WATER QUALITY EVALUATION USING BENTHIC MACROINVERTEBRATES, PHYSICOCHEMICAL PARAMETERS AND HEAVY METAL LEVELS IN TWO LAKES (NORTHWESTERN ALGERIA)

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Abstract. In North Algeria, human activities have dramatically deteriorated the water quality of fresh waters and threatened aquatic ecosystem health. These rare hydrosystems deserve special attention because they are an important source of water, supporting the local ecological and environmental balance in this semi-arid region. To monitor the surface water quality of two lakes (Sidi M'hamed Benali and Lalla Setti), benthic macroinvertebrates, physicochemical parameters and heavy metals of the water were studied between May 2017 and May 2018. The results from a collection of 21462 individuals showed that macroinvertebrate assemblages significantly varied between the two lakes. Thirteen orders, 19 families and 64 genus-species taxa were identified for the two lakes, with the most dominant orders belonging to Hexapods, Copepoda and Platyhelminthes (Dugesiidae). The seven taxa collected are tolerant and highly adaptable to various environmental conditions. Thus, tolerant taxa such as the insect families Caenidae (34%) and Chironomiidae (10%) achieved the highest relative abundances in both lakes. The metric index values showed the highest diversity and evenness in Lake Lalla Setti communities. The biotic indices indicated a greater deterioration of water quality in the two lakes. The results of the physicochemical and heavy metal analyses show an ecological state conditioned by the excess of Calcium, $CaCO_3$ and Magnesium, which considerably increase the hardness of the water, to which anthropic pollutants, mainly nitrates and lead, are added.
Keywords: *benthic macrofauna, diversity indices, biological metrics, Lake Sidi M'Hamed Benali, Lake Lalla Setti*

Introduction

Faunistic and ecological studies address the fundamental importance of understanding the structure and function of natural systems and provide evaluations of the environmental "health" of hydro systems with insight into their management for sustainable equilibrium (Kaboré et al., 2016). Lakes are an important element of the natural environment that characterizes both the landscape and its ecological functioning (Jekatierynczuk-Rudczyk et al., 2012). They also provide various resources and ecosystem services to the human population, including water availability and storage for grazing and agriculture, as well as tourism (Sterner et al., 2020; Heino et al., 2021). These services include flood control, retention of pollutants and nutrients, climate regulation, recreation, tourism, and aesthetic values (Tranvik et al., 2009; La Notte et al., 2012; Vilbaste et al., 2016). Multiple ecosystem services are largely sustained by biodiversity and associated ecosystem functions (Schröter et al., 2014).

Aquatic biota in general and insects in particular provide reliable signals of the effects of pollutants or habitat alteration for direct biological assessment and monitoring (Karr

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and Chu, 1999). The trophic status of lakes determines the development and functioning of aquatic organisms (Jekatierynczuk-Rudczyk et al., 2012). Macroinvertebrates are mostly sessile or burrowing animals of limited horizontal mobility, i.e., they cannot evade a local environmental stressor and their community composition and structure are likely to reflect the environmental conditions at a given place (Avramidi et al., 2022). In addition, macroinvertebrate communities in lakes constitute a significant biomass and play an important role in overall production (James et al., 1998), they also act as ecosystem engineers by influencing sediment characteristics (Wantzen et al., 2011). They are key components of lake ecosystems that must be monitored along with other biological groups to define the ecological status of these ecosystems (Free et al., 2009). Macroinvertebrates are among the most frequently used bioindicators in water-quality assessment, mainly because of their relatively large size, ease of sampling, low to moderate identification effort, and relatively long-life cycles (Hellawell, 1986; Metcalfe-Smith et al., 1996; Barbour et al., 1999). Biological monitoring is considered to provide an integrated approach to assessing water and overall environmental quality (Hynes, 1970). Several investigations have been conducted on macroinvertebrates and their use as bioindicators (e.g., Blocksom et al., 2002; Nalepa et al., 2007; Schartau et al., 2008). Diversity indices are important statistical measures used to characterize richness and evenness of the species in the community (Magurran, 1988) and are used as tools for determining an ecosystem’s health and pollution status (Norris and Georges, 1993; Guerold, 2000). Consequently, in this study, different diversity indices were calculated to highlight their importance with respect to macrobenthic invertebrate communities.

In northwestern Algeria, most macroinvertebrate studies have been carried out on rivers, seldom on lakes. Some works concerned the nature and sources of water pollution in connection with copepods and zooplankton were realized at Lake Sidi M'Hamed Benali (Kerfouf et al., 2008; El Badaoui et al., 2015; Chiali and Cherifi, 2019), but no studies have been conducted on aquatic macroinvertebrates in our study sites. Lakes are severely affected and damaged due to human economic development and other aspects of anthropization. Various activities have an impact on water quality, nutrient levels, and macroinvertebrate communities. The critical factors that influence the spatiotemporal distribution of organisms are an interesting topic in ecological studies (Garrido et al., 2013). This study aims to evaluate the quality of the waters of the two lakes in Northwest Algeria by comparing the composition and structure of the invertebrate communities between the two lakes using ecological indices, physicochemical parameters, and heavy metals and to identify the environmental factors influencing the diversity of the macrobenthic fauna.

Materials and Methods

Study area

Located in northwestern Algeria (*Fig. 1*), two lakes have been surveyed: Lake Sidi M’hamed Benali (LSMB) is a reservoir retained by a settling and filtration dam constructed in 1945 to prevent flooding in the center of Sidi Bel Abbes. It is located at 1.7 km north of Sidi Bel Abbes; it has a garden on the north shore, a tourist attraction on the south shore, and is surrounded by fields of cereal crops presenting a source of contamination by phytosanitary products such as fertilizers, pesticides, and sediment. It also receives various pollutants from tributaries in the watershed and particularly from Oued Mekerra. It is part of the natural freshwater reserves of northwestern Algeria

