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ORIGINAL ARTICLE

Seasonal variation in physicochemical characteristics and lead contamination of Lake Tonga and their effects on waterbird populations

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Being the Ramsar site, Tonga Lake is one of the most important wetlands in Numidia for its habitat diversity and its fauna and flora richness. It is known as a wintering and breeding site for many waterbirds species. However, it is confronted with an increasing pressure linked to various anthropogenic activities. This study was carried out between December 2015 and August 2016 to assess the physicochemical quality and lead contamination of the surface waters and their impacts on the waterbirds population dynamic. Seven physicochemical parameters were considered (Temperature, pH, Electrical Conductivity, Turbidity, Dissolved Oxygen, TDS, and Salinity). Waterbirds monitoring revealed that 43 species were counted in winter and 26 in summer, with some endangered ducks, such as White-headed Duck, Marbled Teal, and Ferruginous Duck. The highest number of abundances was recorded in January (27,507 individuals). The results of water physicochemical parameters measurements showed strong mineralization, neutral to alkaline pH values, and high turbidity. The high lead values obtained from water samples have exceeded WHO standards. During the two seasons studied, correlations were identified, indicating a probable seasonal association between studied parameters (limnological and lead concentrations) and Lake Tonga waterbirds population dynamics.
Keywords: Tonga Lake; waterbirds; Physico-Chemical parameters; Lead

Introduction

Among the various compounds emitted by human activities, trace metal elements are significant environmental contamination sources (Tessier, 2012). These pollutants' harmfulness is related to their persistence and toxicity (Ouali, 2018; Lienard & Colinet, 2014). Furthermore, they can change their forms and become more or less mobile. The most dangerous of these metals are lead, cadmium, and mercury, which have no positive biological activity (Ramaroson, 2008). Lead is the most widespread and used heavy metal in the world. His toxicity, persistence, and bioaccumulative nature caused a severe environmental and public health problem. The World Health Organization (WHO), classified lead as one of the three metal water priority pollutants (Belli et al., 2010).
Wetlands are among fragile ecosystems affected by heavy metals pollution, especially lead. Through trophic chains, this contamination can spread or change and can result in bioconcentration or bioturbation phenomena. Thus, metallic trace elements are transferred to biota (amphibians, reptiles, fish, birds), where they directly affect organisms by accumulating in their bodies or indirectly by transfer via the food chain after reach humans (Smatti. Hamza et al., 2019).
There are several approaches to assess aquatic ecosystems' contaminations by different pollutants, including physical, chemical, and biotic methods. These allow optimal monitoring of a natural environment's ecological quality (Keddari et al., 2019). Waterbirds are one of the essential components of wetlands. They are excellent bio-indicators to determine the health status of ecosystems (Bediaf et al., 2020).
Several studies were conducted on lead contamination of aquatic environments worldwide (Moutou & Joseph. Enriquez, 1991; Duranel, 1999; Bana et al., 2004; Lefranc, 2006; Besombes, 2006). However, in North Africa and particularly in Algeria, this topic remains very little documented (Bendjama, 2007; Souissi, 2007; Belabed, 2010; Bendjama, 2014; Chaguer, 2013; Melghit, 2012; Bensaci et al., 2014; Benkaddour, 2018) hence the interest of this study carried out in a Ramsar site. This study carried out in Lake Tonga (North-East Algeria) attempts to provide recent and unpublished data on an international importance wetland's health by assessing physicochemical quality and lead contamination of its surface waters. Induced variation effects of these parameters on the waterbird population were also investigated. Information gathered during this study will serve for the management and conservation of this lake and its biodiversity.

Materials and Methods

Study site

The study was conducted at Lake Tonga, a freshwater marsh of 2600 ha that communicates with the sea through the artificial Messida Channel (Figure 1). Two tributaries supply it: Oued El Hout from the southeast and Oued El Eurg from the east, which is added many small rivers fed by groundwater. This lake is protected as a Ramsar site within the National Park of El Kala (North-East of Algeria). Its watershed, 16,390 ha, is located at the extreme East of El-Tarf Wilaya and borders Tunisia. It plays an essential role in flood control during winter by retaining ripped-out sediments upstream, which leads to its gradual filling (Lazli et al*.,* 2012).

Lake Tonga is known for its high biodiversity. There are 82 plant species, some of which are classified as rare, such as *Marsilea diffusa*, *Utricularia exoleta* (Gherib & Lazli, 2017). Helophytes cover almost 80% of its area (Lesser bulrush *Typha angustifolia*, Club-rush *Scirpus lacustris,* Reed *Phragmites australis*) and hydrophytes (White water lily *Nymphaea alba* and Fennel pondweed *Potamogeton pectinatus*) (Lazli et al., 2011). It is considered an important wintering and nesting site for several waterbird species (Boumezbeur, 1993; Lazli et al., 2011; Gherib & Lazli, 2017), some of which are threatened as White-headed duck *Oxyura leucocephala*, and Marbled Teal *Marmaronetta angustirostris*. Besides, there is a fish diversity, including Barbel *Barbus callensis,* Mosquitofish *Gambusia affinis*, and European eel *Anguilla anguilla* (Lazli, 2011; Benmetir et al., 2020).

