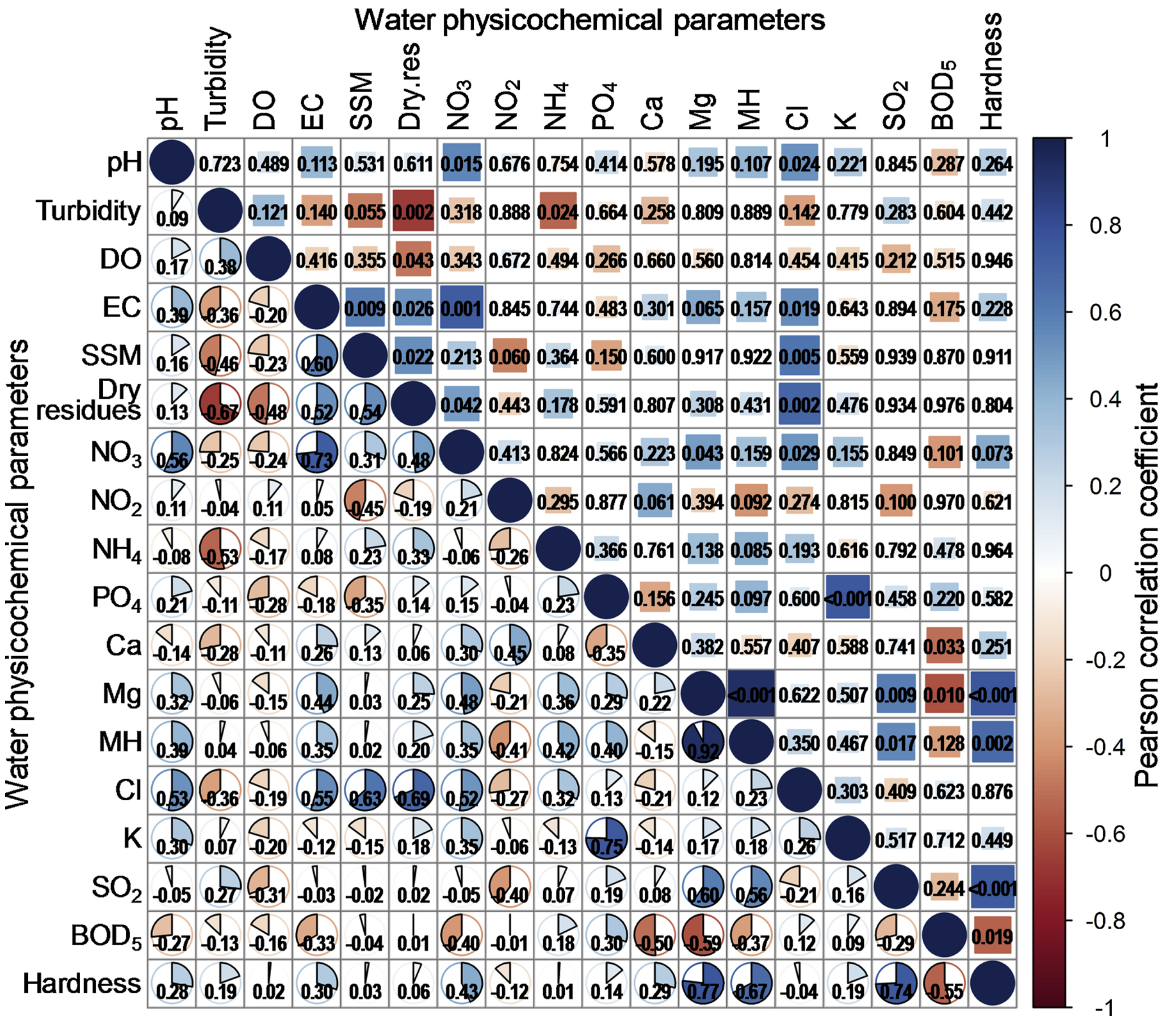

Fig. 3. Correlation matrix displaying interrelationships between physicochemical parameters of Lake Tonga water, northeastern Algeria. Pearson correlation tests are given as correlation coefficient values (below the diagonal) and the *P*-value (above the diagonal). Shading and intensity of colors in pie charts and squares visualize also Pearson coefficient values. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

mineralization (Brémaud et al., 2006), recorded an average value of 1379.46 µS/cm, which is less than 1500 µS/cm (WHO, 2017) and 2800 µS/cm (Journal Officiel de la République Algérienne JORA, 2011). However, it remains high since the range of natural water is about 50-1500 µS/cm (De Villers et al., 2005; WHO, 2017). It was reported that beyond the maximum limit (1500 µS/cm), the water condition becomes abnormal (Rodier et al., 2009). According to Irshad et al. (2011) and Ben Hida et al. (2012), this content could be attributed to the leaching of salts from agricultural soils near the study area, the dissolution of certain mineral substances from either rocks surrounding the aquifer, or the mineralization of organic substances of various origins (public dump, industries and wastewater) joining the aquifer by infiltration.