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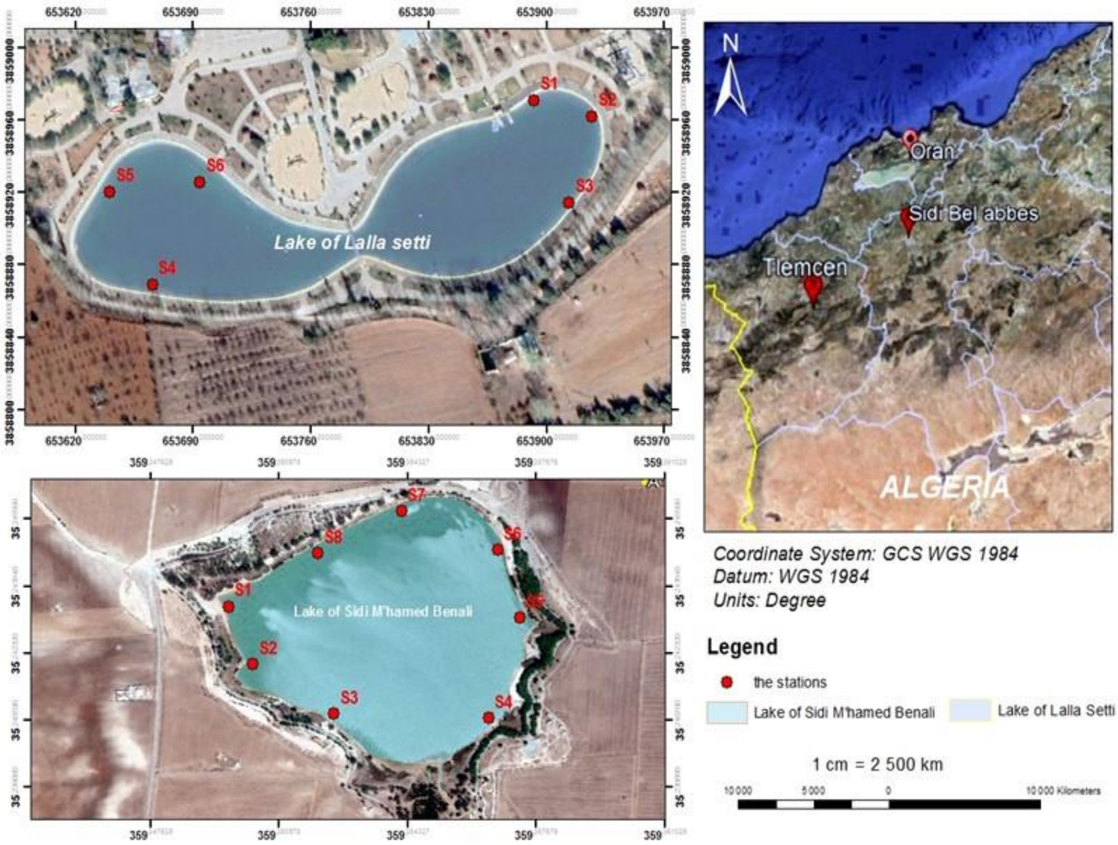
(Kerfouf et al., 2008). The second is Lake Lalla Setti (LST), a man-made lake constructed in 1988 and located 2.5 km south of the city of Tlemcen. This lake is delimited in the south by agricultural land, in the north by cliffs and houses, on the west by a recreation area, and on the east and west sides by tar-paved roads which penetrate the heart of the Hauts Plateaux. The threats to and pressures on these ecosystems are severe because such places are very attractive to a great number of tourists. The characteristics of the two lakes are mentioned in *Table 1*. These lakes are influenced by the Mediterranean climate with a mild and humid winter characterized by irregular precipitation, which causes flash floods and very hot and dry summers. The dry period can extend from four to six months between May to October.



Sites		S1	S2	S3	S4	S5	S6	S7	S8
LST	Latitude	34,86396	34,86392	34,86341	34,86298	34,86348	34,86359		
	Longitude	-1,31635	-1,31589	-1,31613	-1,31892	-1,31924	-1,31846		
LSMB	Latitude	35,24363	35,2423	35,24107	35,24042	35,24344	35,24565	35,24591	35,24461
	Longitude	-0,65302	-0,65233	-0,65081	-0,64528	-0,64412	-0,64538	-0,64824	-0,65133

Figure 1. *Geolocation of two study sites (Lalla Setti and Sidi M'Hamed Benali) and sampling points coordinates*

Methods

Macroinvertebrates samples were collected twice a month during May 2017 and May 2018 at 14 sampling points, eight in Lake Sidi M'hamed Benali and six in Lake Lalla Setti. Sampling was done randomly at a distance of 0.1 m to 1.0 m from the shore. A net with a diameter of 22 cm and a mesh of 250 µm were used for sampling and the material was preserved in 70% ethanol. In the laboratory, observations were made using a Ecoline

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Motic stereomicroscope with magnifying powers of 4x, 10x and 40x. Identification of some macrobenthic taxa (Trepaxonemata, Bivalvia, some Gastropoda, Malacostraca, some Crustacea, Insecta) was undertaken with appropriate keys to the family level (Tachet et al., 2000, 2006) and the genus level and sometimes the species level (Bedel, 1895; Perrier, 1927, 1930; Guignot, 1947; Tachet et al., 1980, 2000; Du Chatenet, 2005). Confirmation of specific names was performed with the assistance of specialists mentioned in the acknowledgments. For other macroinvertebrate groups (e.g., Copepoda, Cladocera, Ostracoda, and immature macroinvertebrates), the identification was limited to the more-inclusive order level.

Table 1. *Characteristics of lake Lalla Setti and lake Sidi M'hamed Benali, northwestern Algeria*

Characteristics	LST	LSMB
Situation	2.5 km south of Tlemcen	1.7 km north of Sidi Bel Abbes
Latitude	34°51'46.67"	35°14'30"
Longitude	-1°19.02'.93"	0°38'50"
Altitude (m)	1027	460
Date of creation	1988	1943
Purpose of dam	Tourism	Flood control, sediment filtration (Tourism)
Area (m^2)	22,100	450,000
Water depth max (m)	10	30
Volume of water (m^3)	1,590,772	3,000,000 (Boudiffa, 1993)
Source of water	Maffrouche dam & well	Wadi Mekerra (Kerfouf et al. 2008.
Environment	Agricultural	Agricultural
Max Temperature of air (°C)*	39	40.2
Min Temperature of air (°C)*	1.7	-2.4
Wind speed maximum (km/h)*	88.9	59.4

*Tutiempo.net 2021

The annual means of various diversity indices were calculated with the software Past (Paleontological Statistics v2.02). The eight diversity indices computed were taxonomic richness, dominance, Diversity H' (Shannon and Weaver, 1949), Simpson's index of diversity (1949), taxonomic evenness (Margalef, 1958; Piélou, 1966; Berger and Parker, 1970) and Jaccard (Magurran, 1988) to determine the interrelationship between the communities' composition and structure. Our study also computed indicators related to the species sensitivity to pollution: Nepal Lake Biotic Index (NLBI) based on a tolerance score of taxa, used to determine the ecological quality of lakes (Shah et al., 2011), the Family Biotic Index (FBI) (Hilsenhoff, 1988) and Average Score Per Taxon (ASPT) (Friedrich et al., 1996).

For the physicochemical and metal analyses, a total water volume of 1.8 L was taken at each station from a depth of 1.0 m. These surface water samples were collected in sterile polyethylene bottles and kept in an ice box, protected from the sun, and transported to the laboratory for analys. In the laboratory, 1.5 L was used for measuring chemical and heavy metal parameters and 300 ml for physical parameters following ISO 14001 and 5667.1. The parameters temperature, pH, dissolved oxygen (O_2), conductivity (CDT), salinity (S), and redox potential were measured in situ with a multi-parameter WWT P4. Turbidity (TRBT), Color (Cl), Calcium hardness ($CaCO_3$), Calcium (Ca), Nitrates (NO_3-), Nitrites (NO_2-),

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Zinc (Zn), Total Copper (Cu), Magnesium (Mg), and Manganese (Mn) were quantified with spectrophotometry (spectrophotometer WTW 340i, Wagtech WTD 7100). Orthophosphates (PO_4-) measurements were taken with a multiparameter bench photometer for wastewater treatment application (HANNA instrument HI 83214). Dosages of metals (Iron Fe, Cadmium Cd, and Lead Pb) determined with Spectrophotometry Atomic Absorption with Flame (SAAF Perkin Elmer Analyst Atomic Absorption spectrometer 300. Logiciel AA Win Lab.).