Lake Tonga has been experiencing increasing adverse environmental pressures that threaten its sustainability (bank erosion, water scarcity in summer, and eutrophication). Various activities such as urbanization, poaching, egg collection, increasing demands for water for human consumption and agriculture) have further exacerbated conservation problems at the lake (Lazli et al*.,* 2014; Gherib & Lazli, 2017). Moreover, this wetland was ceded as a concession for Eel exploitation.

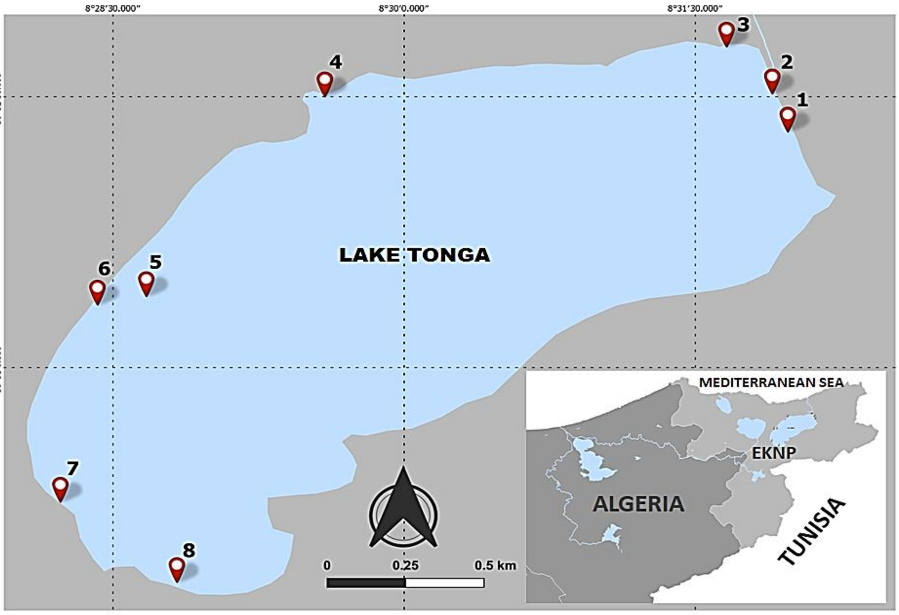

Figure 1. Location of the study area and sampling stations.

Methodology

The fieldwork was spread over two seasons, winter and summer, between December 2015 and August 2016. Eight sampling stations were chosen for their accessibility and proximity to domestic water discharges, points or hunting shelters, and crops using pump motors (Figure 1).

Measurement of physicochemical water parameters: Physico-chemical water parameters (pH, temperature, conductivity, turbidity, dissolved oxygen, TDS, salinity) were measured in situ using a portable multi-parameter (Horiba U-50 Series Multiparameters).

A sampling of surface water and lead dosage: water was collected in plastic bottles previously rinsed with distilled water, then before sampling, with water from the lake. The water samples were taken 25 cm deeper, avoiding the introduction of air bubbles. They were then transported to the laboratory in a cooler. Before lead dosage, samples were acidified with few nitric acid drops (Ahoudi et al., 2015). The assay was performed using a PERKIN ELMER 3110 atomic absorption spectrometer (AAS).

Waterbirds diversity. We determined the abundance and species richness of the bird population during the study period to assess the effects of physicochemical quality and likely contamination of Lake Tonga water on aquatic avifauna. The inventory and waterbird censuses were carried out twice a month during the winter of 2015 and the summer of 2016. A KONUS-SPOT (20×60) telescope and a KERN pair of binoculars (10x50) were used to scan the water surface, with observations made from elevated platforms, bird watching observatories, or other elevations to achieve good visibility. Thus, the total number of birds present across the site was recorded.

Data Analysis

Statistical analyzes were carried out using R software version 4.0.1 (06-06-2020). The values cited are means ± standard deviation, and $p < 0.05$ was retained as the significance level. To calculate the correlation coefficient between the different physicochemical parameters and lead in water during the two seasons separately, we used the "corrplot" package. Finally, a principal component analysis (biplot) was performed using the "FactoMineR" and "factoextra" packages. Student and Mann-Whitney tests were used to check whether there were significant differences between physicochemical parameters, abundances, and species richness by season.

Results

Physico-chemical characteristics of Lake Tonga surface waters:

The results of the main physicochemical parameters measurements and lead content of water samples taken from Lake Tonga showed different average values depending on the season (Table 1).

Table 1. Main physicochemical parameters of Tonga Lake (Mean ± SE, min-max).

