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SELECTED CASE STUDIES ON THE ENVIRONMENT OF THE MEDITERRANEAN AND SURROUNDING REGIONS

Evaluation of the trophic status in three reservoirs in Algeria (north west) using physicochemical analysis and rotifers structure

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Abstract
The aim of this study is to examine the trophic state of three reservoirs located in the northwest of Algeria based on the physicochemistry of water and the community of rotifers. The measurements of the physicochemical variables were carried out monthly over a 2-year period from December 2015 to November 2017. The rotifers were sampled simultaneously. Abiotic and biotic indices such as the Carlson index, $Q_{B/T}$, and TSI_{ROT} were determined in order to classify the three reservoirs according to their trophic state. Thus, the diversity indices of Shannon-Wiener (H′), Margalef richness index (D), Pielou evenness (J′), and the density were calculated in order to study the structure of the rotifers. The Kruskal-Wallis test confirmed the heterogeneity of the physicochemical quality (P value < 0.05) among the three reservoirs. A total of 71 species were identified during this study. The result of the various indices affirms this heterogeneity and indicates a trophic state hypereutrophic for the Hammam Boughrara reservoir, eutrophic for the Bakhadda reservoir and meso-oligotrophic for Sidi Yacoub. The use of canonical correspondence analysis (CCA) has shown that the structure of rotifers is influenced by local environmental factors. Some species such as the genus *Brachionus* species have shown their preference for extreme conditions. The use of biotic indices is highly recommended for the trophic state evaluation of reservoirs for a better water resources management.

Keywords Reservoirs · Physicochemistry · Rotifers · Trophic state · Biotic index · Water quality

Introduction

The eutrophication of aquatic ecosystems keeps increasing due to nutrient inputs from diverse sources. This growth in nutrient inputs can lead to perilous ecological and water supply problems (Paerl et al. 2016). Reservoirs in the Mediterranean, which combine the distinctive characteristics of reservoirs, such as hydrographic basins larger than those of natural lakes and the poorly developed coastline which show seasonal water scarcity, are exceptionally affected by this process (Moreno-Ostos et al. 2016; García-Chicote et al. 2019). Trophic state is regarded as the most important characteristic of aquatic ecosystem (Andronikova 1993; Wen et al. 2011). Various physical and chemical indicators are used to assess the trophic status of the lakes (Thakur et al. 2013). According to Carlson (1977), the trophic state of lakes indicates their biological productivity; however, it is usually assessed from data on total phosphorus and chlorophyll *a* concentrations and visibility of the Secchi disc depth. Currently, biomonitoring has become an integral part of water quality assessment and is included in many water pollution studies (Mohan and Omana 2007). Eutrophication, due to an exaggerated growth in nutrients (phosphates and nitrates), leads to a strong reduction of dissolved oxygen and asphyxiation of the environment that affects all aquatic communities. According to Paerl et al. (2016), eutrophication is caused by an increase in nutrient inputs which can lead to serious ecological and water supply problems. Zooplankton species are known as sentinel organisms and pollution indicators, and are, therefore, important for biomonitoring of water quality (Ejsmont-Karabin 2012; Gazonato Neto et al. 2014; Haberman and Haldna 2014; Tasevska et al. 2017). Rotifers

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comprise the necessary structural and functional component of these pelagic communities, and an important part of freshwater zooplankton (Tasevska et al. 2012). They play a significant role in the functioning of ecosystem. Moreover, their species composition can be used as an indicator of the trophic state of lakes (Maemets 1983; Bērziņš and Pejler 1989; Duggan et al. 2001a; Wen et al. 2011).

A disturbance in the environment can cause profound changes in the structure of rotifers. These upheavals can manifest themselves by a change in the relative dominance of the species and/or even by the complete disappearance of certain species (Duggan et al. 2001a; Xiong et al. 2003; Yoshida et al. 2003; May and O'Hare 2005; Ejsmont-Karabin 2012; Thakur et al. 2013). The biotic indices based on the rotifer community are widely used in the assessment of trophic state in developed regions, including Europe (Dembowska et al. 2015; Rosińska et al. 2019), Latin America (Nogueira 2001; Gazonato Neto et al. 2014), Asia (Chen et al. 2012; Thakur et al. 2013), and New Zealand (Duggan et al. 2001a, 2001b). The application of these indices remains very limited in North Africa, more precisely in the Maghreb.

In Algeria, reservoir pollution has experienced a worrying evolution, especially in the big watersheds. The regions near the latter have experienced a population explosion. Their agro-industrial development, during the last decade, has influenced diversely the most natural ecosystems. Many Algerian reservoirs and lakes of shallow depth are influenced by the eutrophication phenomena (Nasri et al. 2008). It is therefore necessary to assess the current state of water quality in these reservoirs. In order to test their status, three reservoirs located in north-western Algeria belonging to two large watersheds, Sidi Yacoub and Bakhadda, belonging to the Chellif watershed, and Hammam Boughrara, belonging to the Tafina watershed, were selected for our study. The water of these three reservoirs contribute greatly to irrigation, and even to the supply of drinking water. The work already carried out in these reservoirs was much more based on the physicochemical characteristics of the water and on phytoplankton (Bouzid-Laghe and Djelita 201; Djelita et al. 2015, 2016; El Haouati 2015). The work on the fish fauna in these water bodies was carried out solely by the national agency for water resources.

However, much less attention has been paid to rotifers in these reservoirs, with only one exception—Amar et al. (2012)—and to our knowledge, no studies on rotifers as bioindicators of the trophic status have been conducted here. This study aims at testing the hypothesis that the physicochemical characteristics of water are useful for determining its state and whether rotifer communities are bioindicators of the trophic state of the three Algerian reservoirs. In order to test this hypothesis, the abiotic index (Carlson index) based on physicochemistry and the biotic indices ($Q_{B/T}$ and TSI_{ROT}) based on rotifer species were calculated.

Study zone

The geographical situation of the three reservoirs is presented in Fig. 1. The topographic details and use of these three reservoirs are shown in Table 1. The Sidi Yacoub reservoir is situated at 20 km south of the city of Oued Fodda (Chleff province). Bakhadda reservoir is located near Mechraa-Sfa city (Tiaret Province) and it is one of the first reservoirs built in Algeria. The Hammam Boughrara reservoir is situated in the far northwest of Algeria, 13 km east of the city of Maghnia (Tlemcen province).

Materials and methods

Sampling

Sampling was carried out monthly for 2 years from December 2015 to November 2017 in order to obtain a representative image of the quality of the water and its changes. At each reservoir, two stations were sampled, dam station and the station near the main water course supplying the reservoir (Fig. 1). At each station in addition to the surface, three levels of distinct depths (3, 6, and 9 m) were sampled along a surface-to-bottom transect of the water column.

Physicochemical analyses

For each station and each depth level, five physicochemical parameters were measured in situ: water temperature (WT), pH, salinity (Sal), conductivity (Cond), and dissolved oxygen (DO), using the multi-parameter analyzer (Hanna GPS HI 9829 type), and further, on each station water transparency (Tr) using the Secchi disc. For chemical analyses, the water samples were taken using a Niskin type inversion bottle (capacity, 1 L). This device is used to take water samples at the desired depth without the danger of mixing it with water from other depths; then, the samples were kept in a 1-L polypropylene bottle after rinsing. Care was taken to not contaminate or modify the samples, which were transported to the laboratory in a cooler at 4 °C and analyzed within 24 h. Seven physicochemical parameters (nitrate [NO_3^-], nitrite [NO_2^-], phosphate [PO_4^{3-}], calcium [Ca^{2+}], magnesium [Mg^{2+}], chloride [Cl^-], and suspended matter [SM]) were analyzed in the laboratory according to the protocol described by Rodier et al. (2009). For chlorophyll *a* (Chl. *a*), the examination was performed using the fluorometric method according to the protocol described by Millerioux (1974-1975) from the equations of Scor-Unesco (1964). The parameters chemical oxygen demand (COD) and biochemical oxygen demand (BOD) were analyzed using an automated analysis SP2000, and ammonium (NH_4^+) and organic matter (OM) were measured by the spectrophotometric method. These

Table 1 The topographic details and use of the three reservoirs

Information	Sidi Yacoub reservoir	Bakhadda reservoir	Hammam Boughrara reservoir
Year of creation	1985	1936	1998
Bioclimate	Aride	Semi-Aride	Semi-Aride
Dry season	April–November	May–October	May–November
Altitude	245	582	275
Coordinates	35° 57′ 38.97″ N	35° 20′ 1.54″ N	34° 52′ 13.89″ N
	1° 19′ 7.64″ E	1° 3′ 39.63″ E	1° 39′ 15.15″ O
Mean depth (m)	30	15	25
Surface area (km^2)	9.3	4.79	9.16
Watershed area (km^2)	1280	920	4000
River	Oued Ardjem	Oued Mina	Oued Tafna
Reservoir use	Water supply, irrigation	Water supply, irrigation	Water supply, irrigation

four parameters were carried out by the technical staff of the laboratory of the national agency of water resources.