Statistical analysis

The normal distribution was verified in advance by the application of the Shapiro-Wilk test. The distributions were mostly asymmetrical, which led us to choose non-parametric alternatives for the statistical analysis. The data are presented as the averages plus or minus standard deviation (m ± SD). Intersite comparisons were performed using ANOVA 1 and the Tuckey test followed by the Kruskal-Wallis test. Furthermore, a Principal Component Analysis (PCA) was performed using the XLstat 21 on standardized data, whose objective is to characterize, by a multivariate approach. In addition, a dendrogram based on Hierarchical Ascending Classification "HAC" was constructed to visualize the similarities more accurately among the parameter's variations. Principal Component Analysis (PCA) and HAC were performed to identify the most influential variables affecting the biodiversity indices of the macrobenthic invertebrates.

Results and discussion

Composition and structure of communities

In total, 21,461 individuals and 64 taxa were collected, representing 17 orders, 30 families, 40 genera, and at least 53 species in LSMB and 13 orders, 24 families, 28 genera, and at least 40 species in LST (*Table 2*). A faunistic comparison between the two lakes shows 19 orders, 13 families, and 29 genus-species taxa in common (*Table 2*) and the fauna of LSMB lake is more diverse than that of LST. The composition of the two communities is very different (similarity Jaccard index = 30.77%).

The greatest abundances were observed in LSMB where 18,834 specimens were collected against only 2,627 individuals in LST. The faunistic spectrum consists in the two lakes mainly of hexapods, crustaceans, and molluscs. Three families (Dugesiidae, Caenidae, and Chironomidae) are the most abundant; however, the Chironomidae are the most abundant in LST, with 32%, and the Caenidae were most common, with 50%, in LSMB (*Table 2*). The malacofauna included a total of 6 families of Gastropods with 6 taxa constituting 11.32% of the taxonomic richness of LSMB and 3 taxa (7.5%) in LST. The crustacean fauna is represented mainly by copepods with 32.9% in LSMB and 29% in LST. However, the insect fauna is the most dominant group with 19 families and 48 genus-species taxa identified for LSMB versus 18 families and 30 genus-species taxa for LST. Among insects, 15 genus-species taxa belonging to families of Coleoptera were identified, followed by Odonata (12), Heteroptera (9), and Ephemeroptera (5).

The analysis of the macroinvertebrate fauna of the two lakes shows that the LST fauna is significantly lower than that of LSMB in number of individuals and in family and taxonomic richness. This difference can be explained primarily by the different typology of the two lakes.

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Table 2. *List of macrobenthic taxa recorded from lake Lalla Setti and lake Sidi M'Hamed Benali, northwestern Algeria*

Class	Order	Family	Genre / Species	LST	LSMB
Trepaxonemata	Tricladida	Dugesiidae	*Dugesia sp*	261	2150
Bivalvia	Unionoida	Unionidae	*Anodonta sp*	0	88
Gasteropoda	Basommatophora	Physidae	*Physella sp*	7	312
		Lymnaeidae		0	10
			Galba sp	0	2
	Caenogastropoda	Planorbidae		15	78
		Ancylidae	*Ancylus fluviatilis* (Müller, 1774)	61	117
Malacostraca	Isopoda	Asellidae	*Assellus aquaticus* (Linnaeus, 1758)	0	63
Crustacea	Copepoda			756	6025
	Cladocera			26	111
		Daphniidae	*Daphnia* sp	7	37
	Ostracoda			43	159
Entognatha	Collembola	Poduridae	*Podura aquatica* (Linnaeus, 1758)	0	114
Insecta	Ephemeroptera	Caenidae	*Caenis* sp	200	6303
			Caenis luctuosa (Bürmeister, 1839)	74	100
		Baetidae	*Procloeon* sp	25	129
			Cloeon sp	13	96
			Baetis sinespinosus (Soldán & Thomas, 1983)	0	145
	Odonata	Coenagrionidae		40	39
			Cœnagrion sp	0	25
			Smatocholora sp	8	0
			Enallagma sp	0	4
			Nehalennia sp		2
			Erythromma sp	6	2
			Ischnura sp	0	10
		Platycnemididae	*Platycnemis sp*	0	1
		Aeshnidae		3	0
			Aeshna sp	0	55
		Libellulidae		1	17
			Orthetrum sp	0	3
			Sympetrum sp	0	3
			Brachytron sp	0	1
	Hemiptera	Notonectidae	*Notonecta sp*	103	0
		Naucoridae		0	227
		Nepidae	*Nepa sp*	2	0
		Pleidae	*Plea sp*	33	2
		Corixidae	*Paracorixa sp*	161	0
			Corixa sp	42	0
			Cymatia sp	91	2
			Micronecta sp	5	0
		Mesoveliidae		1	0
		Veliidae		17	0
		Gerridae	*Gerris sp*	2	0
		Hydrometridae	*Hydrometra* sp	0	1
	Megaloptera	Sialidae	*Sialis sp*	10	81
	Coleoptera	Noteridae	*Noterus laevis*	1	21
		Dytiscidae	*Acilius sp*	1	0
			Hydrovatus	5	14
			Hygrotus inaequalis (Fabricius, 1777)	1	2

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Class	**Order**	**Family**	**Genre / Species**	**LST**	**LSMB**
			Laccophilus hyalinus (DeGeer, 1774)	1	7
			Laccophilus minutus (Linnaeus, 1758)	2	1
			Agabus nebulosus (Forster, 1771)	1	0
		Hydrophilidae	*Anacaena sp*	1	5
		Hydrophilidae	*Helochares sp*	8	15
			Helochares lividus (Forster, 1771)	0	86
			Berosus linear collus (Leach, 1817)	0	2
			Coelostoma hispanicum (Küster, 1848)	6	128
		Hydraenidae	*Ochthebius sp*	1	1
			Hydreana sp	0	2
		Hydrophilinae	*Laccobius sp*	0	1
		Dryopidae	*Dryops algiricus*	0	2
			Dryops gracilis	0	2
	Trichoptera	Economidae	*Ecnomus deceptor* (McLachlan, 1884)	5	73
	Diptera	Chironomidae		582	1944
Arachnida	Araneae	Dictynidae	*Argyroneta aquatica* (Clerck, 1758)	0	14

According to Moss et al. (2003), the typology of the lakes is primarily based on physical criteria (climatological, geological, morphological, or hydrological, including conductivity) and these parameters influence the group composition of macroinvertebrates, secondarily by different design dates, with the establishment of macroinvertebrate communities occurring earlier in LSMB (1945) than in LST (1988). Riparian and aquatic vegetation is a source of nutrients; Breitburg et al. (1999) found that most taxa increased in abundance in response to nutrient additions, Harding and Wright (1999) found no change in species richness but indicated that species composition changed with nutrient concentrations. Riparian vegetation is also considered to be a factor affecting the faunal composition of the two lakes studied, as the shores of LSMB are densely vegetated, whereas riparian vegetation in LST is more sparce. Number of families (24 at LST and 30 at LSMB) is relatively higher, compared to other lakes; 22 families belonging to seven orders were sampled at Lake Réghaïa where insects were the best represented group with 18 families (Djitli et al., 2021). Similar figures have been reported in Lake Tonga (Djamai et al., 2019) but, according to other studies, this richness is clearly underestimated (Khedimallah and Tadjine, 2016). Conversely, the family richness observed in our study is slightly lower than that of other oligohaline coastal lakes in the Mediterranean basin or at other latitudes (Boix et al., 2010; Pérez-Bilbao et al., 2013).

