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How do environmental conditions in artificial wetlands affect waterbird communities? Case of the hillside reservoir of Sebkhates of Aures wetlands complex (northeast Algeria)

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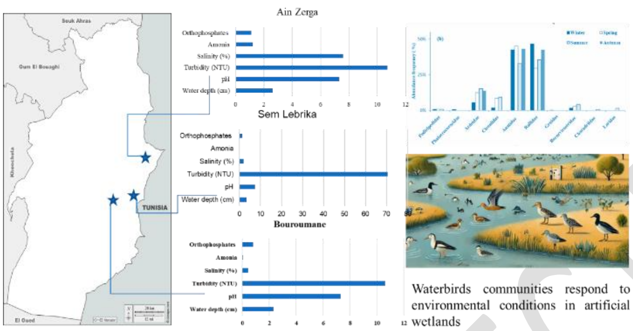
Graphical abstract



Abstract

Our study aims to assess the interactions between environmental variables and waterbirds population dynamics across three artificial wetlands in a semi-arid region (northeastern Algeria). Conducted over two annual cycles (January 2018 to February 2020), the study involved monthly measurement of precipitation, water depth, air and water temperature, 5 physicochemical parameters of water and waterbirds census. Across the surveyed wetlands, we recorded 28 waterbird species belonging to 10 families and 7 orders. Anatidae was the best represented family with 11 species. According to the IUCN Red List, *Aythya nyroca* is considered near threatened; *Aythya ferina* is vulnerable, and *Oxyura leucocephala* is endangered. Nine species are protected by the Algerian law. The phenological status showed that wintering species were the most represented (42.85%). The trophic status was dominated by polyphagous species (53.57%). The linear mixed model (LMM) analysis indicated that water depth, salinity, turbidity, ammonia, and orthophosphate exhibited significant differences across the three study sites, whereas pH did not display any significant variation. However, the variables that are significantly different between climatic seasons were water depth, air temperature and phosphate. The variables with no significant differences between climatic seasons were pH, salinity, turbidity, and ammonia. The canonical correspondence analysis (CCA) revealed that air temperature and precipitation were key factors influencing waterbird distribution across seasons.

Keywords: Artificial wetland; Water quality; Waterbirds; Medjerda watershed; North-east Algeria.

1. Introduction

Wetlands are one of the most productive ecosystems on the planet and host a large proportion of the world's biological diversity (Mandishona and Knight 2022). They provide essential functions for life (such as feeding and reproduction) and shelter (refuge and rest) for many plant and animal species (Zhang *et al.* 2022; Nie *et al.* 2023). These ecosystems are among the most valuable resources and play an important role in fundamental processes, agriculture, irrigation, aquaculture, water supply for drinking purposes and hosting an important number of fish fauna and migratory birds (Gherzouli 2013; Marques *et al.* 2019; Zou *et al.* 2024).

Waterbirds are a key part of wetland ecosystems and serve as important indicators of the health and productivity of these environments (Kingsford *et al.* 2017; Zhang *et al.* 2022). Their presence and behavior can tell us a lot about the condition of the wetland. Waterbirds are highly sensitive to climate change, they are particularly affected by changes in precipitation and temperature, which are major factors that influence where these birds are found and how many there are (Amano *et al.* 2020). Several studies have shown that precipitation and temperature are two driving forces that can influence the distribution and bird's density (Liang *et al.* 2020; Habibullah *et al.* 2022). Numerous studies have demonstrated that habitat selection by waterbirds is influenced by various factors, such as wetland size, which positively influences the richness and abundance of waterbirds; extensive wetlands tend to be more varied in their habitats and are more likely to support a greater diversity of waterbirds (Sánchez-Zapata *et al.* 2005; Robinson *et al.* 2018; Frank *et al.* 2022). In addition, the aquatic vegetation structure affects the use of habitat by birds (Lorenzón *et al.* 2017) providing shelter from predators and weather conditions (Bortolotti *et al.* 2022). Furthermore, water depth is an important variable that directly determines the accessibility of foraging for waterbirds (Xia *et al.* 2017). On the other hand, physico-chemical parameters of water (salinity, pH, temperature, oxygen content, mineralization and conductivity) influence the choice of feeding, resting and breeding sites and also affect the composition, abundance and physiology of bird species (Muralikrishnan *et al.* 2017; Djerboua *et al.* 2022; Vyas *et al.* 2022, Wang and Ma 2024). Over the past century, the Mediterranean region has lost 50% of its wetlands, areas that are essential for sustainable development in the region (Perennou *et al.* 2015; MWO 2018).