In general, the turbidity of water is associated with clay, silt, finely divided organic and inorganic matter, algae, soluble colored organic compounds, plankton and other microscopic organisms (Roohul et al. (2012), but is likely to be associated with high coliform load (US-Environmental Protection Agency (US-EPA), 2012). It reached an average value of 9.56 NTU (Range: 5–30 NTU) qualifying the water as slightly hazy (Hakmi, 2002). Overall, in surface water, this parameter varies between 10 and 50 NTU (Rodier et al., 2009). This property is even higher when the density of particles exceeds 200 NTU during heavy rainfall.

The suspended solids (clays, silts, fibrous particles, colloidal organic particles, plankton and microscopic organisms) are responsible for the turbid appearance of water, which recorded an average value of 11.80 mg/L (limits 0–30 mg/L), qualifying water of good quality according to ANRH (2003). A study conducted by Benyacoub et al. (2011), reported low SSM levels in the Tonga Lake, which was partially related to a low phytoplankton production and lack of favorable environmental conditions for their proliferation. The variations of SSM are a function of different factors viz. the nature of the crossed terrain, seasons, rainfall, flow regime of water, and nature of the discharge (Rodier et al., 2009). According to Bourrier and Selmi (2011), surface water has variable and sometimes high turbidity and SSM levels, which depends on terrain features and seasonal regimes of rainfall and discharges.

Concerning dry residues in water, the lake contains 1167.21 mg/L. This value is below the limit value, 1500 mg/L and 2000 mg/L fixed respectively by Rodier et al. (2009); WHO (2017) and (Journal Officiel de la République Algérienne JORA, 2011). Concentrations of dry residues are low when the substrata are granitic rocks or siliceous sand, but increase in the case of sedimentary rocks composed of carbonates, bicarbonates, chlorides, sulfates, phosphates, nitrates (Kumar et al., 2018). It should be noted, however, that given the scarcity of water in North Africa, the strict application of these standard values would significantly limit water supply possibilities. Moreover, many African populations consume such quality without particular noticed pathology, which is the case of Gabes in Tunisia where dry residues = 3 g/L (Rodier et al., 2009).

The dissolved oxygen is of paramount importance in surface water as it affects water self-purification and preservation of aquatic life

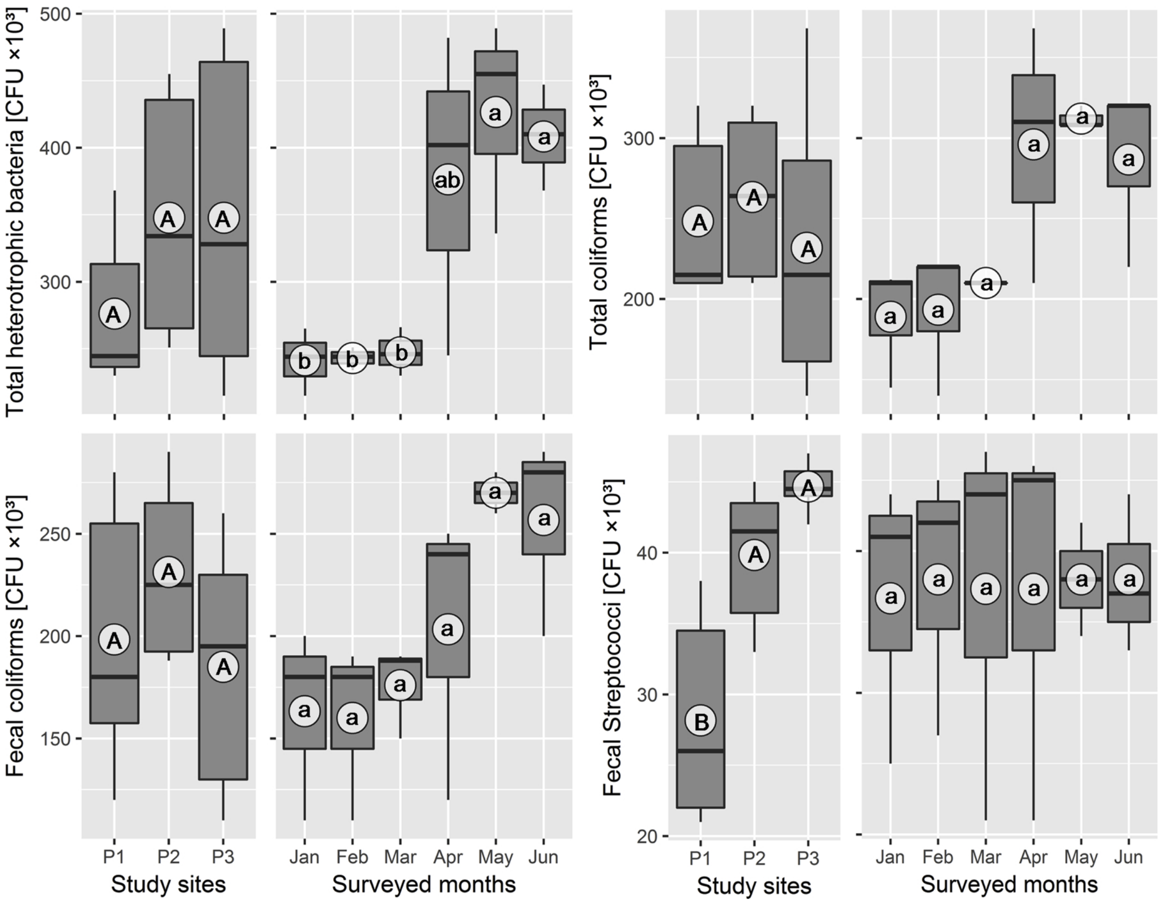

Fig. 4. Boxplots displaying the variation of bacterial loads (in CFU/100 mL) of total heterotrophic bacteria, total and faecal coliforms, and faecal Streptococci measured in along a depth water gradient at Lake Tonga in northeastern Algeria. The same letters associated with average values (white circles) are significantly not different at $P \leq 0.05$ following Tukey's post-hoc tests, which were displayed with capital and small letters for sites (P1-P3) and months, respectively.