Rotifer sampling

The rotifers were gathered after filtration of the water samples (capacity, 1 L) in a 60-mL collector, using plankton net SDMO QUINIOU model F131P20 (mesh 20 µm, diameter 30 cm, length 90 cm), fixed with formalin to achieve final 4% concentration. Rotifers have been identified at the species level under an optical microscope (Euromex, × 100) using the keys developed by Koste (1978) and Nogrady et al. (1993). Quantitative samples were concentrated to 10 mL after sedimentation. One milliliter of the concentrated sample was taken randomly after mixing it and then analyzed in a Sedgewick-Rafter chamber using an inverted microscope (Zeiss-Winkel).

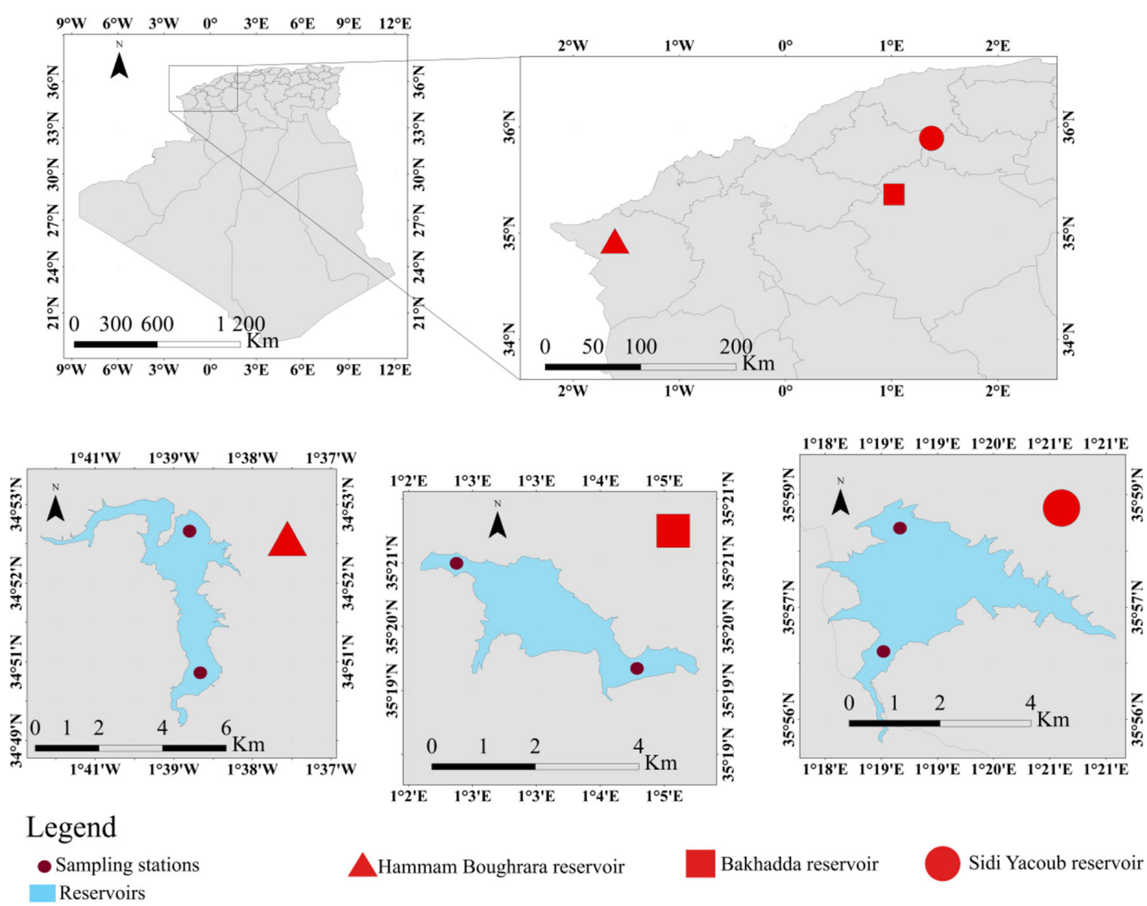

Fig. 1 Maps showing the location of the three reservoirs and the sampling stations

Data analyses

Statistical tests were applied on datasets of physicochemical and biological parameters obtained during the study period in all stations at different levels of each reservoir grouped by season and presented in the form of average values. Spearman's bivariate correlation test was used to describe relationship among the physicochemical parameters. The Shapiro-Wilk normality test was used to determine if the data set is well modeled by a normal distribution. The differences between physical and chemical water parameters among the reservoirs were studied by means of the Kruskal-Wallis test at a significance level of 5%.

A canonical correspondence analysis (CCA) was performed in order to explain the relationship between the identified species and physicochemical parameters. The Monte Carlo permutation test was applied on 9999 random permutations. The analyses were performed using R (R Development Core Team 2018). The spatial distribution map of the three reservoirs was created using the ArcGIS 10.3 software.

Several indices have been calculated to evaluate the trophic state of the three reservoirs:

(1) Trophic state index (Carlson 1977) (CTSI) uses mainly algal biomass involving three variables, namely chlorophyll *a* (TSI_{CA}), Secchi disc depth (TSI_{SD}), and total phosphorus (TSI_{TP}). PO_4^{3-} was converted to total P using the following: Total P $= PO_4^{3-}\left(\text{mg L}^{-1}\right) \times 0.3262$ (Moreno-Gutiérrez et al. 2018).

$(CTSI) = [(TSI_{CA}) + (TSI_{SD}) + (TSI_{TP})]/3)$, in which, $(TSI_{CA}) = 9.81 \text{In chlorophyll } a\ (\mu g\ L^{-1}) + 30.6$; $(TSI_{SD}) = 60 - 14.41 \text{In secchi depth(m)}$; $(TSI_{TP}) = 14.42 \text{ In total phosphorus } (\mu g\ L^{-1}) + 4.15$ (Devi Prasad and Siddaraju 2012). Based on the CTSI values, the reservoirs are classified as follows: oligotrophic (CTSI > 40, low productivity), mesotrophic (40 < CTSI < 50, moderately productive), eutrophic (50 < CTSI < 70, highly productive), and hypereutrophic (70 < CTSI, extremely productive).

(2) The relative proportion of species in both genera, or the "*Brachionus*: *Trichocerca* quotient" ($Q_{B/T}$) (Sládeček 1983) given that the genus *Brachionus* is linked to eutrophic water and that the genus *Trichocerca* is almost exclusively oligotrophic, $Q_{B/T}$ was calculated to evaluate the nature of the eutrophic conditions. These values vary from 1.00 to 4.00 ($Q_{B/T} < 1.00$ indicating oligotrophic conditions, $1 < Q_{B/T} < 2$ indicates mesotrophic conditions, $Q_{B/T} > 2$ eutrophic conditions indicated).

(3) When rotifers dominate aquatic systems and their density is known, the trophic state index proposed by Ejsmont-Karabin (2012) is useful: $TSI_{ROT} = 4.64 \text{ Ln } (N) + 25.36$, where, N is the total rotifer density (ind./L). TSI_{ROT} values = < 45: mesotrophic; between 45 and 55: meso-eutrophic; 55–65: eutrophic; and $TSI_{ROT} > 65$: hypertrophic.

Data on the richness and abundance of rotifer species were used to calculate three species indices: the diversity index (Shannon and Weaver 1949) (H'): $H' = -\sum_{i=1}^{S} P_i \log_2 P_i$, $P_i = \frac{ni}{N}$; richness index (Margalef 1958) (D): $D = \frac{(S-1)}{\ln N}$; and evenness index (Pielou 1966) (J'): $J' = \frac{H'}{\ln S}$, in which ni is the individual number of species i, Pi is the ratio of the individual number of the species i and total individual number N, and S is the total number of species in a month.

Results

Throughout the study period, for each reservoir, the data of the physicochemical parameters obtained in the stations and different levels were grouped by season and presented in the form of average values.