Some groups (e.g., Odonata, Planariidae, Lymnaeidae, and gastropods) presented the lowest abundances of our sample, although in general they are known for their high abundance in coastal wetlands (Correa-Araneda et al., 2014; Martinez-Haro et al., 2015; Khedimallah and Tadjine, 2016; Djamai et al., 2019; Guézo et al., 2019; Sellam et al., 2019). Regarding the order Heteroptera, the endemic Ibero-Maghreb family Veliidae (Aukema and Rieger, 1995) is known in Morocco, Algeria, and southern Spain (Slimani et al., 2022). Naucoridae is an abundant species in the temporary tides in East Algeria (Zouaidia et al., 2021). Trichoptera are one of the most sensitive insect groups to human disturbance and are used for biomonitoring of many types of freshwater habitats (Hornung and Rice, 2003; Houghton, 2015) but *Ecnomus deceptor* is the only Trichoptera species found in the LSMB and has already been mentioned in northwestern Algeria as a tolerant and widely distributed species (Bemmoussat-Dekkak et al., 2021).

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Chironomidae were very abundant during our study and especially at the LSMB, where they represented 30% of the fauna. According to Hone and Beneberu (2020), the diversity of chironomids was relatively higher at a site that was relatively far from the waste discharge tube of a tannery. A suggestion made by Oliveira et al. (2010) and confirmed by the work of Hone and Beneberu (2020), provides that a decrease in Chironomid diversity in a given site and the dominance of the genus *Chironomus*, a species tolerant to organic and industrial pollutants, indicates poor water quality. However, we cannot confirm these suggestions in our observation as the chironomid larvae could not be identified.

The order Tricladida was represented by a single family, Dugesiidae, and probable by a small number of species (Dejoux and Wasson, 1990). The genus *Dugesia* also was most abundant during our survey. Similar abundance was also noted in stagnant water in Sidi Mohammed Ben Abdellah in Rebat (Morocco) (Arifi et al., 2019). According to AFNOR (1992), the Platyhelminthes are resistant to pollutants and their abundance is synonymous with environmental disturbance. Abundance of this genus is related to water quality. Freshwater planarians of the genus *Dugesia* are well represented in the Mediterranean region (Sluys et al., 1998; Charni et al., 2004). In North Africa, asexual populations of *Dugesia* constitute the majority of triclads present in freshwaters (Charni et al., 2004).

Six taxa of Ephemoptera (*Caenis* sp., *Caenis luctuosa*, *Procloen* sp., *Cloeon* sp., *Baetis* sp. and *Baetis sinespinosus*, which are tolerant to organic pollution, were identified during our research. *Caenis luctuosa* and *B. sinespinosus* are fairly frequent in western Algeria (Benhadji et al., 2019). *Caenis luctuosa* is a species of both running and stagnant waters (Bebba et al., 2015; Lamine, 2021) and also has been reported in freshwater. It was present in both lakes with large numbers during our survey.

Faunistic similarities were noticed between the two surveyed lakes and that of neighboring Algerian lakes, namely 22 and 20 families listed respectively at Lake Reghaïa (Djitli et al., 2021) and lake Tonga (Djamai et al., 2019). Six from Reghaïa and 13 from Tonga are in common with the two lakes examined in our study.

The degradation of the water quality and pollution of some Algerian lakes are been reported by more authors (Ahriz et al., 2009; Nadir and Boualem, 2016; Djitli et al., 2021; Bouchelouche et al., 2021; Naili et al., 2021; Houmani et al., 2023). The works of Djitli et al. (2016), Khedimallah et al. (2016), and Bouchelouche et al. (2021) have shown a low taxonomic richness and diversity that corroborate with our results. The developed NLBI index has performed well for the Nepalese lakes and the reservoir (Shah et al., 2011). The results of the biological analyses indicated different conditions between the two lakes (*Table 3*). The indices rank Lake LST generally in a better status with a rather moderate diversity and a more marked regularity. Values of diversity indices were usually lower in LSMB than LST in except that the Berger-Parker index shows a higher value. The Margalef Index and the FBI Index are also lower for LST than LSMB. The low values of the Parker-Berger index could be explained by the strong dominance of the taxa. The indices show that LST communities are well regulated, and water is less polluted than LSMB (*Table 3*). The biotic indices also show a higher degree of pollution in the LSMB. Thus, the NLBI values appear to indicate moderate pollution in LST (value 4.56) against heavy pollution (value 3.85) in LSMB. This The FBI index indicates organic pollution ranging from substantial pollution in LST (value 5.76) to very substantial pollution likely in LSMB (value 6.96). The ASPT index represents the average tolerance score of all taxa within the community, it is calculated by dividing the total score of families of benthic macroinvertebrates that have been given a score between 1 and 10 based on their pollution

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tolerance, with the most sensitive receiving the highest score by the total number of species counted. It indicates doubtful water quality with similar values (*Table 3*). All the indices selected to determine the water quality indicate mediocre water quality in both lakes with a more accentuated degradation in LSMB.

Table 3. *Indices of diversity values of macroinvertebrates communities from lake Lalla Setti and lake Sidi M'Hamed Benali, northwestern Algeria*

Indicators	LST	LSMB
Taxonomic richness	41	53
Individuals	2628	18834
Simpson's diversity (1-D)	0.84	0.76
Shannon Weaver Index H'	2.35	1.88
Evenness_e^H/S	0.26	0.12
Margalef Index	5.08	5.28
Piélou Equitability (J)	0.63	0.47
Berger-Parker Dominance	0.29	0.33
NLBI (Biotic Index)	4.56	3.85
FBI Index	5.76	6.96
ASPT Index	5.11	5.04

The degradation of the water quality by pollution of some Algerian lakes has been reported by other authors (Ahriz et al., 2010; Nadir and Boualem, 2016; Bouchelouche et al., 2021; Djitli et al., 2021; Naili et al., 2021; Houmani et al., 2023). The works of Khedimallah and Tadjine (2016), Djitli et al. (2021), and Bouchelouche et al. (2021) have shown a low taxonomic richness and diversity that correspond with and corroborate our results. The NLBI index has performed well for Nepalese lakes and a reservoir (Shah et al., 2011). The values obtained from this index in our study are in agreement with those of the (FBI, ASPT) used for lakes in the neighboring European area. Although Nepal is very far from our study site and the index was designed for lakes and reservoirs of that region, it also performed well for the Algerian lakes studied.

Analysis of physicochemical parameters and heavy metals of the water

The variations of physicochemical parameters and heavy metals (Mn, Cu, Zn, Cd, Fe, and Pb) in the water are represented in *Table 4* using the minimum, maximum, mean, standard deviation, and their p-values. Results of ANOVA 1 and T-test showed no significant ($p > 0.05$) differences between months for twelve of the water variables during the study period (*Table 4*).

Temperature, color, potential redox, dissolved oxygen, salinity, conductivity, nitrates, nitrites, Zinc and Lead were relatively constant throughout the year. The standard deviation values show also that there was no significant difference between the samples during the study year. Thus, for the two lakes, the water was alkaline, turbid, oxygenated, and with a negative redox potential (*Table 4*).