Table 3

Two-way ANOVAs testing the effects of sites and months on the variation of water bacterial loads of total heterotrophic bacteria, total and faecal coliforms, and faecal Streptococci measured in Lake Tonga water, northeastern Algeria, along a depth gradient.

Variables	*Df*	*SS*	*MS*	*F*	*P*	*Sig.*	*SS*	*MS*	*F*	*P*	*Sig.*
		Total heterotrophic bacteria					Total coliforms				
Sites	2	20449	10225	3.83	0.058	NS	2979	1490	0.63	0.554	NS
Months	5	118991	23798	8.91	0.002	**	47425	9485	4.00	0.030	*
Model	7	139440	19920	7.46	0.003	**	50404	7201	3.03	0.055	NS
Error	10	26714	2671				23732	2373			
Total	17	166155					74137				
		Faecal coliforms					Faecal Streptococci				
Sites	2	6827	3414	1.90	0.200	NS	863.4	431.7	10.03	0.004	**
Months	5	34498	6900	3.84	0.034	*	4.4	0.9	0.02	0.999	NS
Model	7	41325	5904	3.28	0.044	*	867.9	124.0	2.88	0.063	NS
Error	10	17989	1799				430.6	43.1			
Total	17	59314					1298.4				

(*Df*: degrees of freedom, *SS*: sum squares, *MS*: mean squares, *F*: *F*-statistics, *P*: *P*-value, *Sig.*: statistical significance, **: $P < 0.01$, *: $P \leq 0.05$, ^{NS}: $P > 0.05$).

(Haritash et al., 2016; Kumar et al., 2018). In addition, seasonal and diurnal variations of DO depends on many factors such as the oxygen partial pressure of the atmosphere, water temperature, salinity, light, agitation of water, nutrient availability and other physicochemical and microbiological processes (Ouali et al., 2018). In the present study, the concentration of DO recorded was 0.69 mg/L; this value is well below the thresholds set by WHO (2017) which is of (5–8 mg/L). Low levels of DO in water indicate a state of eutrophication-driven deoxygenation in the environment, which can be attributed to an increase of algal activities (Ngodhe et al., 2013), high phosphate and ammonia concentrations (Ouma et al., 2016), or high loads of untreated wastewater discharges (Blume et al., 2010). Bourrier and Selmi (2011) argue that dissolved oxygen is absent in highly polluted waters. Besides, De Villers et al. (2005) showed that dissolved oxygen concentration less than 1 mg/L indicates a near anaerobic state, causing an increase in the solubility of toxic elements that release from sediments and promote bioaccumulation and biomagnification processes (Ouali et al., 2018).