Curiously, the progressive loss and extensive degradation of natural wetlands due to the consequences of human use has somehow required waterbirds to exploit artificial wetland habitats to fulfil their vital needs (Santoul *et al.* 2004). Numerous studies revealed that although the creation of artificial wetlands can have injurious environmental effects (Verhoeven *et al.* 2006; Winemiller *et al.* 2016), in some cases they also have the prospective to play a crucial complementary role in conserving biodiversity (Sirami *et al.* 2013) and maintaining ecosystem services (Demnati *et al.* 2020).

Despite the fact that this type of artificial continental aquatic ecosystem is becoming more and more widespread in the arid and semi-arid regions of North Africa (Bortolini *et al.* 2018; Djerboua *et al.* 2022; Hayouni *et al.* 2024), only few researches studied the ecological importance of artificial wetlands and the place they occupy in the functioning of wetlands and waterbirds throughout the region (Sirami *et al.* 2013; Merouani *et al.* 2018). Indeed, in the south side of Meditarranean, studies have being made concerned natural wetlands, generally large water bodies of brackish to salty water (Si Bachir 1991; Bensizerara *et al.* 2013, MWO 2018; MedWet 2019; Benzina *et al.* 2022; Bougoffa *et al.* 2023). Our study aims to fill this gap and assess the ecological conditions of artificial wetlands being part of the Sebkhates of Aures wetlands complex located in the vast Medjarda watershed, a semi-arid region of northeast Algeria and southwest Tunisia.

We hypothesized that water quality and metrological factors, particularly temperature and precipitation, play a determining role in shaping seasonal variation in waterbird assemblages in artificial wetlands. The regime and the rigor of the arid climate would also have repercussions on this spatio-temporal variation studied over several years. To this purpose, the study was conducted from January 2018 to February 2020 in three hillside reservoirs in Algeria, used for irrigation and watering livestock. The water quality, its variation between sites and seasons; and waterbird diversity, status, and abundance were described. Then, the relationship between the ecological conditions and the seasonal evolution of waterbird communities was analyzed. These findings allow enhancing the knowledge of artificial wetlands that might be used as an alternative habitat for waterbirds and could support the protection and conservation of bird species in these artificial habitats.

2. Materials and Methods

2.1. Description of the region and study sites

The study was carried out in the region of Tebessa, located in northeast Algeria with an average altitude of 960 m a.s.l,) in three artificial wetlands (hillside reservoirs): Ain Zarga, Bouroumane, and Sem Labrika (**Figure 1**). The area is characterized by a semi-arid bioclimatic area with cold and little rainfall winters and dry hot summers (Sbiki 2017); and suffers from long period of drought, drying out streams and water bodies (Sbiki *et al.* 2015). The Tebessa plain is part of the Medjerda watershed (Ghreieb 2011) which stretches between Algeria and Tunisia and covers an area of 23600 km^2 of which 7500 km^2 in Algeria and flows over 482 km of which 350 in Tunisia (Benzina *et al.* 2024). The Medjerda basin is crossed by one of the main Maghrebian wadis (rivers), the Medjerda Wadi in the North and the Mellegue Wadi in the South (Khoualdia *et al.* 2014). The region is known by an active supervised agricultural uses (**Table 1**). Over the last few years, many hillside reservoirs have been created in the region and are essentially intended for crops irrigation, livestock watering (sheep, goats, and cattle) and grazing around the sites (DHT 2021).