	Winter Period		Summer Period	
	N	Mean. ± SE (min-max)	N	Mean. ± SE (min-max)
T (°C)	24	16.23 ± 0.48 (15.11 – 17.11)	21	25.24 ± 3.28 (20.42 – 29.73)
pH	24	7.36 ± 0.40 (6.22 – 7.97)	21	7.53 ± 0.71 (6.65 - 8.7)
CE (µS/cm)	24	773.8 ± 244.6 (475 - 1730)	21	686.4 ± 220.4 (102 - 1180)
Turb. (NTU)	24	37.64 ± 35.68 (6.96- 119)	21	77.59 ± 48.79 (23.8 -178)
DO (mg/L)	24	8.80 ± 2.95 (5.07 – 17.25)	21	9.27 ± 4.31 (3.0-18.30)
TDS (mg/L)	24	0.483 ± 0.12 (0.30 -0.88)	21	0.470 ± 0.12 (0.312 – 0.75)
Sal (%)	24	0.036 ± 0.009 (0.03 – 0.07)	21	0.036 ± 0.008 (0.02 – 0.05)

N - Number of samples; **T -** water temperature; **pH -** Potential of hydrogen; **CE -** Electric Conductivity; **Tur -** Turbidity; **DO -** Dissolved oxygen; **TDS -** Total dissolved solids; **Sal -** Salinity.

The results obtained during the study period indicated that water temperatures varied significantly between the seasons (t=12.96, p<0.000). Thus, the temperatures recorded ranged from 15.11 to 17.11 °C in winter and from 20.42 to 29.73 °C in summer (means seasonal temperatures were 16.23 and 25.24 °C, respectively) (Table 1). Water pH was relatively neutral to alkaline, with no significant differences between seasons (t=0.72, p=0.47). Seasonal values ranged from 6.22 to 8.7 (means seasonal pH values were 7.36 and 7.53, respectively) (Table 1). Electrical conductivity was higher during winter, with no significant differences between seasons (t=0.72, p=0.47). Indeed, the recorded values were between 475 and 1730 µS/cm during December and from 102 to 1180 µS/cm in August (Table 1). Water turbidity ranged from 6.96 to 178 (means seasonal turbidity values were 37.64 and 77.59, during winter and summer, respectively) (Table 1). The highest values were recorded downstream of the lake during summer. No significant difference in turbidity could be observed between seasons (t=0.03, p=0.97).

The mean dissolved oxygen values of Lake Tonga surface water varied between 8.80 and 9.27 mg/L. According to the results obtained, the lowest values were recorded in winter. No significant difference in dissolved oxygen could be observed between seasons (t=0.48, p=0.63). Total dissolved solids (TDS) provide information on salt and organic matter concentrations in water. They showed an average of 0.483 mg/L in the wet season and 0.470 mg/L in the dry one (Table 1). The highest value, 0.883 mg/L, was recorded during winter.No significant difference in TDS could be observed between seasons (t=0.36, p=0.71). Salinity ranged from 0.02% to 0.07%, with an average value of 0.036% during both sampling seasons (Table 1). The highest salinity values were observed in December. No significant difference in salinity could be observed between seasons (t=0.23, p=0.81).

Lead dosage in Lake Tonga water

The lead concentration in water samples was high (maximum: 0.44 mg / L and minimum: 0.01 mg/L in both sampling campaigns). Mean value varied significantly between the seasons (0.32 ± 0.08 mg / L in winter and 0.12 ± 0.1 mg / L in summer (t=6.29, p<0.000). We noted a particularly high content during the winter season (Table 1).

Characterization of the Lake Tonga Waterbirds Stand

During the study period, Lake Tonga hosted an abundant and varied aquatic avifauna, which showed different phenological statuses: wintering, sedentary nesters, migratory visitors, sedentary non-nesters, summer nesters (Table 2).

Abundance: During winter, waterbird numbers varied between 9,335 and 27,507 individuals (Table 3; Figure 2). At first, the observed populations were composed of sedentary species (Podicipedidae, Anatidae, Rallidae, and Ardeidae), and individual numbers per species were more or less low. After that, numbers increased gradually to reach a peak in January, then declined from mid-March. During summer, a peak of 3614 individuals is recorded during the first half of August.

Table 2. Phenological status of the observed families (**TM:** Transite migrant, **O:** wintering, **SN:** breeding, **SNB:** non-breeding).