In environments with low turnover rates such as lakes, dams, bays,

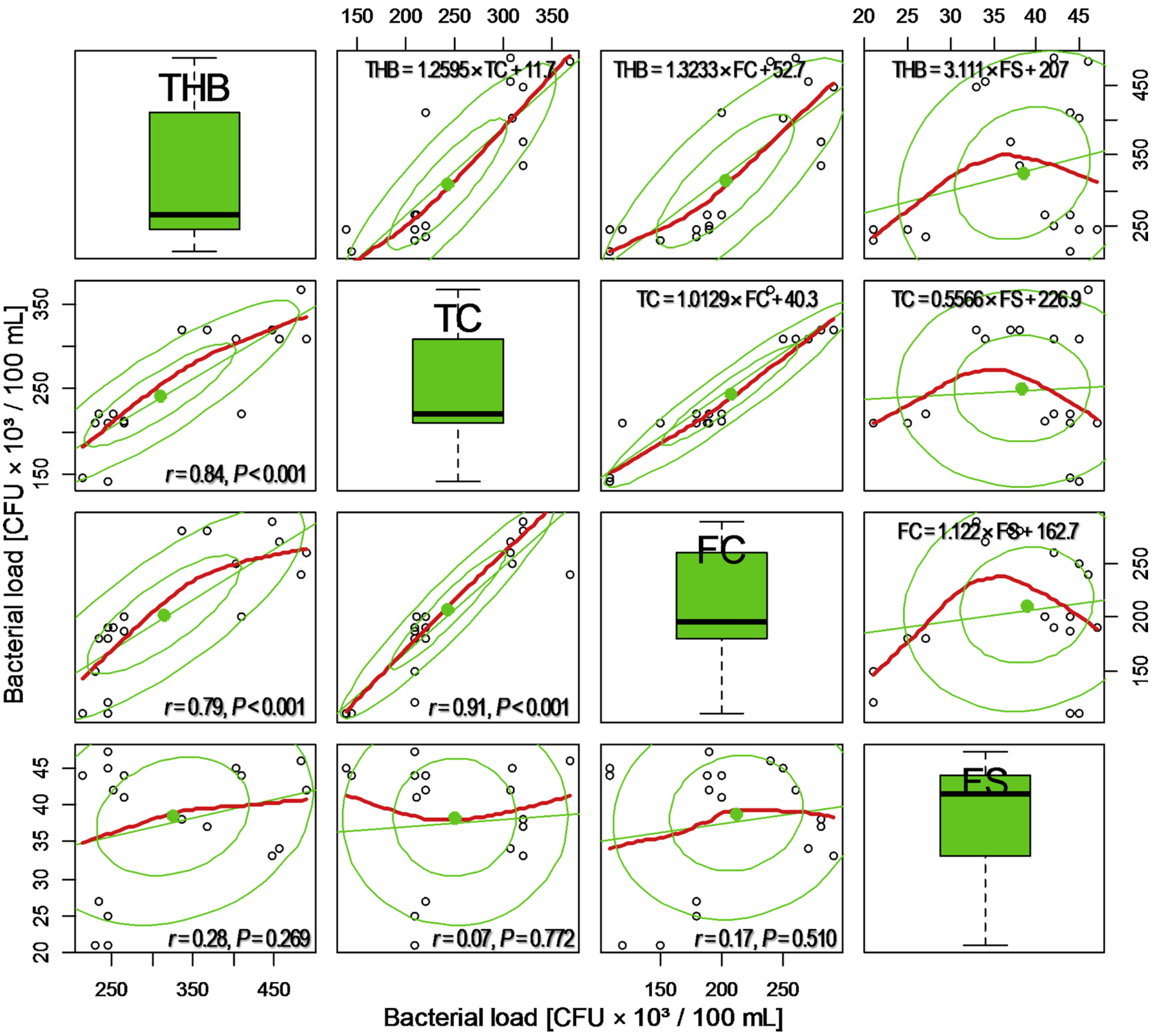

Fig. 5. Scatterplot matrix between all pairs of bacterial groups (THB: total heterotrophic bacteria, TC: total coliforms, FC: faecal coliforms, and FS: faecal Streptococci) screened in Lake Tonga water (northeastern Algeria). Red curves are LOWESS smoothers. Green lines represent linear regressions with the equations given at top of plots above the diagonal. Pearson correlation tests between bacteria density are displayed in plots below the diagonal where *r* = correlation coefficient value and *P* = *P*-value. Green ellipses represent 40% and 80% concentration levels of observations with the center in solid green circle (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

etc., the low dissolved oxygen can be explained by the absence of water–atmosphere contact and thus the absence of perpetual water renewal (Tampo et al., 2014). In the present case, the low concentration would be attributed mainly to the presence of vegetation and animal organisms present in the water, but also by a defect of mixing of the waters by the wind, in spite of the shallowness of the lake (2.8 m), due to the obstacles that constitute the helophyte vegetation Benyacoub et al. (2011).

Regarding the eutrophic substances (NO_3^-, NO_2^-, NH_4^+ and PO_4^{3-}), concentration levels vary from one substance to another; NO_3^- (14.4 mg/L) (< 50 mg/L) (WHO, 2017). Rejsek (2002) and Rodier et al. (2009) reported that in unpolluted natural waters, the variation of nitrate level depending on different factors including season and origin of the water, oscillating between 1–15 mg/L and a concentration of 2 or 3 mg/L can be considered as normal. From the standpoint of health, what is known is that nitrates are not dangerous but become toxic by the fact that they turn into nitrites and participate in the important eutrophication phenomenon of stagnant water (Rejsek, 2002). Nitrites, however, reached a level of 0.82 mg/L, exceeding the threshold established by Journal Officiel de la République Algérienne JORA, 2011 and WHO (2017) which is 0.1 mg/L. according to ANRH (2003) this water in the middle category (between 0.1–3 mg/L). De Villers et al. (2005) considered that the situation as a very critical often reflecting the presence of toxic materials, especially for young fish.

It has been reported that nitric pollution of water is due to animal waste, manure or chemical fertilizers used in the fertilization of neighboring farmland (Lagnika et al. (2014). The situation is repeated when ammonium ion concentration exceeds 0.5 mg/L (WHO, 2017) with 2.62 mg/L, a very high content, which by oxidation is transform relatively and quickly into nitrates and nitrites, thereby form an index of anthropogenic pollution (Kumar et al., 2018). According to Derwich et al. (2008), this situation generates low oxygenation and a lack of dilution in the environment. Overall and given the instability of the reactions involved in the nitrogen cycle, any interpretation turns out to be complicate Bousseboua (2002).