Spearman's correlation statistical analysis revealed strong correlations between the variables BOD and COD (P value < 0.0001, $r = 0.74$), between BOD and SM (P value < 0.0001, $r = 0.76$), BOD and PO_4^{3-} (P value < 0.0001, $r = 0.73$) (Table 2). It was also found that PO_4^{3-} was positively correlated with NO_2^- (P value < 0.0001, $r = 0.71$), with Chl. *a* (P value < 0.0001, $r = 0.77$) and with SM (P value < 0.0001, $r = 0.71$). On the other hand, SM were correlated with Chl. *a* (P value < 0.0001, $r = 0.84$), and Tr was negatively correlated with NO_3^- (P value < 0.0001, $r = -0.70$).

The physicochemical data measured in the three reservoirs reflect a spatial variation for the majority of the parameters, as confirmed by the Kruskal-Wallis test (P value < 0.05) with the exception of the WT, pH, and Mg^{2+} (P value > 0.05).

The average WT recorded during this study indicate that there is no spatial variation in the three reservoirs (Kruskal-Wallis, P value = 0.56). The maximum average values in the three reservoirs were recorded in summer 2017 with a maximum of 28.41 °C at Hammam Boughrara while the minimum average values were recorded in winter 2017 with a minimum of 11.06 °C in Bakhadda (Fig. 2).

The average pH values recorded in the three reservoirs show that there is no heterogeneity (Kruskal-Wallis, P value = 0.07 > 0.05). The minimum average value 7 was recorded at the Hammam Boughrara reservoir in summer 2016 and the maximum average value 10 was recorded in the same reservoir in autumn 2017.

The results show that DO follows a spatial variation (Kruskal-Wallis, P value = 0.02). The Sidi Yacoub reservoir

Table 2 Correlation matrix for physicochemical parameters (Spearman's correlation coefficients (*r*))

Variables	BOD	Ca^{2+}	Chl. *a*	Cl^-	Cond	DO	COD	Mg^{2+}	NH_4^+	NO_2^-	NO_3^-	OM	pH	PO_4^{3-}	Sal	SM	Tr	WT
BOD_5	1.00																	
Ca^{2+}	0.56	1.00																
Chl. *a*	0.67	0.52	1.00															
Cl^-	0.49	0.61	0.47	1.00														
Cond	0.27	0.67	0.17	0.45	1.00													
DO	−0.25	−0.06	−0.38	0.08	0.34	1.00												
COD	0.74*	0.27	0.51	0.32	0.16	−0.13	1.00											
Mg^{2+}	−0.03	0.38	−0.10	0.11	0.38	0.18	−0.03	1.00										
NH_4^+	0.50	0.39	0.34	0.17	0.02	−0.28	0.34	−0.21	1.00									
NO_2^-	0.51	0.25	0.50	−0.06	−0.04	−0.40	0.26	−0.01	0.37	1.00								
NO_3^-	0.37	−0.01	0.45	−0.09	−0.29	−0.51	0.26	−0.26	0.40	0.69	1.00							
OM	0.57	0.26	0.44	0.53	0.21	0.14	0.51	0.07	0.12	0.18	0.09	1.00						
pH	0.44	0.11	0.47	0.42	0.15	0.14	0.47	−0.24	0.04	−0.02	0.11	0.50	1.00					
PO_4^{3-}	0.72*	0.46	0.77*	0.28	0.03	−0.47	0.53	−0.07	0.58	0.71*	0.69	0.26	0.17	1.00				
Sal	−0.15	0.27	−0.07	0.42	0.59	0.33	−0.11	0.28	−0.21	−0.58	−0.52	0.09	0.24	−0.34	1.00			
SM	0.76*	0.54	0.84*	0.48	0.13	−0.54	0.56	−0.17	0.34	0.49	0.44	0.36	0.37	0.74*	−0.17	1.00		
Tr	−0.47	−0.28	−0.62	−0.18	0.11	0.49	−0.42	0.21	−0.47	−0.44	−0.70*	−0.22	−0.45	−0.62	0.25	−0.68	1.00	
WT	0.21	−0.01	0.17	0.50	0.26	0.30	0.16	0.09	−0.19	0.04	0.01	0.45	0.47	0.04	0.14	0.03	−0.08	1.00

*Correlation is significant at *P* value < 0.0001 level

recorded the highest DO levels during the entire study period except for the summer 2016 when the Hammam Boughrara reservoir recorded a maximum average value of 13.43 mg L^{-1}. The minimum average value of 3 mg L^{-1} was recorded in winter 2016 in the same reservoir. The average levels of Chl. *a* show a very marked spatial variation among the three reservoirs (Kruskal-Wallis, *P* value = 0.0001). Sidi Yacoub and Bakhadda reservoirs were recorded very low levels. The Hammam Boughrara reservoir presented the highest average values in Chl. *a* with a maximum 460.15 μg L^{-1} in winter 2017. The lowest values at the three reservoirs were recorded in autumn 2016.

The variation of Tr during our study is very remarkable (Kruskal-Wallis, *P* value = 0.0003). The minimum average value was recorded in the Hammam Boughrara reservoir 0.3 m in autumn 2017. In view of our results, the water from the Sidi Yacoub reservoir was the most transparent compared to the two other reservoirs, and the maximum average value in this reservoir 3.71 m was recorded in summer 2017.

The average values of chemical elements (cations and anions: Ca^{2+}, Cl^-) show that there was a spatial variation among the three reservoirs (Kruskal-Wallis, *P* value (Ca^{2+} = 0.0001, Cl^- = 0.0006)). In addition, the values recorded in the Hammam Boughrara reservoirs were very high compared to those obtained in the other two reservoirs. The maximum value in Ca^{2+} 189 mg L^{-1} was recorded in winter 2017 and the maximal mean value of Cl^- 518 mg L^{-1} was recorded in summer 2017.

The mean values of Cond and Sal of water are heterogeneous among the three reservoirs (Kruskal-Wallis, *P* value (Cond = 0.0005, Sal = 0.0008)). Mean levels were higher during the dry season than during the rainy season. The highest values were recorded at Hammam Boughrara reservoir in summer 2016 Cond: 2151 μs cm^{-1}; Sal: 0.97 psu.

The mean SM levels show a great variation (Kruskal-Wallis, *P* value = 0.0001). The Hammam Boughrara reservoir records very high levels compared to the other two reservoirs. The maximum level in this reservoir was recorded in autumn 2017 with 173 mg L^{-1}.

The mean concentrations of NO_2^- and PO_4^{3-} vary greatly from one reservoir to another (Kruskal-Wallis, *P* value (NO_2^- = 0.001, PO_4^{3-} = 0.0002)). The maximum values were recorded at the Hammam Boughrara reservoir in winter 2016 NO_2^-: 2.9 mg L^{-1}; PO_4^{3-}: 1.2 mg L^{-1}. The Sidi Yacoub reservoir recorded the lowest mean concentrations throughout the study period.

The NO_3^- contents were high in the reservoirs of Bakhadda and Hammam Boughrara compared to Sidi Yacoub reservoir which records low mean values during the entire study period (Kruskal-Wallis, *P* value = 0.0003). The maximum mean value 21.3 mg L^{-1} was recorded in winter 2016 at the Bakhadda reservoir.

The mean levels of BOD and COD were significantly different (Kruskal-Wallis, *P* value (BOD = 0.0003, COD = 0.01)). The water of the Hammam Boughrara reservoir showed the highest levels of BOD during the entire study