No	Families	Number of species	Status
1	Alcedinidae	1	SN
2	Anatidae	14	O; SN;TM
3	Ardeidae	8	SN; SNB; EN
4	Charadriidae	4	O;TM
5	Ciconiidae	1	EN
6	Laridés	6	O; EN
7	Phalacrocoracidae	1	O
8	Phoenicoptéridae	1	TM
9	Podicipedidae	3	SN;TM
10	Rallidae	4	SN
11	Recurvirostridae	2	O; SNB
12	Scolopacidae	7	O;TM
13	Threskiornithidae	2	SN; TM

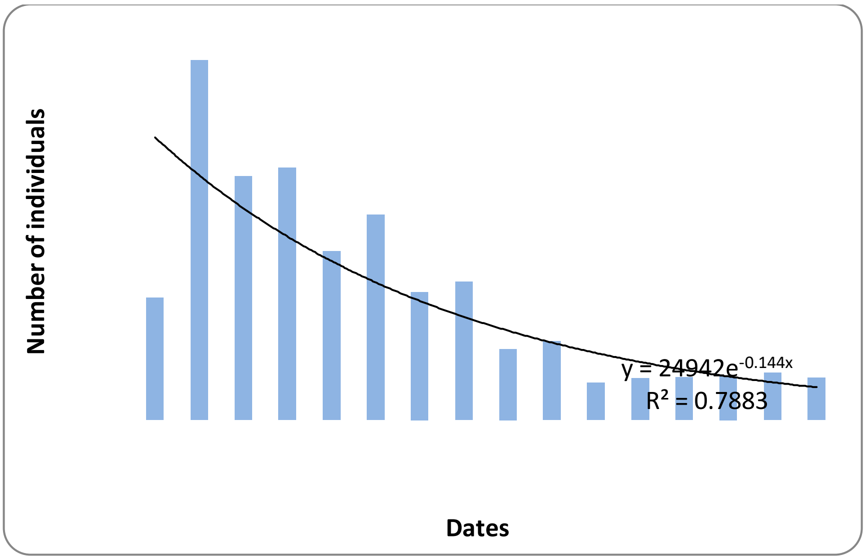

Figure 2. Changes in waterbird numbers in Tonga Lake during the study period.

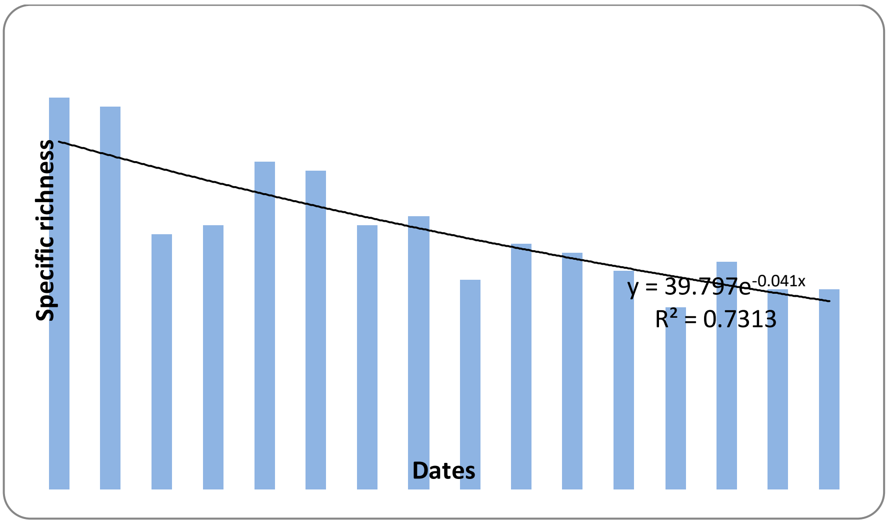

Figure 3. Changes in waterbird species richness in Tonga Lake during the study period.

Specific richness: Waterbird inventory identified 43 species in winter and 26 species in summer. The highest species richness was recorded in the first half of January and the lowest, 19 species, in mid-July 2016 (Figure 3). According to Birdlife international data (2020), some have protected status such as Marbled Teal (which is vulnerable species), White-headed Duck (which is endangered species), Common Pochard (which is vulnerable), Ferruginous duck (Which is Near Threatened).

Table 3. Species diversity of Tonga Lake waterbirds (Mean ± SE, min-max).

	Winter Period	Summer Period
	Mean ± Stand.dev (min-max)	Mean ± Stand.dev (min-max)
Abundance	17533 ± 6934.20 (9335-27507)	3403 ± 202.68 (3161-3614)
Specific richness	35.4 ± 6.27 (28-43)	22.2 ± 2.77 (19-26)

Mann-Whitney test results showed significant differences for abundances and specific richness between the two seasons (Figure 4) (for the abundances: W = 372.5; p = 0.04 * and for the richness: W= 363.5; p = 0.003 **).