Similarly, the phosphate content in the lake, which with 5.81 mg/L exceeds the threshold of 5 mg/L recommended by Rodier et al. (2009) and (WHO, 2017). Its natural presence in the waters is related to the characteristics of the lands crossed and the decomposition of organic matter (Kumar et al., 2018). Therefore, a concentration beyond 0.2 mg/

Table 4

Generalized linear models (Poisson distribution and log link) testing the effects of water physicochemical parameters on the variation of bacterial loads of total heterotrophic bacteria (THB), total coliforms (TC), faecal coliforms (FC), and faecal Streptococci (FC) screened in water of Lake Tonga (northeastern Algeria). GLM parameters were selected using the 'backward/forward' stepwise procedure based on the lowest Akaike information criterion (AIC) score.

Variables	*Est.*	*SE*	*z-value*	*P*	*Sig.*
TBH	($AIC = 169.96$, $\Delta AIC = 2.42$)				
(Intercept)	8.92	1.722	5.18	< 0.001	***
pH	−2.38	0.486	−4.9	< 0.001	***
DO	2.55	0.379	6.73	< 0.001	***
EC	−0.00	0.000	−5.3	< 0.001	***
SSM	1.52	0.291	5.22	< 0.001	***
Dry.res	−0.00	0.001	−2.13	0.033	*
NO_3^-	0.03	0.012	2.8	0.005	**
NO_2^-	3.74	0.733	5.1	< 0.001	***
NH_4^+	−0.41	0.091	−4.47	< 0.001	***
PO_4^{3-}	0.05	0.011	4.34	< 0.001	***
Ca^{2+}	−0.05	0.01	−4.96	< 0.001	***
Mg^{2+}	0.02	0.004	4.5	< 0.001	***
Cl^-	0.00	0.000	6.36	< 0.001	***
SO_2^{2-}	0.01	0.002	4.07	< 0.001	***
Hardness	−0.07	0.012	−5.86	< 0.001	***
TC	($AIC = 165.9$, $\Delta AIC = 1.80$)				
(Intercept)	24.25	4.559	5.32	< 0.001	***
pH	−5.65	0.881	−6.41	< 0.001	***
Turbidity	−0.13	0.046	−2.87	0.004	**
DO	4.32	0.566	7.64	< 0.001	***
EC	−0.00	0.001	−6.6	< 0.001	***
SSM	3.12	0.471	6.61	< 0.001	***
Dry.res	−0.01	0.002	−3.81	< 0.001	***
NO_3^-	0.11	0.017	6.63	< 0.001	***
NO_2^-	8.4	1.281	6.56	< 0.001	***
NH_4^+	−0.77	0.144	−5.35	< 0.001	***
PO_4^{3-}	−0.03	0.018	−1.66	0.097	NS
Ca^{2+}	−0.13	0.02	−6.61	< 0.001	***
Mg^{2+}	0.04	0.006	6.01	< 0.001	***
Cl^-	0.00	0.000	5.57	< 0.001	***
SO_2^{2-}	0.02	0.004	5.9	< 0.001	***
BOD_5	−0.17	0.071	−2.45	0.014	*
Hardness	−0.14	0.019	−7.25	< 0.001	***
FC	($AIC = 157.45$, $\Delta AIC = 6.66$)				
(Intercept)	2.61	1.083	2.41	0.016	*
pH	−1.08	0.319	−3.38	< 0.001	***
Turbidity	−0.1	0.031	−3.38	< 0.001	***
EC	−0.00	0.000	−4.66	< 0.001	***
SSM	1.09	0.238	4.6	< 0.001	***
NO_2^-	3.14	0.598	5.26	< 0.001	***
PO_4^{3-}	−0.14	0.027	−5.05	< 0.001	***
Ca^{2+}	−0.07	0.011	−6.27	< 0.001	***
Mg^{2+}	0.01	0.002	4.02	< 0.001	***
K^+	0.04	0.005	9.74	< 0.001	***
SO_2^{2-}	0.00	0.001	1.42	0.157	NS
BOD_5	−0.18	0.061	−2.89	0.004	**
Hardness	−0.01	0.006	−1.58	0.113	NS
FS	($AIC = 106.82$, $\Delta AIC = 27.06$)				
(Intercept)	2.57	0.293	8.77	< 0.001	***
PO_4^{3-}	0.11	0.019	5.47	< 0.001	***
Turbidity	0.04	0.026	1.66	0.097	NS

(ΔAIC = AIC difference between the full GLM (see Appendix 1) and the simplified model with the lowest AIC based on 'backward/forward' stepwise selection procedure, *SE*: standard error, *Z*: *z*-statistics, *P*: *P*-value, Sig.: statistical significance, ***: $P < 0.001$, **: $P < 0.01$, *: $P \leq 0.05$, ^{NS}: $P > 0.05$).

L, the proliferation of algae and phytoplankton lead to the eutrophication of lakes and streams, which may present a real threat to aquatic life (Benammar et al., 2015; Haritash et al., 2016). The high values of phosphorus are attributed to the intense fertilization of the soil (chemical fertilizers), or alternatively due to the proliferation of algae that are able to bind to PO_4^{3-} directly from the air Mutlu et al. (2018). In a study conducted by Saadali et al. (2015), on the El Kala Park, which is a region of strong agricultural vocation using chemical fertilizers/pesticides and extensive livestock breeding thus causing the deterioration of the plant cover and also soil contamination due to various animal releases.