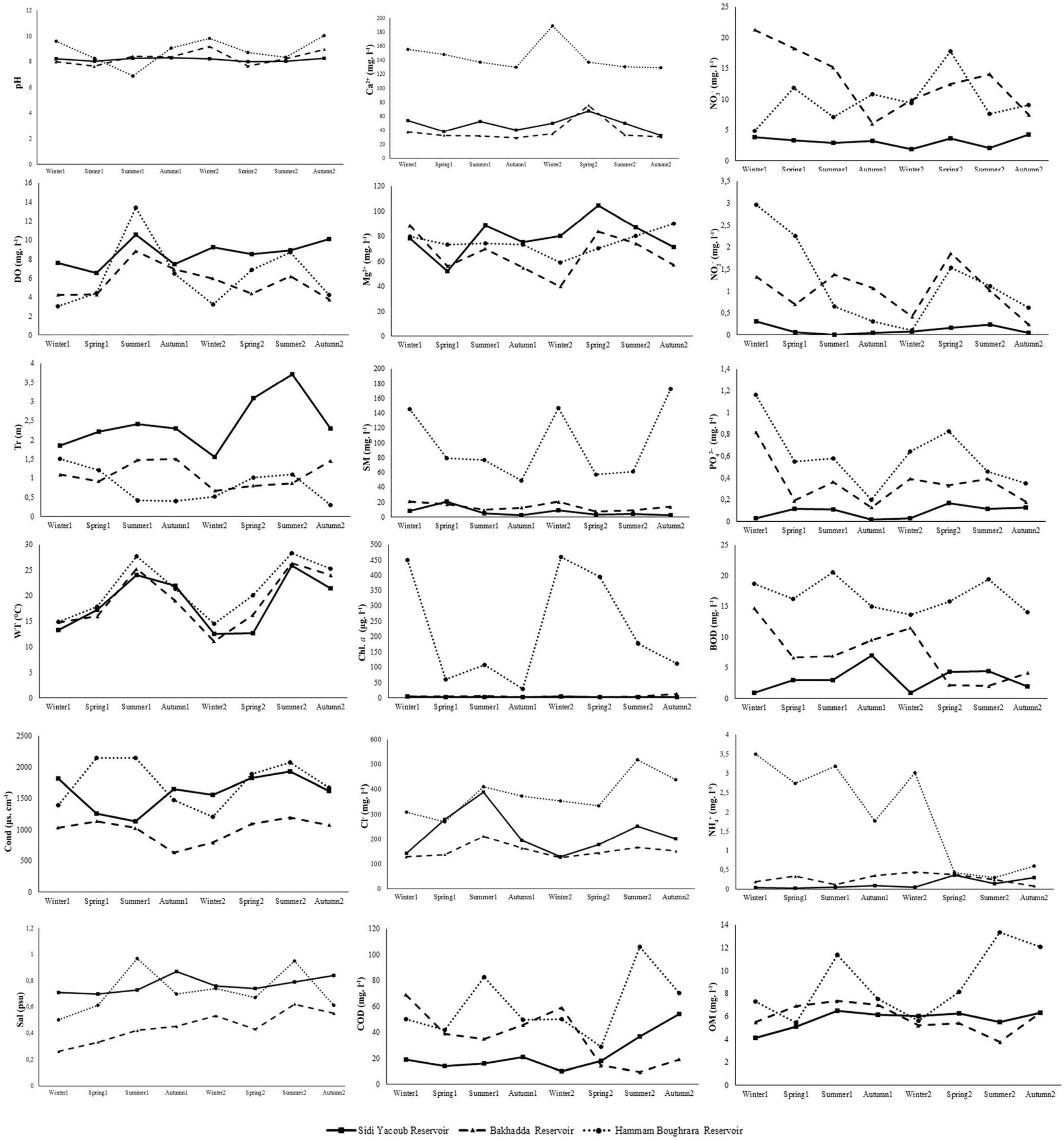

Fig. 2 Seasonal variation of physicochemical variables of three reservoirs

period, the maximum mean values of BOD and COD were recorded in the summer period (summer 2016/2017) with 20.5 and 19.4 mg L^{-1}, and 106 and 83 mg L^{-1}, respectively. The mean a NH_4^+ contents are very variable (Kruskal-Wallis, *P* value = 0.02), and mean levels are high in the Hammam Boughrara reservoir with a maximum 3.5 mg L^{-1} in winter 2016.

The mean values of the pollution parameters obtained in the three reservoirs during the 24-month period were classified according to the standards grid of the National Agency for Water Resources Alger (N.A.W.R. 2019) (Table 3). The water quality of the Hammam Boughrara reservoir was medium according to DO, NO_3^-, Ca^{2+}, and OM; poor according to PO_4^{3-}, Cl^-, and NH_4^+; and very poor according to COD and

Table 3 The mean values of physicochemical parameters in the three reservoirs (December 2015 to November 2017) and water quality according to Algerian water guidelines (N.A.W.R. 2019)

Parameters	Sidi Yacoub reservoir	Bakhadda reservoir	Hammam Boughrara reservoir
	Mean	Mean	Mean
	Quality	Quality	Quality
DO (mg L^{-1})	8.6	5.3	6.5
	Good	Medium	Medium
NO_3^- (mg L^{-1})	3.1	12.8	10.5
	Good	Medium	Medium
PO_4^{3-} (mg L^{-1})	0.1	0.3	0.5
	Medium	Poor	Poor
Ca^{2+} (mg L^{-1})	51.2	42.4	144.8
	Good	Good	Medium
Cl^- (mg L^{-1})	250.9	165.6	364.3
	Medium	Medium	Poor
COD (mg L^{-1})	21.1	33.3	61.4
	Medium	Medium	Very poor
BOD (mg L^{-1})	3.9	6.8	16.9
	Good	Medium	Very poor
NH_4^+ (mg L^{-1})	0.1	0.2	1.9
	Medium	Poor	Poor
OM (mg L^{-1})	5.9	6.1	9.1
	Medium	Medium	Medium

BOD. The water quality of the Bakhadda reservoir is medium according to DO, NO_3^-, Cl^-, COD, BOD, and OM, and poor according to PO_4^{3-} and NH_4^+. The water quality of the Sidi Yacoub reservoir varies from good according to DO, NO_3^-, Ca^{2+}, and BOD to medium according to PO_4^{3-}, Cl^-, COD, NH_4^+, and OM.

Structure and distribution of rotifers

A total of 71 rotifer species were detected at the three sampling sites. The species richness decreases from the Bakhadda reservoir, Hammam Boughrara reservoir, and Sidi Yacoub reservoir, with 39, 28, and 22 species, respectively (Fig. 3). Only two species (2.8%) *Keratella quadrata* and *K. cochlearis* were found in all three reservoirs. *Keratella quadrata* was common in all the three reservoirs with a high abundance in Sidi Yacoub and Hammam Boughrara reservoirs. *Keratella cochlearis* was rare at the Sidi Yacoub reservoir and common at the Bakhadda and Hammam Boughrara reservoirs, with Bakhadda reservoir having the highest abundance of this species (Table 4). The highest number of reservoirs-specific species was detected in the Bakhadda reservoir (23 species, 32.4%). The maximum number of the common species (9 species, 12.2%), *Brachionus angularis*, *B. budapestinensis*, *B. calyciflorus*, *B. urceolaris*, *Keratella cochlearis* var. *hispida*, *K. tropica*, *Polyarthra euryptera*, *P. remata*, and *Trichocerca pusilla*, was noted between the two reservoirs, Bakhadda and Hammam Boughrara.

Brachionus angularis was very abundant in the Hammam Boughrara reservoir with an abundant frequency; in Bakhadda reservoir, this species was weakly abundant with an occasional frequency. *Brachionus calyciflorus* was present in Bakhadda with occasional frequency and in Hammam Boughrara with frequent frequency. *Polyarthra euryptera* was present with abundant frequency; it was more abundant in Hammam Boughrara reservoir. *Polyarthra remata* was common in Bakhadda and present in Hammam Boughrara with rare frequency. *Keratella cochlearis* var. *hispida* was present with abundant frequency in the Bakhadda reservoir and rare in the Hammam Boughrara reservoir. *Keratella tropica* was present with low abundance and frequent frequency in the Bakhadda reservoir and very high abundance with abundant frequency in the Hammam Boughrara reservoir. The other species were present with varying abundance and frequency.

Diversity and density indices

The results of the indices diversity (Shannon-Wiener H′), richness (Margalef D), evenness (Pielou J′), and density for the three reservoirs are reported in Fig. 4. The total average values of H′ for the three reservoirs of Sidi Yacoub, Bakhadda, and Hammam Boughrara are 1.84, 2.22, and 1.90, respectively.

Table 4 Relative abundance, frequency, and seasonality of rotifers encountered in the different reservoirs between December 2015 and November 2017