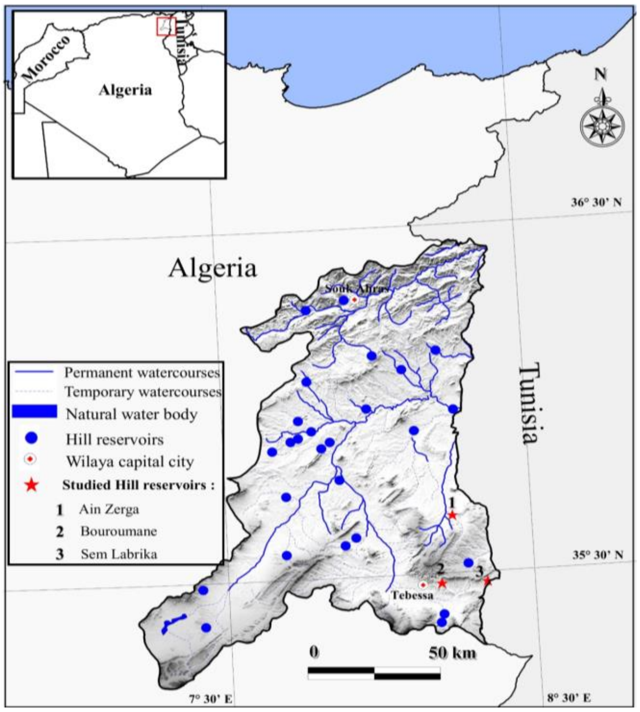


Figure 1. Distribution of water bodies and location of the three artificial wetlands (hill reservoirs) studied in the province of Tebessa (Medjarda watershed).

Table 1. General characteristics of the three artificial wetlands (hillside reservoirs) studied in the Medjerda watershed (Tebessa, Algeria).

Characteristics	Reservoir Sem Labrika	Reservoir Bouroumane	Reservoir Ain Zarga
Latitude	35° 27′ 44′′ N	35° 21′ 49′′ N	35° 39′ 21′′ N
Longitude	8° 20′ 59′′ E	8° 11′ 57′′ E	8° 14′ 45′′ E
Altitude (m)	956	918	824
Year of creation	2007	2009	2016
Surface area (ha)	6	2	6
Depth (m)	1 - 5	2 – 4	1 – 4
Riparian vegetation	*Stipa tenacissima, Salvia rosmarinus, Tamarix* sp., vegetable and cereal crops	*Diplotaxis erucoides, Scolymus* sp, cereal crops	*Moricandia arvensis, Juncus maritimus, Scolymus* sp, cereal crops

2.2. Measurement of water depth and physico-chemical quality of water

During more than two annual cycles (from January 2018 to February 2020), the water depth (± 10 cm) was measured monthly in the three sites with a graduated ruler resting vertically in a flat area whose height is close or equal to the correct measurements.

In the same period and monthly, a set of 4 physico-chemical parameters of the water were measured *in situ*: water temperature (°C), pH, and Salinity (%) using a multi-parameter waterproof meter HI98129® (HANNA instruments). The turbidity (Nephrometric Turbidity NTU) was measured with a turbidimeter (HANNA C102 instruments). In the laboratory, ammonia NH_3 (mg/l) and orthophosphate PO_4^{3-} (mg/l), key indicators of wetlands eutrophication, were measured using colorimetric reaction with a Spectrophotometer (HI83099-02) (AFNOR 2005).

2.3. Waterbirds census and bio-ecological status

Waterbirds counts were carried out using the absolute method, during the study period (from January 2018 to February 2020). Three to four counting census points were chosen along the site's boundary to obtain a complete view of present waterbirds in each wetland, depending on their area, shape, and visibility. The counting was done monthly, from 8:00 a.m. to 2:00 p.m. This time was more appropriate, as most waterbirds were actively engaged in foraging and performing other activities. When the group of birds is less than 200 m away and consists of less than 200 individuals, an individual count is made. In contrast, an approximate visual estimate was adopted when the group was very distant and/or more than 200 individuals (Lamotte and Bourlière 1969). We used binoculars (10x50) during each survey to observe waterbirds at the fixed counting points within 20 to 30 min. We recorded all waterbirds within the observation areas, including those flushing within the boundaries, while excluding those flying over (Delany 2005). The guide ′′Birds of Europe, North Africa and the Middle East′′ (Heinzel *et al.* 2004) was used for identification.

Inventoried waterbird species were divided into five phenological classes, namely: passing migrant PM (species observed only a few times during the study period, mainly in spring and autumn); wintering W (observed during the wintering season, that is arriving early and staying until late spring); sedentary breeding SB (present throughout the year and usually nesting in the region); sedentary non–breeding SNB (observed throughout the year without formal proof of nesting); and summer nesting SN (migratory species observed in the area during spring and summer) (Benzina *et al.* 2022; Gherib *et al.* 2021).