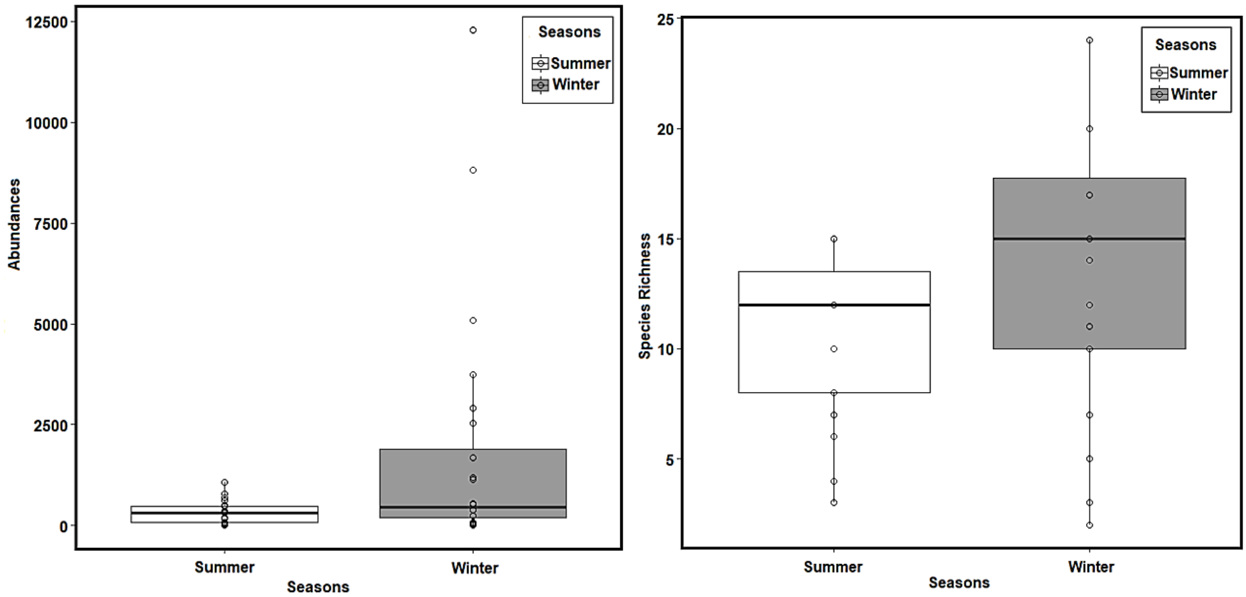

Figure 4. Box and whisker (Boxplots) variations in the abundances and species richness of Tonga Lake waterbird stand during the two study seasons.

Correlation of physicochemical and lead parameters with waterbirds abundance and species richness in Lake Tonga
During winter, a significant correlation (negative) was recorded between specific richness and two physico-chemical parameters: turbidity (r= - 0.79; p=0.006) and water dissolved oxygen (r=-0.66; p=0.036). Similarly, water lead concentration was significantly correlated with turbidity (r= - 0.7; p=0.024). In summer, a significant correlation was found between lead and species richness (r = - 0.81; p=0.004) and between lead and abundance (r = - 0.93; p=0.000). in addition, there was a significant correlation between richness and abundance (r = 0.75; p = 0.01) during this period.
In winter, water temperature showed significant correlations (p <0.05) with pH, dissolved oxygen, electrical conductivity, and TDS (Figure 3). The pH showed a significant correlation with dissolved oxygen, and salinity was significantly correlated with electrical conductivity and TDS (Figure 3). In summer, several significant correlations were observed for specific environmental parameters (p <0.05). The temperature was significantly correlated with pH, electrical conductivity, dissolved oxygen, TDS, and salinity.TDS showed a significant correlation with salinity, dissolved oxygen, electrical conductivity, and turbidity. Salinity was significantly correlated with electrical conductivity and oxygen demand (Figure 5).