Calcium and magnesium are the most important and abundant dissolved solids in water (Mutlu and Uncumusaoğlu, 2016). The water contains 75.5 mg/L of calcium, below the limit of WHO (2017) which is 200 mg and between 75 and 200 mg/L (Journal Officiel de la République Algérienne JORA, 2011). Rejsek (2002) stated a range of 70–120 mg/L on calcareous substrate. Calcium salts are obtained mainly during the attack of calcareous rocks by carbon dioxide (CO_2). They constitute the dominant cationic element of the surface waters as well as the main element of water hardness (Bhandari and Nayal, 2008). Rodier et al. (2009) report that from a concentration of 100 mg/L, magnesium gives an unpleasant taste to drinking water.

As for magnesium, the results showed high concentration (107.13 mg/L), which is possibly due to its geological abundance (i.e. presence of limestone and dolomitic rocks) (Nouayti et al., 2015). A high rate of Mg^{2+} promotes higher development of exchangeable Na^+ in irrigated soils, and may become harmful for irrigation (Bouaroudj et al., 2019). The magnesium adsorption ratio (MAR) or magnesium hazard index, known also as the risk ratio of Mg^{2+} (WHO, 2008; Kumar et al., 2017), would be suitable for irrigation if its value is less than 50%. Groundwater with MAR greater than 50% are considered harmful and unsuitable for irrigation.

According to De Villers et al. (2005), high chloride content indicates pollution by domestic and industrial wastewater. The results showed high concentration of chloride (614.06 mg/L), which is the threshold indicated by WHO (2017) and Journal Officiel de la République Algérienne JORA, 2011. Raachi (2007) reported that the contents of chloride element increase with the degree of mineralization, related to the presence of Pontian formations with marly and gypseous red clays in the Tonga basin. Rodier et al. (2009) reported that chloride levels in water are extremely varied and mainly related to the nature of the lands crossed. Their levels in natural waters are subject to variations following superficial leaching in the event of heavy rains, hence their increase, especially during the wet season.

In this report, potassium content was 78.16 mg/L, which is 6 times more than the threshold set by WHO (2017), 4 times more than the Algerian threshold (Journal Officiel de la République Algérienne JORA, 2011), and 8–16 times greater than the range established by Rodier et al. (2009). In contrast, sulfates levels (148.73 mg/L) are below the threshold set by WHO (2017) and Journal Officiel de la République Algérienne JORA, 2011. Sulphates may have a natural origin as result of the leaching of gypsum and other mineral matter (Manivaskam, 2005) or anthropogenic sources (industrial waste and domestic wastewater (Patil and Patil, 2010).

BOD_5 can reflect the amount of labile organic matters in water (Wang et al., 2007). The amount of oxygen required by the microorganisms to degrade the organic matter present in the Lake under aerobic conditions is 4.33 mg/L, slightly lower than the threshold value set by WHO (2017), indicating that the lake is not polluted because according to Derwich et al. (2008) above 25 mg/L, water pollution by fertilizers is reported.

In most natural waters, the total hardness is mainly regulated by carbonates, bicarbonates, chlorides, sulphates, calcium and magnesium etc. (Chenchouni, 2010; Khan et al., 2012; Haritash et al., 2016). The presence of two cations (Calcium and magnesium) often tends to reduce the toxicity of metals (De Villers et al., 2005). The dissolution of these cations (Presence of limestone and dolomitic gypsum rock formations), of which hardness is likely to reach 1 g of $CaCO_3$/L (Figarella and Leyral, 2002). On the other hand, chemicals could cause the hardness, such as lime and NPK fertilizer used by farmers (Rodier et al., 2009) as well as urea mixing wastewater effluents into the river (Krishnan et al., 2007).

What is to be retained is, that although some parameters revealed significant differences between the stations (turbidity, EC, dry residues, PO_4^{3-}, Ca^{2+} and BOD_5) and between the months, such chlorides, dry residues and BOD_5, their variations remain within the permissible limits.

All the parameters mentioned above showed correlations between them. The positive ones concerned the pairs: pH—NO_3^-; pH—Cl^-, EC—SSM, EC—dry residues, EC—NO_3^-, EC—Cl^-, SSM—dry residues, SSM—Cl^-, dry residues—NO_3^-, dry residues—Cl^-, NO_3^-—Mg, NO_3^-—Cl^-, PO_4^{3-}—K^+, Mg^{2+}—MH, Mg^{2+}—SO_2^{2-}, MH—hardness, MH—SO_2^{2-}–, SO_2^{2-}—hardness, while negative correlations affected: turbidity—dry residues, turbidity—NH_4^+, DO—dry residues, Ca^{2+}—BOD_5, Mg^{2+}—BOD_5, BOD_5—hardness.

Referring to Delfino et al. (1969), the statistical correlation does not necessarily imply a causal link, because according to Bhandari and Nayal (2008), a large number of factors and geological conditions influence directly or indirectly the correlations between the different parameters such as of the hardness of the water, which is a function of the content of sulphates, chlorides, magnesium and calcium (Khan et al., 2012).