The trophic status was grouped into four diet categories, namely: piscivorous (P): birds for which the most important part of their diet is fish; invertebrate consumer (Inv): dietary spectrum dominated by aquatic invertebrates and/or terrestrial arthropods; polyphagous (Pp): diet consists of several categories depending on food availability; granivorous (G): most important part of the diet consists of grains (Bensizerara *et al.* 2013; Benzina *et al.* 2022).

For the protection status of waterbird species, we used the list of species protected by Decrees N° 12-236 issued on 24 May 2012 in Algeria legislation (JORA 2012), and the international Red List of the International Union for Conservation of Nature (UICN 2024).

2.4. Data mining and statistical analysis

Data was processed by calculating means and standard deviations. The diversity of waterbird communities was evaluated by the total species richness "S", estimated by the total number of species identified in each sample taken. The abundance frequency (AB in %), corresponds to the percentage of individuals of a species (ni) compared to the total number of individuals accounted (N) in a sample: AB (%) = ni / N ×100. The Shannon diversity index (H′) was calculated ($H' = -\sum P_i \log_2 P_i$); where: P_i represents the number of individuals (ni) of i species relative to the total number of counted individuals (N): $P_i = ni / N$. The Piélou evenness index (E = H'/ H'max) was calculated by the ratio between H' and the maximum diversity H'max with $H'max = Log_2 S$ (Magurran 2004)].

The mixed linear model was carried out for testing the spatio-temporal variation of the physico-chemical characteristics of the water. The latter were used as response variables, while sites and seasons was considered as an independent variable and the year as a random factor.

Afterwards a Tukey-HSD test was used for post-hoc pairwise comparison of the spatio-temporal variation of the physico-chemical characteristics of the water with ''sites'' (three artificial wetlands) and ''seasons'' (winter: December-February, spring: March-May, summer: June-August, and autumn: September-November).

A canonical correspondence analysis (CCA) was carried out to relate the abundance of waterbird populations with environmental variables: four climatic season, water depth (m), air temperature (°C), and precipitation (mm). Thanks to its ability to combine the functions of ordination and gradient analysis, the CCA is convenient for visualizing dimensional ecological data in an easily interpretable way without prior transformation. Statistical analyzes were performed using the R (R Development Core Team 2014) and XLSTAT version 2014.

3. Results and discussion

3.1. Spatio-temporal variation of environmental parameters

Among all the recorded measurements, the water depth ranged between 1 and 5 meters. This depth was relatively shallow and exhibited significant seasonal fluctuations. The highest depths were observed in autumn and spring due to winter and autumn precipitations, and the lowest in summer due to water pumping. This fluctuation suggests that the artificial wetland's hydrology is mainly influenced by seasonal factors, mainly rainfall patterns, evaporation rates, and water management practices (Ma *et al.* 2010). pH ranged from 7.01 to 7.7 and the turbidity varied from 10.2 to 70.5 NTU. The recorded salinity level ranged from 0.18 mg/l to 12.80 mg/l, the values of ammonia varied from 0.01 to 1.89 mg/l, and the orthophosphate ranged between 0 and 1.9 mg/l. The water temperature measured ranges from 5.60°C to 30.10°C, with the highest value noted in summer and the lowest in winter. Since the time of water temperature sampling differs from one site to another, we preferred not to consider the analysis of this parameter. However, these values experience significant fluctuations from one site to another and from one season to another.

Table 2. Comparison of the means of water depth and quality in the three studied sites (capital bold letters show significant differences among sites according to the Pos-Hoc test).