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Table 4. *The minimum, maximum and average values of physicochemical parameters and heavy metals in water samples analysed at the two sampling sites (lake Lalla Setti and lake Sidi M'hamed Benali) (Mean values±SD, n=12)*

Site Name	**LST**			**LSMB**		
Chemical parameters	Min	Max	Mean ± SD	Min	Max	Mean ± SD
Temperature (°C)	6.6	26.6	16,63±5,11	5	30.2	16.60±5.80
Color (Pt)	5	940	293.83±202,75	5	950	349.37±0,23
Potentiel Hydrogen pH	7,3	8.46	7.89± 0,31	7.7	9.24	8.44± 0,40
Dissolved Oxygen ($mg.L^{-1}$)	3.22	8.3	6.6±1.14	4.11	8.32	6.10± 1.24
Potentiel Redox (mV)	-42	-136	-83.45 ± -23.53	-82	-18	-52.45 ± -19.98
Turbidity (NTU)	6	135	40.75 ± 39.48**	6	220	54.08 ± 52.31**
Salinity ($mg.L^{-1}$)	0.00	0.002	0,001 ± 0.00015	1.2	1.4	1.35 ± 0.078
Conductivity (mS/cm)	0.31	0.36	0.34 ± 0.0013	2.54	3	2.84 ± 0.15
Nutrients						
Calcium ($mg.L^{-1}l$) Ca^{2+}	12	36	25.75 ± 7	90	175	127 ± 25.69**
Hardness ($mg.L^{-1}$) $CaCO_3$	26	86	63,3± 17,50	174	480	314.75 ± 64.85*
Total Phosphorus ($mg.L^{-1}$)	0.11	0.92	0.53 ± 0.20**	0.11	0.97	0.43 ± 0.23***
Nitrates ($mg.L^{-1}$)	0.56	17.2	4.35 ± 4.79	0.38	7.4	2.29 ± 1.73
Nitrites ($mg.L^{-1}$)	0.03	0.14	0.078 ± 0.03	0.02	0.2	0.065 ± 0.04
Magnesium ($mg.L^{-1}$) Mg^{2+}	21	70	38.33 ± 15.52	30	380	194.37 ± 130.26***
Heavy metals						
Manganese ($\mu g.L^{-1}$)	1.01	8.01	3.08 ± 0.02	2.01	28.01	8.3 ± 6.6**
Copper ($mg.L^{-1}$) Cu^{2+}	0.12	0.66	0.37 ± 0.18*	0	1.15	0.33 ± 0.24
Iron ($mg.L^{-1}$) Fe^{2+}	0.43	2.32	0.74 ± 0.5	1.32	2.12	1.80 ± 0.24
Zinc ($mg.L^{-1}$) Zn^{+}	0.08	0.36	0.19 ± 0.09	0.04	0.9	0.29 ± 0.27
Cadmium ($mg.L^{-1}$) Cd^{+}	0.02	0.067	0.036 ± 0.017**	0.002	0.04	0.019 ± 0.013**
Lead ($mg.L^{-1}$) Pb^{2+}	0.75	2.12	1.37 ± 0.43	0.51	1.84	1.00 ± 0.42

Using the Anova test and T-Test: *indicates that temporal variations are significant ($p < 0.05$), ** high significant difference ($p<0.01$) and *** highly significant difference ($P < 0.001$)

During the rearing period, nine parameters (pH, turbidity, hardness $CaCO_3$, phosphate, Calcium, Magnesium, Manganese, and Cadmium) were significantly different ($p <0.05$) (*Table 4*). The application of the Kruskal-Wallis test to compare physicochemical parameters and heavy metals in water showed that there were significant intersite differences for pH, salinity, conductivity, $CaCO_3$, Calcium, Iron, Magnesium, Manganese and Cadmium (*Fig. 2*).

The water temperature values varied between 16.60 ± 5.80°C in LSMB and 16.63 ± 5.11°C in LST with a maximum value of 30.2°C recorded at LSMB. However, they presented seasonal fluctuations with values ranging from 5 to 6°C in winter and 26.6 and 30.2°C in summer. The waters of the two lakes were colored green, indicating the presence of Cyanobacteria. Regarding pH, the analytical data revealed a difference in mean values in the two sites ($F = 17.22$ df = 19, $p = 0.000$). The average values were around 7.89 ± 0.31 in LSMB and 8.44 ± 0.40 in LST (*Fig. 2*). Dissolved Oxygen levels revealed similar means between the two sites, ranging from 6.10 ± 1.24 mg L^{-1} to 6.6 ± 1.14 mg L^{-1} at LSBM and LST, respectively. Mean values of turbidity were in the order of 40.54 ± 39.748 NTU at LST and 54.08 ± 52. 31 NTU at LSMB.

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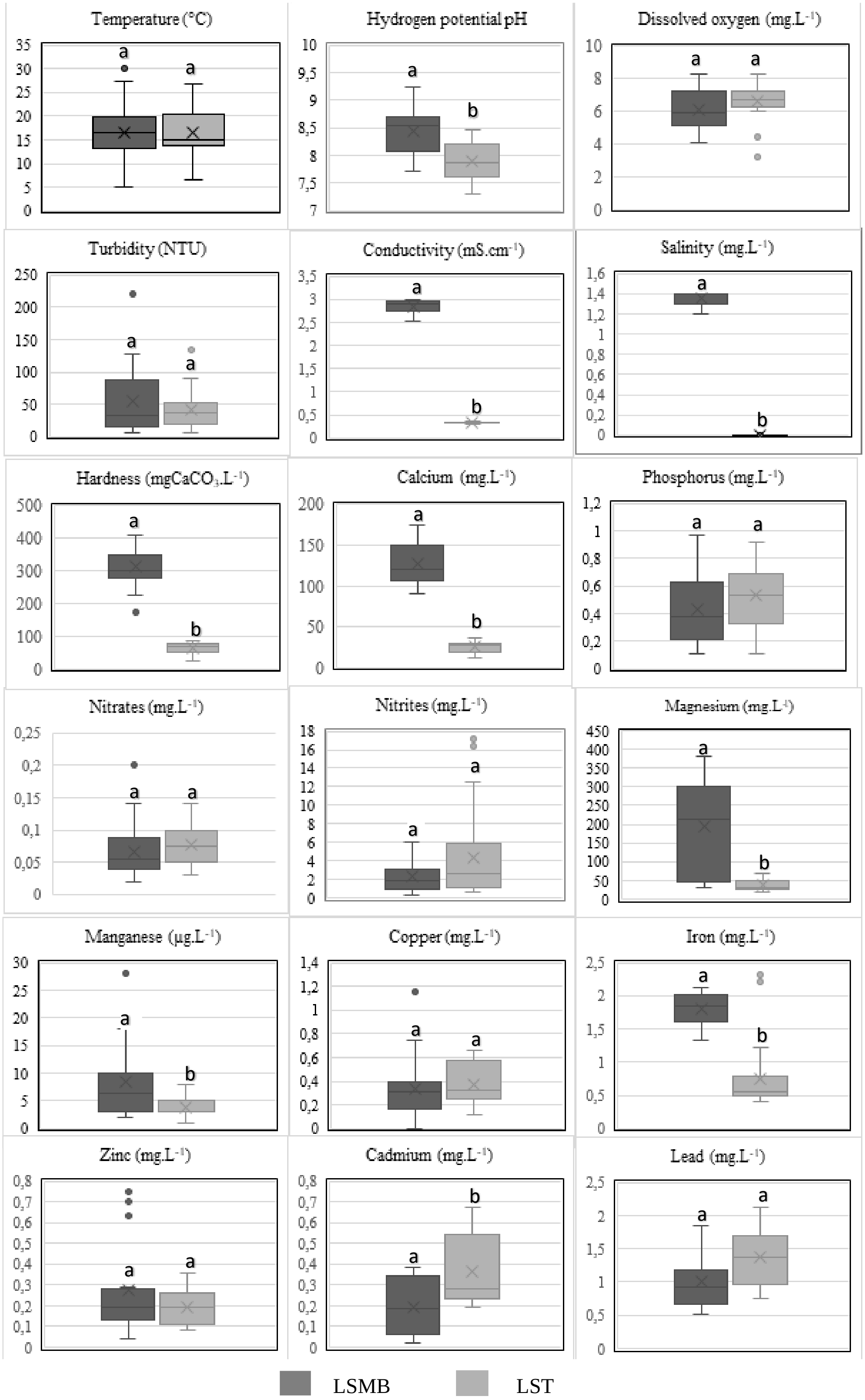