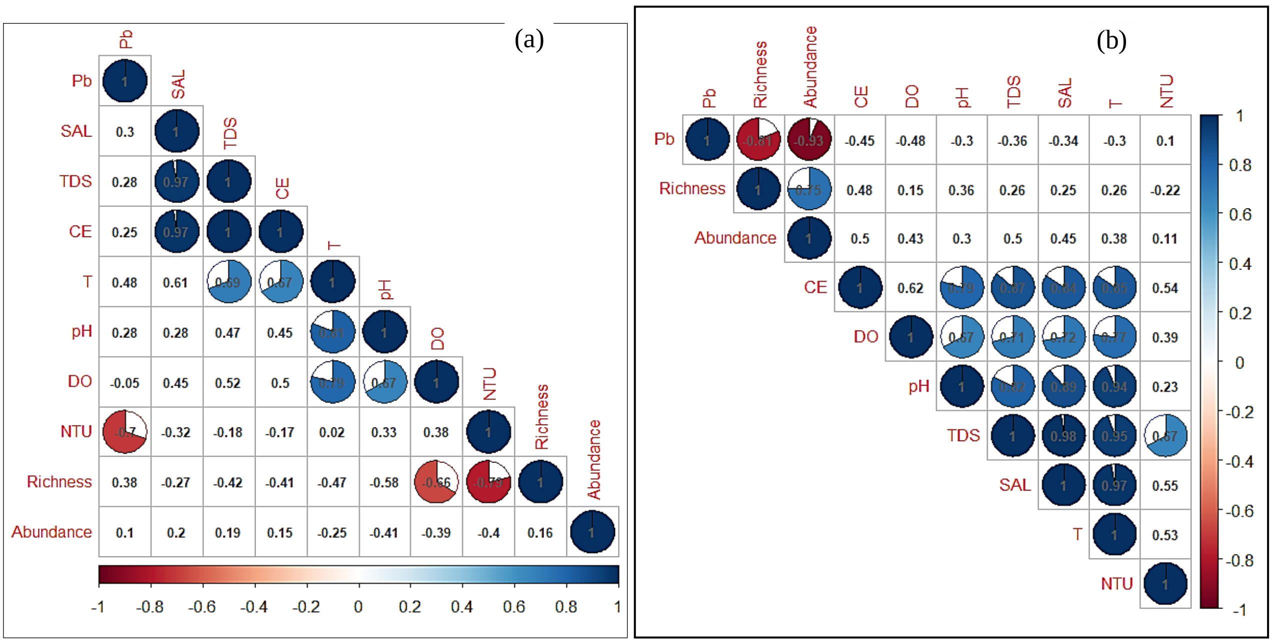

Figure 5. Seasonal correlation matrixes between physical-chemical parameters, lead and waterbirds diversity parameters, a) winter period; b) summer period.

Discussion

Physico-chemical quality of water

The Tonga lake physicochemical water analyses showed insignificant variation between seasons except for Temperatures. Indeed, this parameter's variations can be linked to regional climatic conditions and, more particularly, to air temperature (Souissi, 2007; Makhoukh et al., 2011). Based on the collected temperatures range, Tonga lake can be categorized as warm monomictic lakes

(Mouissi & Alayat, 2016; Mehanned et al., 2014). These recorded temperatures are consistent with those of Bendjama (2014) at the same site but are lower than those reported by Bendali-Saoudi et al. (2014) and Souissi (2007).
The pH values obtained meet Algerian standards defined, which set variance values to range from 6.5 to 9 for surface water (JORA, 2011). They were consistent with those obtained near Oubeira Lake by MOUISSI & ALAYAT (2016), Lala Fatma Lake (Ouargla) (Lemkeddem & Telli, 2014), and Bini and Dang Lakes (Ngaoundéré, Cameroon) (Oumar, 2014). Moreover, similar to Loucif et al. (2020) study at Tonga lake, the measured surface water pH values were reflecting a neutral to the slightly alkaline environment and were meeting WHO (2017) standards. The highest pH values were observed in the summer when the increase in temperature affects the calcium-carbonate equilibrium, leading to carbonates' formation under the effect of photosynthesis and the presence of high organic matter due to the significant evaporation (Derwich et al., 2010; Rodier et al., 2009). Also, winter precipitation and runoff loaded with biodegradable organic matter can affect the Tonga lake's acidity or alkalinity (Bendjama, 2014). A low alkaline pH would increase the solubility and mobility of heavy metals, which algae and other aquatic organisms may subsequently adsorb, thereby posing a severe danger to animal and human health (Kobielska et al., 2018; Loucif et al., 2020).
The low dissolved oxygen (DO) concentration recorded could be related to low photosynthetic activity induced by high turbidity and a decrease in plant biomass and oxygen consumption by aerobic bacteria during biological degradation of dead organic matter (Dedjiho et al., 2013; Guitoun & El Hella, 2014). These DO values reflected the eutrophication phenomenon reported in Tonga Lake previous studies (Lazli et al., 2014; Menasria & Lazli, 2017). This phenomenon is compounded by anthropogenic pollutions such as pesticides and chemical fertilizer inputs from runoff, which degrade water quality (Diallo et al., 2008). Our DO results were consistent with those of Mouissi & Alayat (2016) at Lake Oubeira and Lemkeddem &Telli (2014) at Lake Lala Fatma (Ouargla).
Our results showed that the dry season was characterized by many parameters (pH, Temperature, Turbidity, and Dissolved Oxygen). These parameters influenced the biodegradation of organic matter, which leads to the organic mineralization of water.
However, the maximum values of conductivity and TDS observed in winter indicated strong water mineralization linked to the water regime, to the mineralization of organic matter in the lake following heavy rainfall, and to the inflow of seawater through the Messida channel (Guitoun & El Hella, 2014; Coulibaly et al., 2018). This second group of parameters (Salinity, Electrical Conductivity, and TDS) reflecting a significant load of dissolved salts in lake waters. These variables characterize the lake's waters' mineralization due to its feeding by the surrounding wadis and the runoff of rainwater during the winter.
For example, turbidity variation could be explained by the inflow of runoff that transports particles during their passage (Allalgua et al., 2017). According to Rodier (2009), the Lake Tonga water could be classified as cloudy. The conductivity values were much higher than those found by Bendjama (2014) and Bendali-Saoudi et al. (2014) in the same study area as well as those found by Berghiche (2015) and Mouissi & Alayat (2016) at Lake Oubeira. This could be explained by the frequent and recent outages of the Tonga Lake bridge valve (that caused the entry of seawater) and the immediate proximity of housing (Gaujous, 1995).
The highest salinity values were found at stations near the shoreline facility around Lake Tonga, which directly discharged domestic water into the lake. Added to this is the rise of marine waters through the Messida Channel, which increases the salt concentration in the lake during the flood season (Souissi, 2007).