Water parameters	Bouroumane	Sem Lebrika	Ain Zerga
	N= 62	N= 62	N= 62
Water depth (m)	2.32 ± 0.08 **(B)**	3.40 ± 0.13 **(A)**	2.60 ± 0.09 **(B)**
pH	7.31 ± 0.02 (A)	7.28 ± 0.02 (A)	7.30 ± 0.02 (A)
Turbidity (NTU)	10.6 ± 0.01 **(B)**	70.5 ± 0.13 **(A)**	10.7 ± 0.06 **(B)**
Salinity (%)	0.44 ± 0.01 **(C)**	1.93 ± 0.17 **(B)**	7.60 ± 0.40 **(A)**
Amonia (NH_3 mg/l)	0.05 ± 0.01 **(B)**	0.10 ± 0.01 **(B)**	1.20 ± 0.01**(A)**
Orthophosphates (PO_4^{3-} mg/l)	0.81 ± 0.06 **(B)**	1.25 ± 0.04 **(A)**	1.10 ± 0.03 **(A)**

Table 3. Comparison of the means of environmental parameters according to the four climatic seasons (capital bold letters show significant differences among seasons according to the Pos-Hoc test).

Variables	Winter	Spring	Summer	Autumn
	N= 9	N= 8	N= 8	N= 8
Air temperature (°C)	7.71 ± 0.20 **(D)**	14.47 ± 0.42 **(C)**	26.30 ± 0.4 **(A)**	17.10 ± 0.7 **(B)**
Precipitations (mm)	16.31 ± 1.70 **(C)**	54.53 ± 4.74 **(A)**	25.20 ± 4.27 **(C)**	40.20 ± 4.95 **(B)**
Water depth (m)	2.37 ± 0.10 **(B)**	3.06 ± 0.13 **(A)**	2.30 ± 0.14 **(B)**	3.30 ± 0.12 **(A)**
pH	7.30 ± 0.02 (A)	7.28 ± 0.02 (A)	7.30 ± 0.02 (A)	7.30 ± 0.02 (A)
Turbidity (NTU)	30.60 ± 0.42 (A)	30.49 ± 0.41 (A)	30.80 ± 0.42 (A)	30.70 ± 0.41 (A)
Salinity (%)	3.68 ± 0.55 (A)	3.59 ± 0.64 (A)	3.00 ± 0.51 (A)	3.10 ± 0.46 (A)
Amoniac (NH_3) mg/l)	0.41 ± 0.09 (A)	0.49 ± 0.09 (A)	0.53 ± 0.09 (A)	0.48 ± 0.09 (A)
Orthophosphates (PO_4^{3-} mg/l)	1.08 ± 0.06 **(A)**	0.91 ± 0.01 **(B)**	1.10 ± 0.06 **(A)**	1.20 ± 0.05 **(A)**

According to Fisher post-hoc test, the highest mean values of water depth was noted at the Sem Labrika site (3.4 ± 0.13 m, group A) and during the autumn (3.3 ± 0.12 m, group A). The lowest values was recorded at Bouroumane site (2.32 ± 0.08 m, group B) and during the summer (2.3 ± 0.14 m, group B). The highest value of air temperature was noted in summer (26.3 ± 0.4 ^{0}C, group A), and the low value was measured in winter (7.71 ± 0.2 ^{0}C, group D). This reflects the strong influence of seasonal weather conditions on the wetlands, particularly in semi-arid areas. It is known that wetland water masses are strongly influenced by weather conditions and the summer season with its high heat accelerates the phenomenon of water evaporation in the studied sites. This phenomenon represents a major hindrance to the installation of water birds. The highest pH was recorded at Bouroumane site (7.31 ± 0.02, group A) and during winter, summer and autumn with the same value of 7.30 ± 0, 02 (group A). The lowest values of pH was noted at Sem Labrika site (7.28 ± 0.02, group A) and during spring (7.28 ± 0.02, group A). A report from North Carolina claimed that a water pH of less than 5.9 was harmful to waterbird performance (Carter 1987). The pH values found in our studied sites meet with the defined Algerian standards which set variance values ranging from 6.5 to 9 for surface water (JORA 2012) and the World Health Statistics (WHO 2017). The turbidity recorded its highest mean value at the Sem Labrika site (70.5 ± 0.13 NTU, group A) and during summer (30.8 ± 0.42 NTU, group A). The lowest NTU was noted in Bouroumane site (10.6 ± 0.01 NTU, group B) and in spring (30.49 ± 0.41 NTU, group A). The consistent turbidity values across seasons imply that the reservoir experiences minimal fluctuations in water clarity, which could be due to stable environmental conditions, effective sedimentation, and controlled runoff. The slight uptick in summer and autumn turbidity may hint at minor contributions from seasonal rainfall, but overall, the system appears resilient and balanced year-round. According to (Rodier *et al.* 2009) in surface waters, turbidity typically varies between 10 and 50 NTU, maintaining clear water conditions, which is beneficial for the aquatic ecosystem. The highest salinity degree amounted to 7.6 ± 0.4 mg/l (group A) at Sem Labrika site and during winter (3.68 ± 0.55 mg/l: group A). The lowest salinity was recorded in Bouroumane site (0.44 ± 0.01 mg/l: group C) and during summer (3 ± 0.51 mg/l: group A). The low water salinity across the studied sites shows that these wetlands maintain the properties of a freshwater environment, which supports their ecological functions and benefits the surrounding agricultural and pastoral activities. The values of ammoniac was noted with a high average of 1.20 ± 0.01 mg/l (group A) in Ain Zerga site and in summer (0.53 ± 0.09 mg/l: group A) (**Tables 2 and 3**). The lowest ammoniac content was noted in Bouroumane site (0.05 ± 0.008 mg/l: group B) and during winter (0.41 ± 0.09 mg/l: group A). The orthophosphate with a maximum mean value of 1.25 ± 0.038 mg/l (group A) was recorded at Sem labrika site and in the summer (11.2 ± 0.05mg/l: group A). The lowest orthophosphate content was noted at Bouroumane site (0.81 ± 0.061 mg/l: group B) and during spring (0.91 ± 00.007 mg/l: group B). The low orthophosphate and ammoniac levels in the studied sites indicate effective nutrient management and good water quality. These conditions help prevent eutrophication, reduce toxicity, and support a balanced aquatic ecosystem (Rodier *et al.* 2009; Meradi *et al.* 2024).