Name of species	Sidi Yacoub reservoir			Bakhadda reservoir			Hammam Boughrara reservoir		
	RA	RF	Seasonality	RA	RF	Seasonality	RA	RF	Seasonality
Adineta vaga vaga	–	–	–	–	–	–	+	O	W_1-Sp_1
Annureopsis fissa	–	–	–	+	F	$S_{1,2}$-$A_{1,2}$	–	–	–
A. fissa urawensis	–	–	–	–	–	–	+	F	$W_{1,2}$-$S_{1,2}$
A. punctata	–	–	–	–	–	–	+	R	W_1
Ascomorpha ovalis	+	O	Sp_1-A_1	–	–	–	–	–	–
Asplanchna. brightwellii	–	–	–	+	O	Sp_2-A_1	–	–	–
A. herricki	+	O	$Sp_{1,2}$-S_2	–	–	–	–	–	–
A. priodonta	–	–	–	+	C	W_1-$Sp_{1,2}$-S_1-A_1	–	–	–
A. sieboldii	–	–	–	+	O	$S_{1,2}$-A_1	–	–	–
Brachionus angularis	–	–	–	+	O	$A_{1,2}$	+++	A	AS
B. budapestinensis	–	–	–	+	O	$S_{1,2}$	+	R	S_1
B. calyciflorus	–	–	–	+	O	S_1-$A_{1,2}$	+	F	W_2-$S_{1,2}$-A_2
B. c. var. *amphicerus*	–	–	–	–	–	–	+	R	S_1
B. c. var. *dorcas*	–	–	–	–	–	–	+	R	S_1
B. caudatus	–	–	–	+	R	Sp_2	–	–	–
B. leydigii var. *tridentatus*	–	–	–	–	–	–	+	R	Sp_1
B. rubens	–	–	–	–	–	–	+	O	Sp_1-S_2
B. sp	+	R	Sp_2	–	–	–	–	–	–
B. urceolaris	–	–	–	+	R	Sp_2	+	O	Sp_1-A_1
B. quadridentatus quadridentatus	–	–	–	–	–	–	+	F	W_1-$Sp_{1,2}$-A_2
Cephalodella gibba	+	R	W_1	+	O	W_2-Sp_1-A_2	–	–	–
Collotheca ornata	+	O	Sp_1-A_1	–	–	–	–	–	–
Colurella adriatica	+	O	$Sp_{1,2}$-W_2	–	–	–	–	–	–
C. uncinata bicuspidata	–	–	–	+	O	W_1-$S_{1,2}$	–	–	–
Conochilus hippocrepis	–	–	–	–	–	–	+	R	A_1
Dicranophorus forcipatus	–	–	–	+	O	$A_{1,2}$	–	–	–
Dipleuchlanis propatula	–	–	–	+	R	Sp_2	–	–	–
Euchlanis dilatata	+	R	Sp_2	–	–	–	–	–	–
E. triquetra	–	–	–	+	R	Sp_1	–	–	–
Filinia cornuta	–	–	–	–	–	–	+	R	A_2
F. longiseta var. *limnetica*	–	–	–	–	–	–	+	R	A_2
Gastropus stylifer	–	–	–	+	R	Sp_2	–	–	–
Hexarthra intermedia	+	C	W_2-Sp_2-$S_{1,2}$-$A_{1,2}$	+	R	A_2	–	–	–
H. mira	–	–	–	+	C	Sp_1-$S_{1,2}$-$A_{1,2}$	–	–	–
Keratella cochlearis	+	R	A_2	+++	C	W_1-$Sp_{1,2}$-$S_{1,2}$-$A_{1,2}$	+	C	$W_{1,2}$-$Sp_{1,2}$-$S_{1,2}$-A_2
K. c. var. *hispida*	–	–	–	+	A	W_1-$Sp_{1,2}$-$S_{1,2}$-$A_{1,2}$	+	R	A_1
K. procurva	+++	C	W_1-$Sp_{1,2}$-S_2-A_2	–	–	–	–	–	–
K. quadrata	++	C	$W_{1,2}$-$Sp_{1,2}$-S_2-A_1	+	C	W_1-$Sp_{1,2}$-$S_{1,2}$-A_2	++	C	$W_{1,2}$-Sp_1-$S_{1,2}$
K. tecta	–	–	–	–	–	–	+	O	Sp_1-$A_{1,2}$
K. testudo	+	C	W_1-$Sp_{1,2}$-$A_{1,2}$	–	–	–	–	–	–
K. tropica	–	–	–	+	F	$S_{1,2}$-$A_{1,2}$	+++	A	$W_{1,2}$-Sp_1-$S_{1,2}$-$A_{1,2}$
K. valga valga	+	O	$S_{1,2}$-A_1	–	–	–	–	–	–
Lecane aculeata	–	–	–	+	R	W_1	–	–	–
L. bulla	+	R	Sp_1	+	R	A_1	–	–	–
L. closterocerca	+	R	W_2	–	–	–	–	–	–
L. hamata	+	O	$Sp_{1,2}$	–	–	–	–	–	–

Table 4 (continued)

Name of species	Sidi Yacoub reservoir			Bakhadda reservoir			Hammam Boughrara reservoir		
	RA	RF	Seasonality	RA	RF	Seasonality	RA	RF	Seasonality
L. luna	–	–	–	–	–	–	+	O	W_1-$Sp_{1,2}$
L. lunaris	+	O	$Sp_{1,2}$-A_1	+	F	W_1-$Sp_{1,2}$-S_1	–	–	–
Lepadella acuminata	+	R	W_1	–	–	–	–	–	–
L. ovalis	–	–	–	+	R	A_1	–	–	–
L. sp	–	–	–	+	R	Sp_2	–	–	–
Lophocharis gracilis	–	–	–	+	R	Sp_1	–	–	–
Notholca labis	–	–	–	+	O	S_1-Sp_2	–	–	–
N. squamula	–	–	–	+	R	Sp_2	–	–	–
Notommata aurita	–	–	–	–	–	–	+	O	S_2-A_1
Polyarthra dolichoptera	+	C	$W_{1,2}$-$Sp_{1,2}$-S_1	–	–	–	–	–	–
P. euryptera	–	–	–	+	A	AS	++	A	AS
P. major	–	–	–	+	F	$S_{1,2}$-$A_{1,2}$	–	–	–
P. minor	–	–	–	–	–	–	+	C	W_1-$Sp_{1,2}$-$S_{1,2}$-A_1
P. remata	–	–	–	+	C	Sp_1-$S_{1,2}$-$A_{1,2}$	+	R	$S_{1,2}$
P. sp	–	–	–	–	–	–	+	R	S_1
P. vulgaris	++	C	$W_{1,2}$-$Sp_{1,2}$-S_1	+	C	W_1-$Sp_{1,2}$-S_1-A_2	–	–	–
Pompholyx sulcata	–	–	–	+	O	$Sp_{1,2}$	–	–	–
Synchaeta grandis	++	R	Sp_2	–	–	–	–	–	–
S. pectinata	–	–	–	++	A	AS	–	–	–
S. stylata	–	–	–	+	C	$Sp_{1,2}$-$S_{1,2}$-A_1	–	–	–
Testudinella patina	–	–	–	+	R	Sp_1	–	–	–
Trichocerca cylindrica	–	–	–	–	–	–	+	R	A_1
T. sp	+	O	$Sp_{1,2}$	–	–	–	–	–	–
T. porcellus	–	–	–	+	C	Sp_1-$S_{1,2}$-$A_{1,2}$	–	–	–
T. pusilla	–	–	–	++	F	$S_{1,2}$-$A_{1,2}$	+	O	$A_{1,2}$

RF, relative frequency (A, abundant with RF = 100–81%; C, common with RF = 80–61%; F, frequent with RF = 60–41%; O, occasional with RF = 40–21%; R, rare with RF = 20–0%)

RA, relative abundance (+++ with RA > 21%, ++ with RA = 20–11%, + with RA = 10–1%)

W, winter; *Sp*, spring; *S*, summer; *A*, autumn; *AS*, all seasons; -, absent

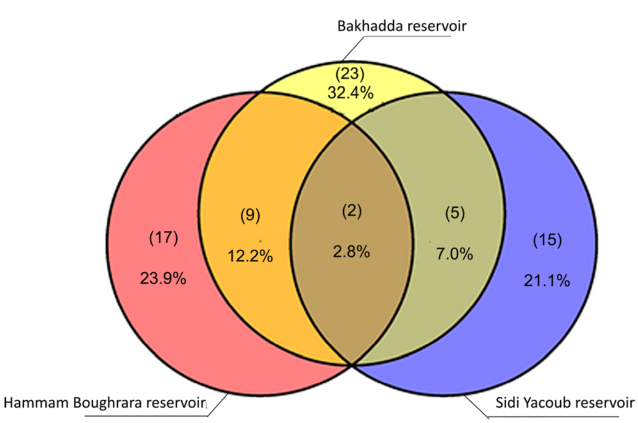

Fig. 3 The distribution of rotifer species in the three reservoirs (Venn diagram). The numbers in parentheses show rotifer species richness, while the percentages reflect the richness at a given site divided by the total richness ($n = 71$)

The total average values of richness (*D*) are 1.10, 1.37, and 1.04, respectively, for Sidi Yacoub, Bakhadda, and Hammam Boughrara reservoirs. The total average values of the Pielou evenness (J′) for the same reservoirs are 0.69, 0.55, and 0.58, respectively. The total average density of rotifers in the three reservoirs is 627 ind L^{-1}, 34,255 ind L^{-1}, and 49,828 ind L^{-1}, respectively, for Sidi Yacoub, Bakhadda, and Hammam Boughrara (Fig. 4).