Figure 2. *Variation of physicochemical parameters and heavy metals in lake Lalla Setti and lake Sidi M'hamed Benali. Letters a and b indicate that intersite variation is significant at p <0.05, using the Kurskal-Wallis test. Boxplots labeled with the same letter are not significantly different at p > 0.05. Mean values ± SE, n=12*

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The highest average values were recorded during the winter with a maximum of 220 NTU at LSBM and 135 NTU at LST. The spring period was characterized by a 5-NTU reduction compared to winter for both lakes. Kruskal-Wallis test revealed a variation of salinity between the two sites (F = 3639, df = 11,01, p = 0,000) (*Fig. 2*); the mean value of salinity was 1.35 ± 0.07 in LSMB and zero in LST. The waters of LSMB were less mineralized than those of LST, which were moderately mineralized. Conductivity results showed that the average values varied from 1.35.95 ± 0.07 $mS.cm^{-1}$ at LST to 0.31 ± 001 $mS.cm^{-1}$ at LSMB, a very high significant difference was noted between two sites (F = 3132, df = 11.1, p = 0.000). We found that the concentrations of nutritional salts are similar at both sites except for Calcium and phosphate. The results found showed that the major calcareous element was calcium bicarbonate, whose values varied from 174 to 480 $mg.L^{-1}$ at LSBM. All the values of the conductivities found in LST (between 0.31 and 0.6 $mS.cm^{-1}$) were lower than the values noted in LSBM (between 2.5 and 3), indicating that water is poorly mineralized in the first and moderately in the second lake. Conductivity results showed that the mean values ranged from 1.35.95 ± 0.07 $mS.cm^{-1}$ at LST to 0.31 ± 001 $mS.cm^{-1}$ at LSBM. A very high significant difference is noted between two sites (F = 3132, df = 11.1, p = 0.000).

We noted that nutritional salt concentrations were similar in the two sites except for Calcium and Phosphate (*Fig. 2*). The results show that the major calcareous element was calcium bicarbonate, varied from 174 to 480 $mg.L^{-1}$ at LSBM; these high values can be explained by the calcareous nature of the soil of that study region. The maximum seasonal values were registered in autumn; however, the lowest mean values were recorded in spring. However, at LST, the mean value does not exceed 86 $mg.L^{-1}$, the high difference is noted between the two sites (F = 213, df = 12.42, p <0,001). The box plots (*Fig. 2*) clearly show that the variation in Calcium at the two sites was almost the same as the Hardness $CaCo_3$ (F = 239.7, df = 12, 84, p <0.001). The values of phosphorus and nitrates are high in the two lakes, but they are more important at LST. The average values for NO_2, are in the order of 4.35 ± 4.79 at LST and 2.29 ± 1.73 $mg.L^{-1}$ at LSMB and for phosphate PO_4, 0.43 ± 0.23 at LST and 0.53 ± 0.2 $mg.L^{-1}$ at LSMB. Their concentrations varied throughout the year: Spring was characterized by the lowest values and the highest values were in autumn (*Fig. 3*). Nitrites were detected in the waters of the two lakes, had very low levels, and were below normal (0.1 $mg.L^{-1}$) most of the time. The average nitrite values recorded were low in both lakes, in the range of 0.07 $mg.L^{-1}$ ± 0.031 at LST and 0.06 $mg.L^{-1}$ ± 0.031 at LSMB. However, maximum values of more than 0.1 $mg.L^{-1}$ were recorded during the autumn months. This alteration of the quality of water by nitrogen compounds and phosphorus could be attributed to the natural degradation of organic matter or nitrogen and phosphorus fertilizers from neighboring agricultural fields.

The concentration of magnesium was low at LST, between 21 and 70 $mg.L^{-1}$, with small variation during the year (*Fig. 3*). However, the highest and lowest concentrations were recorded in LSBM, in the order of 380 $mg.L^{-1}$ during the winter and 30 $mg.L^{-1}$ during the spring, with an annual average of 194.37 $mg.L^{-1}$ (*Table 3*). Regular variations of annual averages occurred at two sites which appeared to have increased greatly at LSBM (F = 18.84, df = 11.23, p = 0.001). The values of Manganese at LST fluctuated between a minimum of 1.01 $\mu g.L^{-1}$ during autumn and a maximum of 8.01$\mu g.L^{-1}$ during winter with an annual average of 3.08$\mu g.L^{-1}$. At LSBM, it attained its minimum of 2.01 $\mu g.L^{-1}$ during winter, tended to increase during spring, and reached a maximum value of 28.01 $\mu g.L^{-1}$ during summer, with an annual average of 83 ± 6.6 $\mu g.L^{-1}$. A significant difference is noted between the two study sites (F = 7.94, df = 12.57, p = 0.014).

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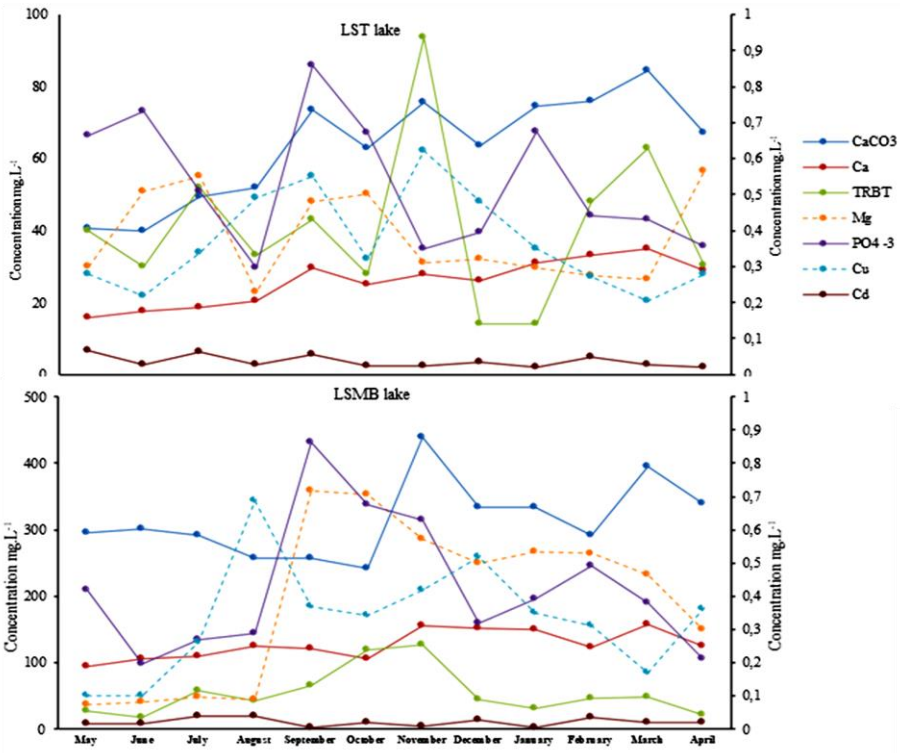