4.2. Bacterial load in lake waters

The bacteriological quality of the water is traditionally assessed by analyzing the load of total and faecal coliforms (Kagalou et al., 2002). In the present study, bacteriological analysis revealed different groups of bacteria with similar trends, expressed by positive linear correlations. Guemmaz et al. (2020) reported similar results on the influence of environmental factors on faecal bacteria loads measured in urban effluents discharged in dryland Wadis of Algeria. At all three sampling points and during the six months of collection, bacterial germs are ubiquitous with average of 32.3×10^3 CFU/100 mL for THB, 24.7×10^3 for TC, 24.8×10^3 for FC and 37.56×10^3 CFU/100 mL for FS.

Regardless of bacterial densities recorded, these agents are mainly derived from humans faeces, livestock and wild animals, surface water receiving wastewater discharges, and agriculture, urban and rainwater, soil and other environments (Medema et al., 2003; US-EPA, 2015; Guemmaz et al., 2020). However, even though not all members of the coliform group are necessarily pathogenic and indicate health risks, their presence correlates with the degradation of water quality and may even increase the risk of gastrointestinal illness following the different uses of water (bathing, gathering, drinking water or other …) (Servais et al., 2005; Sibanda et al., 2013). With the exception of FS, when load increases with depth, the station effect is insignificant on THB, TC and FC. However, the time effect is significant on TC and FC abundance except for FS.

4.3. Effect of water physicochemical factors on bacteria populations

Variable responses of bacterial populations were noted relative to physicochemical parameters of the lake. THB increase with decreasing of pH, NH_4^+, Ca^{2+} and hardness. Furthermore, total coliforms population increase with decreasing of pH, turbidity, dry residues, NH_4^+, Ca^{2+} and BOD_5. For faecal coliforms, loads increases with decreasing of pH, turbidity, PO_4^{3-}, Ca^{2+} and BOD_5. In addition, streptococci group increase with the increase of PO_4^{3-} concentrations.

What needs to be retained is that bacterial populations were simultaneously subjected to abiotic stress factors and predator that may be present in the environment, and the differences in results revert to non-similar experimental conditions (Chedad and Assobhei, 2007). Nevertheless, some links have been established between environmental factors and bacterial populations in aquatic environments. In the present study, the different microbial groups load increase when pH decreases. This result has already been reported by Chedad and Assobhei (2007), where a decrease in FC survival was affected by pH and salinity in water (Bordalo et al., 2002). Streptococci are known to be more resistant than coliforms (Rodier et al., 2009). These bacteria grow in the same direction as EC, SSM, NO_3^-, NO_2^-, Mg^{2+}, Cl^-, and SO_2^{2-}. In fact, the SSM associated with the different anions and cations promote the proliferation of all forms of bacteria (Davies et al. (1995)) and, on the other hand, these elements are essential for bacterial growth (Medema et al., 2003). It has been reported, that the survival of coliforms may be extended or may even sometimes grow under certain environmental conditions such as pH, temperature, rich nutrients and abundant suspended particles (Juhna et al., 2007). According to Hong et al. (2010), rates of disappearance of bacterial loads at the surface of water depend on many factors such as nutrient availability, temperature, salinity, turbidity, degree of mixing of water, solar radiation, predation, competition and bacterial losses due to death or sedimentation.

The results of the temporal evolution of each indicator (total coliforms, faecal coliforms and faecal streptococci) showed specific variations for each bacterial indicator. This was explained by (Rosenfeld et al. (2006) where bacterial density is not only affected due to temporal or spatial variability in their sources but also varies to different environmental factors such as temperature, salinity, nutrient concentration, predation, presence or absence of bacterial toxins, solar radiation, coagulation, flocculation and particle adsorption. According to Oketola et al. (2006), there are a variety of physical, chemical, and biological processes that self-purify and restore the waters of streams, lakes, estuaries, rivers, and oceans to their natural state, even if a certain level of pollution was observed.

5. Conclusion

This study assessed the physicochemical and biological quality of Tonga Lake, classified as Ramsar. The results revealed that several analyzed parameters exceeded the thresholds established by the WHO and the Algerian standards, indicating of a large pollution. The analyzes have revealed that the different bacterial groups are linked together and correlated with the different physicochemical parameters, the case of pH and SSM, EC, turbidity and PO_4^{3-}. The study showed that the lake is subject to large eutrophication that could lead to its disappearance if protective measures are not taken, hence the importance of adopting an appropriate systematic monitoring system to prevent or reduce the risk of contamination of this natural ecosystem.

Authors' contributions

KL conceived the study, conducted field sampling, lab word and compiled data. MCM and MH supervised KL during his PhD. HC analyzed data and designed the paper. SN, HC, TM and KL drafted and revised the MS. All authors reviewed and agreed with the final version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix 1 Summaries of full generalized linear models (GLMs) obtained prior model simplification and selection using “stepwise” method and 'backward/forward' direction and based on Akaike information criterion (AIC) values