Eutrophication index

The total average $Q_{B/T}$ values are variable for the three reservoirs (Table 5): Sidi Yacoub reservoir (low value, 1), Bakhadda reservoir (medium value, 2.5), and Hammam Boughrara reservoir (very high value, 4.5). The total average values of TSI_{ROT} among the three reservoirs are of the

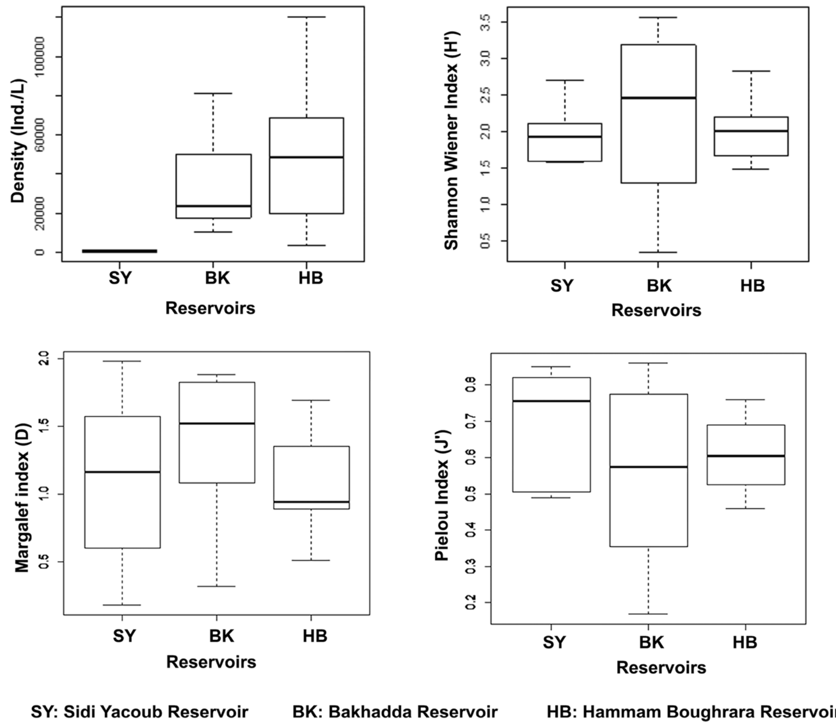

Fig. 4 Box plots of the density and diversity indices of the rotifer communities in the three reservoirs

following order: 41.1 in Sidi Yacoub, 56.95 in Bakhadda, and 57.73 in Hammam Boughrara. Carlson's Trophy State Index (CTSI) values range from 49.76 in Sidi Yacoub and 54.13 in Bakhadda to 80.24 in Hammam Boughrara.

The Monte Carlo permutation test indicates that the result of this analysis is significant (P value = 0.0001 and total variance = 1).

In the canonical correspondence analysis, three axes were retained (axis 1, axis 2, and axis 3). A high portion (61.57%) of the total variation in the rotifer's community is explained by the environmental variables. The first CCA axis explains 26.45% of the variance of the species-environment relationship and represents a mineralization and organic pollution gradient. In fact, the Cond, PO_4^{3-}, BOD, Cl^-, Ca^{2+}, SM, and Chl. *a* were significantly correlated (55, 69, 77, 81, 85, 87, and 92% respectively) with this axis. A number of rotifers species have high scores and are positively correlated with this axis (Fig. 5), in particular the species of the genus *Brachionus*, *Keratella tecta*, *Lecane luna*, and *Polyarthra minor* to a greater extent *Keratella tropica* and *Polyarthra euryptera*. This suggests that these taxa occurred at high mineralization, in waters rich in organic matter in the Hammam Boughrara reservoir with a high concentration of Cond, Cl^- and Ca^{2+}, PO_4^{3-}, and Chl. *a*, weigh heavily on this axis indicating an eutrophication gradient which is confirmed by a significant correlation between PO_4^{3-} and Chl. *a* ($r = 0.77$; P value < 0.0001). This group of rotifers is opposed to *Cephalodella gibba*, *Keratella testudo*, *Lecane lunaris*, and *Polyarthra vulgaris* which also have high scores on this axis, thus suggesting that these taxa have occurred in areas with low levels of these parameters.

The second axis, which represents 21.40% of the total variance, is mainly a pollution gradient in nitrogenous organic matter and a gradient of salinity. The taxa *Ascomorpha ovalis*,

Table 5 Trophic status of the three dams according to the eutrophication indices

	Sidi Yacoub reservoir	Bakhadda reservoir	Hammam Boughrara reservoir
$Q_{B/T}$	1	2.5	4.5
	Oligotrophic	Eutrophic	Hypereutrophic
TSI_{ROT}	41.1	56.95	57.73
	Mesotrophic	Eutrophic	Eutrophic
CTSI	49.76	54.13	80.24
	Mesotrophic	Eutrophic	Hypereutrophic