Lead Levels in Lake Surface Water

The results obtained indicate that almost all of the stations sampled showed lead concentrations above the allowable values recommended by the (W.H.O.), and the EC Directive (Bendjama, 2007). In comparison with other work, the lead levels recorded in this study are lower than those measured by Bendjama (2007) and Belabed (2010) at the same study site. However, they are higher than those found by Bensaci (2014) at Chott El Hodna (M'sila) and Dayet El Kerfa (Medea) and by Oumar (2014) at Bini and Dang lakes in Cameroon.
This pollution is related to anthropogenic activities that develop around and at the watershed level, mainly atmospheric deposition from road traffic (Bendjama, 2007; Oumar et al., 2014). The wetland is close to the national road (RN 44, leads to the Algerian-Tunisian border), which is a busy road throughout the year, especially during the summer months ((Belabed, 2010; Fahssi et al., 2016). Indeed, emissions from vehicles exhaust due to the addition of lead in fuels as anti-depressants are a significant lead source.
Another cause of pollution of Lake Tonga by Lead is the poaching that this wetland is experiencing, especially in winter when large quotas of wintering and/or migrating waterbirds species are counted there. Indeed, the lead contained in the hunting cartridges, fishing nets, and traps, since the site is ceded in concession for the fishing of *Anguilla anguilla*, constitutes a source of contamination of the lake by this metal (Carlier, 2003; Bendjama, 2007).
This seasonal evolution of lead would depend on the supply of water to the lake during the wet season by heavy precipitation. This was increasing the risk of contamination by lead-bearing mineral or organic particles after leaching from the atmosphere and the surface water runoff (Laperche et al., 2004), as well as domestic discharges from wadi waters (W. El-Hout and W. El-Eurg) that feed the wetland (Bendjama, 2007). During the dry season, water supplies to Lake Tonga are mainly from domestic discharges and groundwater (Bendjama, 2007; Belabed, 2010). Lead is an insoluble element in surface water due to its absorption by particles and organic substances. It is then deposited on sediments where it accumulates in stagnant waters where the flow is very low or almost absent (Devallois, 2009; El Azhari, 2013). Several studies have shown that sediments often constitute a stock of pollutants, in particular trace metal elements, which subsequently become a potential source of contamination for water as a result of changes in environmental parameters, such as the turbulence of the water that would cause them to be re-suspended due to the action of the currents (Marcellin et al., 2009; Tessier, 2012; El Azhari, 2013; Smatti-Hamza, 2019). Various studies have confirmed the pollution of Lake Tonga sediments by various heavy metals including lead (Bendjama 2007; Belabed 2010; Belabed et al. 2013).
Other sources of pollution are also considered in the region and threaten this lake ecosystem. These are the former mines of Kef Oum Teboul and their mining waste from the galena that infiltrates after runoff into the lake watershed (Belabed, 2010). Recent studies, such as those of Laperche et al. (2004) and Belli et al. (2010), have also shown the contribution of older mining activities to the enrichment of water with metals where they pose risks to aquatic life.
The lake is also the seat of various agricultural, domestic, and tourist activities that lead to the diffusion of polluting products in surface waters and their infiltration (Belli et al., 2010; Fahssi et al., 2016).
As the region is one of the most renowned in Algeria for its mosaic of ecosystems and its biodiversity, it experiences an intensive tourist influx throughout the yea,r which contributes to the spread and abandonment of different types of waste in nature; this leads to the creation of small uncontrolled landfills scattered holding back different metals (Laperche et al., 2004; Gherib & Lazli, 2017).

Effects of physicochemical parameters and lead in Lake Tonga waters on the population of waterbirds:

Tonga Lake is an important wintering and nesting site for waterfowl. During breeding, it supports a large number of species (Gherib, 2018). During this study, data collected indicate that 43 species visited lake Tonga in winter and 26 in summer. Elafri et al.