THB	Est.	SE	z-value	P	Sig.	TC	Est.	SE	z-value	P	Sig.
(Intercept)	24.76	9.934	2.49	0.013	*	(Intercept)	19.83	10.858	1.83	0.068	•
pH	−5.93	2.394	−2.48	0.013	*	pH	−4.53	2.631	−1.72	0.085	•
Turbidity	−0.06	0.041	−1.49	0.136	^{NS}	Turbidity	−0.13	0.049	−2.59	0.010	**
DO	5.38	2.079	2.59	0.010	**	DO	3.32	2.307	1.44	0.150	^{NS}
EC	0.00	0.002	−2.54	0.011	*	EC	0.00	0.002	−1.65	0.099	•
SSM	3.32	1.248	2.66	0.008	**	SSM	2.54	1.372	1.85	0.064	•
Dry.res	−0.01	0.003	−2.02	0.044	*	Dry.res	0.00	0.004	−1.23	0.218	^{NS}
NO_3^-	0.10	0.050	2.00	0.046	*	NO_3^-	0.09	0.056	1.56	0.118	^{NS}
NO_2^-	8.32	3.068	2.71	0.007	**	NO_2^-	7.01	3.360	2.09	0.037	*
NH_4^+	−1.10	0.504	−2.19	0.029	*	NH_4^+	−0.53	0.555	−0.96	0.339	^{NS}
PO_4^{3-}	0.15	0.089	1.64	0.101	^{NS}	PO_4^{3-}	−0.07	0.102	−0.74	0.462	^{NS}
Ca^{2+}	−0.10	0.034	−3.09	0.002	**	Ca^{2+}	−0.12	0.037	−3.14	0.002	**
Mg^{2+}	0.04	0.016	2.51	0.012	*	Mg^{2+}	0.03	0.018	1.63	0.103	^{NS}
Cl^-	0.00	0.001	2.56	0.010	*	Cl^-	0.00	0.001	1.26	0.207	^{NS}
K^+	−0.03	0.024	−1.19	0.232	^{NS}	K^+	0.01	0.027	0.45	0.654	^{NS}
SO_2^{2-}	0.02	0.010	2.30	0.021	*	SO_2^{2-}	0.02	0.011	1.57	0.116	^{NS}
BOD_5	−0.09	0.062	−1.42	0.155	^{NS}	BOD_5	−0.17	0.072	−2.34	0.019	*
Hardness	−0.16	0.065	−2.46	0.014	*	Hardness	−0.11	0.072	−1.46	0.143	^{NS}
AIC:	172.38					AIC:	167.70				
FC	**Est.**	**SE**	**z-value**	**P**		**FS**	**Est.**	**SE**	**z-value**	**P**	
(Intercept)	6.06	12.107	0.50	0.617	^{NS}	(Intercept)	25.37	29.997	0.85	0.398	^{NS}
pH	−1.60	2.936	−0.54	0.586	^{NS}	pH	−5.04	7.152	−0.71	0.481	^{NS}
Turbidity	−0.13	0.055	−2.33	0.020	*	Turbidity	−0.05	0.117	−0.40	0.690	^{NS}
DO	0.99	2.572	0.38	0.701	^{NS}	DO	4.12	6.340	0.65	0.516	^{NS}
EC	0.00	0.002	−0.65	0.517	^{NS}	EC	0.00	0.005	−0.70	0.482	^{NS}
SSM	1.27	1.528	0.83	0.404	^{NS}	SSM	2.55	3.689	0.69	0.489	^{NS}
Dry.res	0.00	0.004	−0.26	0.796	^{NS}	Dry.res	−0.01	0.010	−0.75	0.451	^{NS}
NO_3^-	0.04	0.062	0.63	0.532	^{NS}	NO_3^-	0.12	0.155	0.78	0.434	^{NS}
NO_2^-	3.70	3.749	0.99	0.324	^{NS}	NO_2^-	6.33	9.127	0.69	0.488	^{NS}
NH_4^+	−0.04	0.616	−0.06	0.950	^{NS}	NH_4^+	−0.97	1.507	−0.64	0.521	^{NS}
PO_4^{3-}	−0.12	0.113	−1.05	0.292	^{NS}	PO_4^{3-}	0.23	0.260	0.90	0.369	^{NS}
Ca^{2+}	−0.08	0.041	−1.82	0.069	•	Ca^{2+}	−0.08	0.101	−0.79	0.428	^{NS}
Mg^{2+}	0.01	0.020	0.51	0.612	^{NS}	Mg^{2+}	0.03	0.049	0.68	0.496	^{NS}
Cl^-	0.00	0.001	0.18	0.860	^{NS}	Cl^-	0.00	0.003	0.66	0.512	^{NS}
K^+	0.04	0.030	1.25	0.211	^{NS}	K^+	−0.04	0.073	−0.59	0.553	^{NS}
SO_2^{2-}	0.01	0.012	0.69	0.493	^{NS}	SO_2^{2-}	0.02	0.031	0.70	0.481	^{NS}
BOD_5	−0.20	0.079	−2.55	0.011	*	BOD_5	−0.07	0.200	−0.35	0.730	^{NS}
Hardness	−0.04	0.080	−0.47	0.639	^{NS}	Hardness	−0.13	0.197	−0.68	0.496	^{NS}
AIC:	164.11					AIC:	133.88				

(THB: total heterotrophic bacteria, TC: total coliforms, FC: faecal coliforms, and FS: faecal Streptococci; Est.: estimate, SE: standard error, P: *p*-value, Sig.: statistical significance, ***: $P < 0.001$, **: $P < 0.01$, *: $P \leq 0.05$, •: $P < 0.10$, ^{NS}: $P > 0.1$).

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