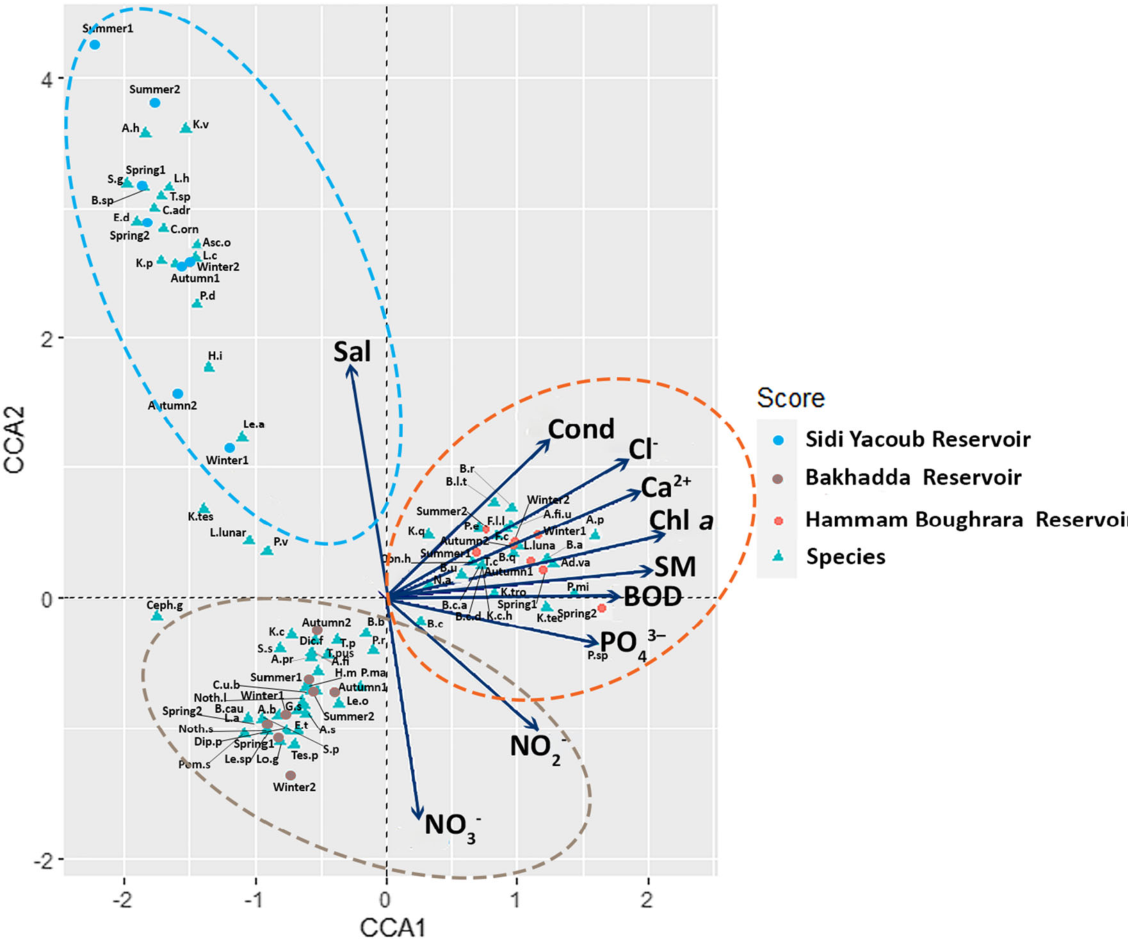

Fig. 5 A canonical correspondence analysis (CCA) of rotifers species and physicochemical parameters. *Adineta vaga vaga*, Ad.va; *Anuraeopsis fissa*, A.fi; *Anureopsis fissa urawensis*, A.fi.u; *Anureopsis punctata*, A.p; *Ascomorpha ovalis*, Asc.o; *Asplanchna brightwellii*, A.b; *Asplanchna herricki*, A.h; *Asplanchna priodonta*, A.pr; *Asplanchna sieboldii*, A.s; *Brachionus angularis*, B.a; *Brachionus budapestinensis*, B.b; *Brachionus calyciflorus*, B.c; *Brachionus calyciflorus* var. *amphicerus*, B.c.a; *Brachionus calyciflorus* var. *dorcas*, B.c.d; *Brachionus caudatus*, B.cau; *Brachionus leydigii* var. *tridentatus*, B.l.t; *Brachionus rubens*, B.r; *Brachionus* sp., B.sp.; *Brachionus urceolaris*, B.u; *Brachionus quadridentatus quadridentatus*, B.q; *Cephalodella gibba*, Ceph.g; *Collotheca ornata*, C.orn; *Colurella adriatica*, C.adr; *Colurella uncinata bicuspidata*, C.u.b; *Conochilus hippocrepis*, Con.h; *Dicranophorus forcipatus*, Dic.f; *Dipleuchlanis propatula*, Dip.p; *Euchlanis dilatata*, E.d; *Euchlanis triquetra*, E.t; *Filinia cornuta*, F.c; *Filinia longiseta* var. *limnetica*, F.l.l; *Gastropus stylifer*, G.s; *Hexarthra intermedia*, H.i; *Hexarthra mira*, H.m; *Keratella cochlearis*, K.c; *Keratella cochlearis* var. *hispida*, K.c.h; *Keratella procurva*, K.p; *Keratella quadrata*, K.q; *Keratella tecta*, K.tec; *Keratella testudo*, K.tes; *Keratella tropica*, K.tro; *Keratella valga valga*, K.v; *Lecane arculeata*, L.a; *Lecane bulla*, L.b; *Lecane closterocerca*, L.c; *Lecane hamata*, L.h; *Lecane luna*, L.luna; *Lecane lunaris*, L.lunar; *Lepadella acuminata*, Le.a; *Lepadella ovalis*, Le.o; *Lepadella* sp., Le.sp.; *Lophocharis gracilis*, Lo.g; *Notholca labis*, Noth.l; *Notholca squamula*, Noth.s; *Notommata aurita*, N.a; *Polyarthra dolichoptera*, P.d; *Polyarthra euryptera*, P.e; *Polyarthra major*, P.ma; *Polyarthra minor*, P.mi; *Polyarthra remata*, P.r; *Polyarthra* sp. , P.sp.; *Polyarthra vulgaris*, P.v; *Pompholyx sulcata*, Pom.s; *Synchaeta grandis*, S.g; *Synchaeta pectinata*, S.p; *Synchaeta stylata*, S.s; *Testudinella patina*, Tes.p; *Trichocerca cylindrica*, T.c; *Trichocerca porcellus*, T.p; *Trichocerca pusilla*, T.pus; *Trichocerca* sp., T.sp.

Asplanchna herricki, *Collotheca ornata*, *Colurella adriatica*, *Keratella procurva*, *K. valga valga*, *Lecane hamata*, *Polyarthra dolichoptera*, and *Trichocerca* sp. are positively correlated with this axis. They are found exclusively in the Sidi Yacoub reservoir (Fig. 5). Their presence is due to the high concentration of salinity linked to the geological nature of the watershed. The species *Anuraeopsis fissa*, *Asplanchna brightwellii*, *Asplanchna priodonta*, *Colurella uncinata bicuspidata*, *Hexarthra mira*, *Polyarthra major*, *Pompholyx sulcata*, *Synchaeta pectinata*, *Synchaeta stylata*, and *Trichocerca porcellus* oppose the first group. They are found merely in the Bakhadda reservoir (Fig. 5). This group of rotifers appears to be determined by a high concentration of NO_3^- and NO_2^- indicating organic pollution of nitrogenous origin and to low levels of salinity.

The third axis explains 13.72% of the total variance. The species *Asplanchna sieboldii*, *Dicranophorus forcipatus*, *Keratella cochlearis*, *Notholca labis*, *Polyarthra remata*, and *Trichocerca pusilla* are correlated to this axis indicating that they have no preference toward the environmental parameters.

Discussion

The good state of the water is based exclusively on the physicochemical parameters. Temperature influences the phenology of all species and conditions the biogeography of organisms. In this study, the fluctuations in this parameter for all reservoirs are related to local climatic conditions and in particular to air temperature. The pH mean values indicates that the water of three reservoirs is alkaline in nature. According to Rodier (1996), these values are characteristic of limestone regions. The pH decreased during summer at the Hammam Boughrara reservoir, which was likely because of increasing WT and OM. These findings agree with those reported by Benzha et al. (2005). The dissolved oxygen content belongs to the most fundamental parameter of water quality. The increase in DO content during the summer in Hammam Boughrara is probably due to the phenomenon of photosynthesis. Our results are in agreement with those of Ouhmidou et al. (2015). According to Alayat et al. (2013), dissolved oxygen essentially depends on the respiration and photosynthesis of planktonic populations and the mineralization of biomass.

According to Brient et al. (2004), Chlorophyll *a* is an indicator of overall algal biomass; it is used to classify water bodies according to their trophic level. The excessive levels of the Chl. *a* at Hammam Boughrara are explained by the increase in algal activity observed at this reservoir and by enrichment or with nutritive salts (phosphates and nitrogen). The low levels in autumn can be explained by the low levels of PO_4^{3-}.

The high values of Tr in summer in Sidi Yacoub are explained by the low contents of Chl. *a*. According to El Ghachtoul et al. (2005), the transparency of water is related to hydrological events and algal biomass development. The low values in Hammam Boughrara in summer are linked to the turbidity of the water. The enrichment of water in suspended matter is the main cause of the low transparency in this reservoir. Our results are in agreement with the results of Doukhandji and Arab (2017).

Ca^{2+} is the most common cation found in surface water. Its content varies according to the nature of the land crossed, in particular when there are gypsum deposits (Rodier et al. 2009). The high levels in winter are due to the erosion of rocks after heavy rains. The excessive Cl^- content is very often an indication of a particular urban or an industrial pollution. The significant concentrations in Hammam Boughrara are probably due to wastewater and domestic water pouring into the wadis feeding this reservoir. The maximum mean concentrations in summer are due to evaporation which increases their content in the water during the summer period. Our results are similar to the results reported by Ouhmidou et al. (2015). The lowering of the mineralization (Cond and Sal) during the rainy season is linked to the increase in the water level. This reduction lies in the dilution of water by the contribution of rainwater. The increase in the conductivity of the water during summer is due to the intense evaporation which induces a strong mineralization of the water in salts (Ouhmidou and Chahlaoui 2013).

The high levels of SM in Hammam Boughrara are explained by the encrustation in mineral and organic matter; the significant correlations with Chl. *a*, BOD, and SM confirm these findings. The increase in concentrations in autumn 2017 is due to the increase in OM during this season. According to Rodier et al. (2009), the high PO_4^{3-} level is explained by the increase in organic compounds in water. PO_4^{3-} primarily originate from domestic and agricultural activities. The highest PO_4^{3-} concentrations in winter 2016 is due to the increase in organic compounds during the flood period which supports a very thorough mineralization of the organic matter (Ouhmidou et al. 2015). The high NO_3^- values are probably due to the use of nitrogen and phosphate fertilizers in agriculture. In fact, due to the importance of agricultural activities in the region, with an agro-pastoral vocation, the leaching of agricultural land (market gardening and citrus fruits) prevailing around the reservoirs would be at the origin of the high levels of nutritive salts. Nitrate inputs could be linked to the leaching of agricultural soils by watering the watershed. These results are in accordance with those reported by Arab and Arab (2017).

Biological oxygen demand is a widely used parameter in the control of organic pollution from industrial and urban effluents. The high values of BOD at Hammam Boughrara indicate the presence of a large amount of organic matter mainly due to the discharges of urban and industrial wastewater from the Moroccan city of Oujda, discharged directly into wadi Bounaïm, main tributary wadi Mouillah, without any prior treatment (Bouzid-Lagha and Djelita 2012).

According to Sanap et al. (2006), the high values of BOD could be explained by the importance of rates of OM, which explains the very significant correlation (P value < 0.0001) found between this parameter and the SM, PO_4^{3-}, and COD. The high level of COD is due to the increase in human activities such as the discharge of natural domestic wastewater, industrial pollutants, and agriculture around the reservoir. According to Al-Taani et al. (2018), agricultural runoff, inadequate waste disposal, and wastewater effluents discharged into the reservoir can contribute to the measured levels of COD and BOD. According to Brient et al. (2004), NH_4^+ is used to classify water bodies according to their trophic level. The excessive levels of this parameter at Hammam Boughrara reservoir is explained by the increase in algal activity. It comes from the biodegradation of waste and inputs of domestic, agricultural, and industrial origin (Barakat et al. 2016; Hamil et al. 2018).