(2016) listed 52 species from 13 families, and Gherib (2018) listed 61 species from 17 families. Indeed, wetlands in this eastern region are known for their remarkable waterfowl diversity (Lazli et al., 2018; Bediaf et al., 2020; Bara et al., 2020). The Anatidae family was the most represented in the study reported in different wetlands in Eastern Algeria (Baaziz et al., 2011; Guergueb et al., 2014; Lazli et al., 2018; Gherib, 2018; Bediaf et al., 2020; Bara et al., 2020).
Monitoring of fluctuations in numbers of waterbirds at Lake Tonga during the two seasons studied showed that the site was frequented by a large number of species that showed different phenological status, made consistent with other work in the region (Gherib, 2018; Lazli et al., 2018; Bediaf et al., 2020; Bara et al., 2020).
At the beginning of the winter season, the observed species showed more or less low numbers and were represented by sedentary (Podicipedidae, Anatidae, Rallidae, and Ardeidae). A gradual change in numbers of waterfowl populations was observed to reach a peak in January, attesting to the staging of certain species such as White Spatulas, Flamingos, and many winterers' arrival such as Piping Ducks, Red-tailed Ducks, Green-winged Teals, and Coots. It is during this month that the specific richness reaches its maximum. These facts have been reported in various works, described the wetlands in Eastern Algeria (Lazli et al., 2018; Gherib, 2018; Bediaf et al., 2020). During this period, these gatherings reflect the preparation for pre-nuptial migration, reported by many authors (Bensaci et al., 2013; Elafri, 2016; Lazli et al., 2018; Bediaf et al., 2020). Towards the end of the winter season, a decline in numbers is perceived towards March's end. Only sedentary species represented by small numbers remain on the site, such as some Anatidae (Mallard, Ferruginous duck, White-headed duck), Ardeidae (Grey Herons, Little Egret), Podicipedidae (Great Crested and Little Grebes), Rallidae (Coots, Common moorhen).
The association of physicochemical parameters and water lead levels from Lake Tonga with the waterfowl population's ecological indices showed correlations over the two study seasons. Numerous studies have associated limnologic heterogeneity with avifauna ecology and dynamics (Dmitrenko et al., 2005; Polak & Kasprzykowski, 2010; Keke & Elizabeth, 2018; Bara et al., 2020).
During the winter period, species richness was correlated with turbidity and dissolved oxygen. Indeed, with the influx of many species, the lake is frequented by large contingents of wintering, sedentary or migratory waterbirds passing through. This avifauna is distributed across the water-body according to its ecological requirements and engages, in particular, in its usual diurnal activities (food, rest, sleep, grooming, and flight) (Lazli et al., 2014; Elafri, 2017; Rizi et al., 2019). Many birds feed by diving to specific depths to find in the water column or into the sediments the trophic resources necessary for their survival (plant debris, seeds, Chironomids, mollusks, crustaceans). This leads to water turbidity, which is further accentuated by nutrient inputs from runoff from the watershed and the two streams that feed Lake Tonga (Wadi El Eurg and Wadi El Hout). During the summer season, abundance and species richness decrease, and only nesting waterbirds remain in Lake Tonga. A correlation between each ecological index and lead is recorded during this period. The lake is frequented in winter by many waterbirds species and is the site of significant poaching (Lazli et al., 2014; Gherib & Lazli, 2017; Menasria & Lazli, 2017) activities contributing to the contamination of the wetland with this metal. Birds, especially diving ducks, can thus accidentally or selectively ingest it during feeding (Bellrose, 1959; Sanderson & Bellrose, 1986) or the search for lodging. However, other species of ducks may also be susceptible to this pollution; it is dabbling ducks and grazing ducks, such as the Piping Duck, which exploit the muddy areas and located further from the bank, where maximum lead falls (Mauvais & Pinault, 1993; Triquet et al., 1992). Lead ingested by these species is then eroded into the gizzard and dissolved under the action of acid pH (Pain, 1996; Duranel, 1999). This can lead to lead poisoning (Forbes & Sanderson, 1978), which impacts different functions of waterbirds (such as reproduction, feeding behavior), resulting in a significant decline in bird population (Besombes, 2006).

Conclusion

This study assessed the physicochemical quality and lead contamination of Lake Tonga waters while linking bird populations to these investigations.
The results obtained show that the temperature, pH, and dissolved oxygen are within the standards. However, these waters exhibit high mineralization, as indicated by the high electrical conductivity values, TDS and turbidity. The lead dose values showed high levels compared to the WHO standard. The characterization of the population of waterbirds under this wetland revealed the presence of a rich and varied avifauna whose specific abundance and richness reach a maximum in winter, the period when large numbers of waterfowl use the lake either as a wintering, sedentary or transient migrant. Analysis of the data revealed winter correlations between species richness and turbidity, and dissolved oxygen. There was a close correlation between the lead content of the lake's surface water and the ecological indices considered in this study in the summer.
The present work has revealed the existence of a medium or long-term risk to the health of the animal and plant species of Lake Tonga and the balance of this ecosystem already threatened by eutrophication. In this respect, we recommend increased monitoring by the services concerned, especially during the wintering and migration periods of birds, and awareness-raising of residents living near the wetland.
Further studies will be needed to complement this work using lead pollution in sediments, knowing that they retain suspended metals in water. Other areas could also be explored, such as bioconcentration or bioturbation. Certain parameters will also have to be considered, particularly those that explain the dispersal of birds through the water body (water depth, habitat type, diet).

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