Table 4. Fixed effects (sites) of the linear mixed models using environmental factors as response variables in the hillside reservoir of Sebkhates of Aures wetlands complex.

Variables		Chisq	Df	*P* < (Chisq)	*P*
Water depth (m)	Intercept	100.507	1	$<2.2e^{-16}$	**<0.0001**
	Site	54.515	2	**$1.45e^{-12}$**	
pH	Intercept	73906.1889	1	$<2e^{-16}$	0.6253
	Site	0.9391	2	0.6253	
Turbidity (NTU)	Intercept	367.8	1	$<2.2e^{-16}$	**<0.0001**
	Site	3161.9	2	**$<2.2e^{-16}$**	
Salinity (%)	Intercept	1.7095	1	0.1911	**<0.0001**
	Site	483.2033	2	**$<2e^{-16}$**	
Ammoniac (NH_3 mg/l)	Intercept	1.8601	1	0.1726	**<0.0001**
	Site	707.7053	2	**$<2e^{-16}$**	
Orthophosphates (PO_4^{3-} mg/l)	Intercept	285.623	1	$<2.2e^{-16}$	**<0.0001**
	Site	44.161	2	**$2.57e^{-10}$**	

Table 5. Fixed effects (seasons) of the linear mixed models using environmental factors as response variables in the hillside reservoir of Sebkhates of Aures wetlands complex.

Variables		Chisq	Df	*P* < (Chisq)	*P*
Water depth (m)	Intercept	339.687	1	$<2.2e^{-16}$	**<0.0001**
	Saison	51.638	3	**$3.58e^{-11}$**	
Air temperature (°C)	Intercept	273.46	1	$<2.2e^{-16}$	0.6253
	Saison	788.69	3	**$<2.2e^{-16}$**	
Precipitations (mm)	Intercept	12.479	1	0.0004117	**<0.0001**
	Saison	47.986	3	**$2.14e^{-10}$**	
pH	Intercept	64108.141	1	$<2e^{-16}$	0.9008
	Saison	0.581	3	0.9008	
Turbidity (NTU)	Intercept	75.952	1	$<2e^{-16}$	0.9508
	Saison	0.348	3	0.9508	
Salinity (%)	Intercept	32.3485	1	$1.289e^{-08}$	0.838
	Saison	0.8478	3	0.838	
Ammoniac (NH_3 mg/l)	Intercept	21.1197	1	0.000004315	0.8035
	Saison	0.9909	3	0.8035	
Orthophosphates (PO_4^{3-} mg/l)	Intercept	329.252	1	$<2e^{-16}$	**<0.05**
	Saison	11.259	3	**0.0104**	

When comparing the variation of environmental parameters, the LMM analysis showed that water depth, turbidity, salinity, ammoniac and orthophosphate showed significant variation across study sites (*P* < 0.0001), however pH was not significantly different (P = 0.6253) (**Table 4**).