Figure 3. *Temporal pattern variation of the physicochemical parameters of water during the studied period in lake Lalla Setti and lake Sidi M'Hamed Benali. Plots correspond to variation in average monthly concentrations of hardness ($CaCO_3$), Calcium (Ca), turbidity (TRBT), and Magnesium (Mg) (left Y- axis) and variation in average monthly concentrations of total Phosphate (PO_4), Copper (Cu) and Cadmium (Cd) (right Y-axis)*

With regard to TMR in water, the mean Cu concentrations of the two sites ranged from 0.37 ± 0.02 mg.L^{-1} at LST to 0.33 ± 0.24 mg.L^{-1} at LSMB. The mean Zn concentrations were between 0.19 ± 0.09 mg.L^{-1} at LST and 0.29 ± 0.27 mg.L^{-1} at LSMB; they reached their maximum values in winter with 0.36 mg.L^{-1}. Iron concentrations ranged from 0.42 to 2.32 mg.L^{-1}, with an average of 0.74 ± 0.5 mg.L^{-1} at LST from a higher concentration in LSMB where the mean values reached 1.80 ± 0.24 mg.L^{-1}. A significant difference of means is noted between the two sites ($F = 39.64$, $df = 15.72$, $p = 0.003$) (*Fig. 2*). For Pb and Cd, the concentrations were above the tolerated concentrations in water. The highest Cadmium average was noted at LST (*Table 4*), a minimum of 0.02 mg.L^{-1} was estimated during winter and a maximum of 0.19 mg.L^{-1} during spring, thus indicating temporal and intersite variation ($F = 7.14$, $df = 20.48$, $p = 0.013$). During the period of study, Cd concentrations averaged 0.036 mgL^{-1}) in LST and 0.019 mg.L^{-1} in LSMB above the allowable limits, with a range of 0.002–0.06 mg.L^{-1}. In LST, the lowest concentration was 0.02 mg.L^{-1} in September and October 2017 and the peak concentration was in February 2018 (0.06 mg.L^{-1}). In LSMB, the lowest concentration was 0.02 mg.L^{-1} in March 2017, and the highest concentration was 0.038 mg.L^{-1} in February, July, and August 2017 (*Fig. 3*). Important variation is noted in each lake (*Fig. 2*), Cd concentration was above the safety standard probably because of spraying agrochemicals rich in Cd compounds which eventually enter the water and increase the concentration.

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A Principal Component Analysis (PCA) was performed, whose matrix is a crossing of the set of variables selected (20 physicochemical parameters and twelve months for the two lakes). The two first axis explained 51.23% of the total variation estimated in all grouped variables, with PC1 including 36.93% of the total estimated variation and PC2 with 14.30%. Characteristics of each PC were determined based on estimated factor loadings. PC1 was related to Ca, $CaCO_3$, salinity, conductivity, and Iron, PC2 referred to turbidity and Mn. To better understand the overall variability of the tested parameters, the recorded data were submitted to hierarchical cluster analysis (HCA, *Figs. 4A and 4B*).

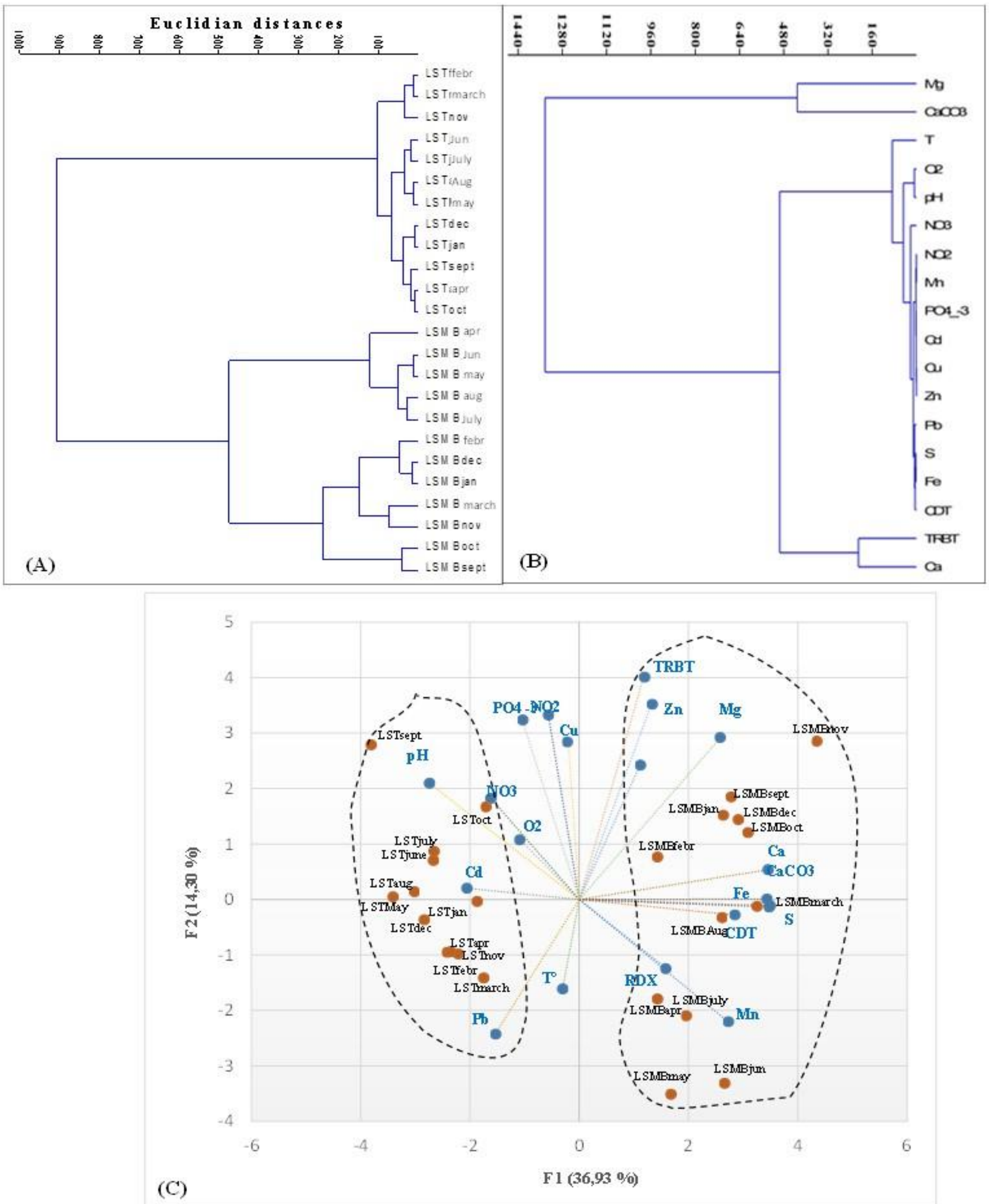

Figure 4. *Statistical analysis of the environmental variables in the two lakes (LST and LSMB) by month: (A) and (B) show hierarchical ascending classification of sampling sites according to the monthly variation of the measured parameters (rows and columns, respectively); (C) PCA plot showing the position of samplings (red color) in relation to the physicochemical characteristics and heavy metals of water (blue color), with the ellipses corresponding to sites of the two lakes*