The deterioration of the water quality of the Hammam Boughrara reservoir (N.A.W.R. 2019) based on PO_4^{3-}, Cl^-, NH_4^+, COD, and BOD is due to the discharge of urban and industrial wastewater, discharged directly into the wadi which feeds this reservoir. Among the three reservoirs, the water quality of Sidi Yacoub is the best (N.A.W.R. 2019). It is also protected from human activities and sources of water pollution.

Due to their great sensitivity to variations in environmental conditions, rotifer communities change when the slightest malfunction occurs. The two common species of the three reservoirs are *Keratella quadrata* and *K. cochlearis.* Segers and De Smet (2008) noted that all of the elements of the genus *Keratella* are considered to be eurytopes and cosmopolitans. In addition, due to its wide ecological value with regard to parameters—temperature and nutrient salts—*Keratella quadrata* has a wide geographical distribution: in eutrophic (Balvay 1989) and thermophilic (Inaotombi et al. 2016) zones. Barrabin (2000) considers this species to be tolerant to a wide range of temperatures and conditions of mineralization. Moreover, Bidi-Akli et al. (2014) explain its presence by enriching the environment with elements of the decomposition of water flowers. *Keratella cochlearis* is found in most freshwater lakes and ponds around the world (Green 1987). This species was reported by Doukhandji and Arab (2017) in a eutrophic reservoir.

The nine common species of the Bakhadda and Hammam Boughrara reservoirs are known for their tolerance to different degrees of pollution. The genus *Brachionus* is considered an indicator of eutrophic water (Sládeček 1983; Branco et al. 2002). The presence of *Brachionus angularis* and *B. calyciflorus* is closely associated with hypertrophic conditions (Duggan et al. 2001a; Stamou et al. 2019). The abundance of *Polyarthra euryptera* is related to the eutrophic state of both reservoirs. These findings agree with those reported by Yin et al. (2018); this species dominates in eutrophic water. The presence of *Polyarthra remata* is also explained by the eutrophic conditions of the two reservoirs. Our results do not agree with those of García-Chicote et al. (2018), who consider *Polyarthra remata* as an indicator of a mesotrophic state. Other authors report the presence of this species in both oligotrophic and eutrophic systems (Barrabin 2000; Duggan et al. 2001b; Baião and Boavida 2005). Our results are similar to the results of Bidi-Akli et al. (2014) and Doukhandji and Arab (2017), who reported this species in a eutrophic reservoir in Algeria. The genus *Trichocerca* is generally found in eutrophic environments (Castro et al. 2005), Bērziņš and Pejler (1989) considers *T. pussila* to be eutrophic.

Biodiversity is one of the important characteristics for ecosystem monitoring. Measuring diversity indices provides important information on the structure of the rotifer's community. By comparing the values of the diversity indices of the three reservoirs, we note that the lowest average value of H′ is found in Sidi Yacoub, explained by the low number of species (22 species) followed by that of Hammam Boughrara where the specific richness is more marked (28 species). The very high density in Hammam Boughrara explains the low value of *D*, unlike that observed in Asia (Xiong et al. 2003; Qian et al. 2007; Chen et al. 2012), which showed that eutrophication can reduce the diversity and evenness of species. According to Weiher and Keddy (1999) and García-Chicote et al. (2019), the composition of zooplankton in reservoirs with a high trophic state can be better explained by the trait-environment paradigm, i.e., the presence of a few species adapted to stressful environments. These results are in agreement with our results in which the number of species raised to the level of Bakhadda and Hammam Boughrara is due to the presence of many tolerant species such as the genus *Brachionus*. According to Angeli (1976), the simultaneous presence of several species of the genus *Brachionus* is a good indication for the eutrophic nature of an aquatic ecosystem. In Bakhadda and Hammam Boughrara reservoirs, it was represented respectively by 5 and 9 species.

Other studies have revealed a great diversity of species in areas with a high level of eutrophication (Guo et al. 2010). This corroborates the conclusions of our study; in fact, the specific diversity is higher in Bakhadda and Hammam Boughrara than in the Sidi Yacoub reservoir, despite their eutrophic nature.

The maximum average value of J′ was recorded in Sidi Yacoub reflecting an equitable distribution of species. The minimum average value is noted in Bakhadda where certain taxa (*Synchaeta pectinata*, *Keratella cochlearis*, *Polyarthra euryptera*, and *Trichocerca pusilla*) predominate. The density of rotifers in the Bakhadda and Hammam Boughrara eutrophic reservoirs is much more significant compared to the Sidi Yacoub reservoir. Our results are consistent with those of Tasevska et al. (2017). The relatively high densities of rotifers observed in these reservoirs may be due to the prevailing environmental conditions favoring the development of certain taxa.

The use of biotic and abiotic indices is a useful tool for assess the ecological quality of reservoirs. The values of $Q_{B/T}$, TSI_{ROT}, and CTSI confirm the degree of eutrophication among the three reservoirs and make it possible to characterize their trophic state. The three indices $Q_{B/T}$, TSI_{ROT}, and CTSI indicate a eutrophic state of the Bakhadda reservoir and hypertrophic ($Q_{B/T}$ and CTSI) and eutrophic (TSI_{ROT}) states for the Hammam Boughrara reservoir. The TSI_{ROT} and CTSI indices indicate that the waters of the Sidi Yacoub reservoir are mesotrophic and oligotrophic ($Q_{B/T}$).

We can say that certain ecological descriptors are responsible for the distribution of the rotifer community in all the stations studied for the three reservoirs, namely Chl. *a*, PO_4^{3-}, BOD, SM, Cl^-, Cond, Ca^{2+}, NO_2^-, NO_3^-, and finally Sal. Thus, most rotifers species show a preference for mineralized waters rich in organic and eutrophic matter.

The species of the genus *Brachionus* and the species *Keratella tecta*, *Lecane luna*, *Polyarthra minor*, *Keratella tropica*, and *Polyarthra euryptera* have shown their preference for eutrophic water rich in phosphates and in mineral and organic elements. According to Arora and Mehra (2003), there is a significant correlation between the species of rotifers and phosphates. According to Pourriot (1980), the enrichment of the environment (passage to eutrophic and hypereutrophic lakes) is accompanied by an increase in the number of species (of the genus *Brachionus* in particular). Eutrophic bodies of water contain higher amounts of suspended organic matter (detritus) and therefore easily support higher biomass and higher microzooplankton productivity with a short generation time (Seda and Devetter 2000; Nogueira 2001; Gazonato Neto and al. 2014; Haberman and Haldna 2014; Tasevska et al. 2017).

The intense agricultural activity (presence of agricultural land) around the Bakhadda reservoir explains the high levels of NO_2^- and NO_3^- which are probably due to the nitrogen fertilizers used in agriculture. The species *Anuraeopsis fissa*, *Asplanchna brightwellii*, *Asplanchna priodonta*, *Colurella uncinata bicuspidata*, *Hexarthra mira*, *Polyarthra major*, *Pompholyx sulcata*, *Synchaeta pectinata*, *Synchaeta stylata*, and *Trichocerca porcellus* seem to prefer water rich in these nutrients (NO_2^-, NO_3^-).

The species *Ascomorpha ovalis*, *Asplanchna herricki*, *Collotheca ornata*, *Colurella adriatica*, *Keratella procurva*, *Keratella valga valga*, *Lecane hamata*, *Polyarthra dolichoptera*, and *Trichocerca* sp. are found exclusively in the Sidi Yacoub reservoir and have shown their preference for saline water. According to Mulhauser and Monnier (1995), the salt content depends on the geology of the catchment area, water renewal, and climate, particularly the thermal radiation causing vaporization.

Conclusion

Based on the present study, the physicochemical and rotifers composition of the reservoirs revealed that among the three selected reservoirs, the water quality of the Sidi Yacoub reservoir is the best. It is protected from human activity and from sources of water pollution. The three eutrophication indices show a eutrophic quality for the Bakhadda reservoir. The Hammam Boughrara reservoir seems to be the most polluted; the results of the calculated indices indicate a hypereutrophic quality ($Q_{B/T}$ and CTSI) for this reservoir. The community structure of rotifers was influenced by local environmental factors. Certain species have indicated their preference for extreme conditions. The use of analyses of the physicochemical parameters of water and the determination of indices were sufficient to characterize the state of eutrophication in these reservoirs. The use of indices based on the rotifer community ($Q_{B/T}$ and TSI_{ROT}) remains an effective tool for monitoring and evaluating the eutrophication of reservoirs especially that this method is inexpensive.

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Authors' contributions GS: conceptualization, investigation, visualization, software, and writing—review and editing.
DB: formal analysis and software.
AT: formal analysis.
AA: supervision, review, and editing.

Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

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