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The analysis of Euclidean distances through the HCA and the PCA revealed different physicochemical conditions in the two lakes (*Fig. 4*) with temporal variation. On axis 1, the Group constructed from six parameters (Ca, $CaCO_3$, CDT, salinity, and Iron on positive coordinates and Cd on negative coordinates) is the most significant in the segregation between the physicochemical conditions of the two lakes studied. The alkalinity, hardness, ionic charge, and iron at LSMB were more accentuated while LST is marked by a significantly higher Cd concentration. The column points (months) are distributed on axis 2 according to the importance of the parameters turbidity and Mg (positive coordinates) and Pb and Mn (negative coordinates). The dry period (i.e., May to August) was characterized by lower values of $CaCO_3$, Ca, and Mn but greater values of turbidity, Mg, and phosphate were associated with the spring period. Thus, two periods were distinguished, and the main differences were observed between summer and the rest of the year (*Figs. 3 and 4*).

According to *Figure 4*, at LST, the months of September, October, and November are marked by an increase in nitrate concentrations and pH, and the months of February, March, and April are marked by an increase in lead concentrations. During the autumn months, water turbidity and magnesium reached maximum values in LSMB but the summer months were marked by high manganese concentrations. High concentrations of physicochemical parameters (conductivity, hardness, Calcium, Magnesium, nitrates, and nitrites) and heavy metals (Iron and Lead) are the principal sources of the degradation of the water quality in the two lakes. However, most water quality parameters do not exceed acceptable limits, especially in LST (Rodier et al., 2009).

Use of pesticides in agricultural land adjacent to the two lakes, water coming from the Mekerra River (enriched by the inflow of sewage and drainage systems), the dissolution of the organic matter coming from the banks of the lakes, and the transport of agricultural residues and animal excrement are the main causes of water pollution in these lakes. Thus, the pollution threat in these lakes includes agricultural and domestic sources. These results corroborate with those of El Badaoui et al. (2015); Bouslah et al. (2017); Hamil et al. (2018); Chiali and Cherifi (2019). Around the lakes, runoff from cereal crop fields leads to contamination by excess fertilizers and pesticides). Thus, the lakes receive various pollutants from their catchment areas and particularly the Mekerra Wadi which has become an open sewer (Boudiffa, 1993).

The values of the means of the physicochemical parameters established in LSMB by Chiali and Cherifi (2019) are slightly different from those of our study: We note a rise in temperature of 1 degree and a decrease of phosphate and nitrate, respectively 0.265 mg and 1.03 mg; these results suggest the phenomenon of self-purification of lakes. The waters of both lakes are turbid and have low oxygen concentrations. The highest turbidity values were recorded during the winter season for both lakes, a result that is inconsistent with that of Lake Tonga (Naili et al., 2021), where extreme turbidity values were recorded during summer. According to Lamizana-Diallo et al. (2008), dissolved oxygen is involved in the respiration of aquatic organisms, the degradation of pollutants, and the abundance of water turbidity favoring the reduction of luminosity and photosynthetic phenomena. Thus, the low oxygen values are the reason for the high turbidity and the eutrophication of both lakes, a phenomenon already observed in Lake Tonga by Naili et al. (2021).

The PCA revealed the direct correlation between $CaCO_3$ and Calcium responsible for the hardness of the waters of the two lakes, a result already mentioned in some other Algerian lakes (Touhari et al., 2015; Bouslah et al., 2017). The sediments of the LSMB consist mainly of ancient calcareous alluvial deposits, which may explain the high

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concentrations of $CaCO_3$ and Calcium (El Badaoui et al., 2015). The survey conducted by El Badaoui et al. (2015) showed that the water in the LSMB had slight inorganic pollution, however, our results show a more pronounced degradation of the water characterized by high levels of conductivity, hardness (Ca, $CaCO_3$, and Mg), nitrates, nitrites, Lead, and Iron. In LST, deterioration of the quality water is mainly linked to total phosphates, nitrates, and Lead which could be related to the use of paint, fertilizers, and pesticides. According to Hinesly and Jones (1990), in surface waters, phosphorus concentrations exceeding 0.05 $mg.L^{-1}$ may cause eutrophic conditions; the high phosphorus concentration in LSMB may explain in part the proliferation of *Stuckenia pectinata* algae which causes eutrophication. Moreover, nitrates were toxic to most freshwater invertebrates (Camargo et al., 2005).

Conclusion

Benthic macroinvertebrate data reflected that both lakes are undergoing ecological degradation. This degradation is indicated by reduced taxa richness, diversity, regularity, and presence of pollution-tolerant benthic macroinvertebrates, generally taxa undemanding and with a wide ecological range tolerance. The ecological status of Lake Sidi M'hamed Benali has been degraded because it receives direct urban wastewaters containing various contaminants. Physicochemical variables related to agricultural activities were present in higher concentrations in touristic Lake Lalla Setti. PCA revealed that physicochemical variables associated with pollution, such as conductivity, hardness, nitrates, Lead, and Iron significantly deteriorate aquatic ecological status and negatively affect benthic macroinvertebrate assemblages. The degradation of the ecological status of lakes is likely to increase in the future with increasing human activities and global warming. Therefore, information derived from this study can be a baseline of data for sensitizing local authorities in managing surface water pollution. Algeria lacks adequate scientific facilities to assess the aquatic health of freshwaters and the use of benthic macroinvertebrates remains a rather inexpensive tool. The use of these bioindicators could be the best option because of their efficiency and reliability.

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Competing interests. The authors declare no competing interests.

Data availability statement. The biological material and all the data generated and analyzed during the current study remain available from authors on request.

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Declaration of Author Contribution. N. Senouci: Doctoral student. Substantial to data acquisition, analysis, and interpretation of data; preliminary drafting of the article (50%). S. Benmoussat–Dekkak: Junio thesard. Contribution to Data acquisition; analysis and interpretation of data; Critical review involving a significant contribution to the intellectual content of the article (20%). R. Ammouri: Doctoral student. Contribution to Data acquisition; analysis and interpretation of data (10%). K. Abdellaoui-Hassaine: thesis supervisor, guided the research work and was involved in the design of the study, the interpretation of the data, and the revision of the article. head of the research team. (20%).

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