In addition, according to post hoc tests, the analysis showed that the variables that were significantly different between climatic seasons at least $P < 0.05$) were: water depth, air temperature, precipitation and orthophosphate (**Table 5**). The analysis revealed that overall; there was no significant variation in the physicochemical parameters between the three sites. Only the pH varied significantly even if the average pH recorded was approximately equal (7.28 to 7.31). This would be because the same sub-catchment area feeds the three reservoirs studied and the substrate's quality is identical. Depending on the climatic seasons, the test revealed significant variations in air temperature, site depth, and orthophosphates. Salinity, turbidity, and ammonia did not vary significantly between seasons. This would be related to the local climatic conditions of each site as well as the human use of water from the sites and the soils surrounding the water reservoirs.

3.2. Waterbird diversity and ecological status

In total, we recorded 28 waterbirds species belonging to 10 families, 7 orders and 18 genera. The most represented families were Anatidae with 11 species and Ardeidae with 4 species. All of the species recorded (S = 28) were observed on Ain Zarga wetland. The hillside reservoir of Bouromane shelters a total specific richness of 22 species, while only 15 waterbird species were noted in Sem Labrika. The highest value of (S) was noted in winter (20 species) and the lowest value was observed in autumn with 18 species. The Great Wihte Heron (*Egretta alba*) and the Little Egret (*Egretta garzetta*) were observed only in Ain Zerga (see appendix 1). This avian community can be considered important since it corresponds to more than half of the species noted in 12 Ramsar sites of the vast region of the Sebkhates des Aurès wetland complex, which is represented by 68 species, 9 orders, and 14 families (Benzina *et al.* 2022). Despite Bouroumane having a smaller surface area of 2 ha compared to Sem Labrika and Ain Zerga, which each cover 6 ha, the higher species diversity observed in Bouroumane might be compensated by a higher degree of habitat complexity with diverse vegetation which provide a high richness of food resources.

The Shannon diversity index (H') was 2.82 in Ain Zarga, 2.6 in Bouroumane, and 2.12 at Sem Labrika. On all the studied sites, Pielou's evenness is always higher than 0.75. Our results showed that the highest seasonal abundance of waterbirds was observed in autumn while species richness and Shannon index reached their maximum during winter. This abundance and diversity might be attributed to the massive arrival of many wintering species, especially Anatidae; as well as the presence of sedentary birds in autumn. This seasonal variation is likely related to bird migration patterns (Loucif *et al.* 2020; Haest *et al.* 2019). Conversely, the lowest abundance was recorded during the spring due to the departure of wintering birds and the sedentary birds en-gaged in their nesting activities. These results align with similar studies in Algeria (Gherib *et al.* 2021, Haest *et al.* 2019) and other regions in the world (Mahar *et al.* 2023) in Trans-Himalayan and (Li *et al.* 2013) in China. On the other hand, the value of Pielou's evenness index is overall quite close to unity reflecting that waterbird populations are fairly well balanced across climatic seasons and exhibit a certain stability and homogeneity demonstrating the rapid evolution of artificial wetland ecosystems whose installation is relatively recent (4 to 13 years).

Despite this richness, natural wetland habitat still more productive and attractive for waterbirds. Compared to some natural wetlands in the same semi arid region, the species richness in the studied sites is lower than that recorded for example in Garaet Tinsilt and Sebkhat Djendhli (Bensizerara et al. 2013). Similar findings have been reported by (Giosa et al. 2018), whom noted that natural wetlands host a greater number of species and support higher relative abundances compared to artificial wetlands. The increased species richness and relative abundance are linked to factors such as wetland size, plant diversity, hunting pressure, and water depth.

Regarding the phenological status, wintering species dominated with 42.85% (12 species) of the total avifauna recorded, followed by passing migrant with 39.28% (11 species). In terms of trophic status, the most recorded species 53.57% (15 species) were polyphagous, followed by invertebrate feeders with 28.57% (8 species). Analysis of the phenological status of waterbirds in studied artificial wetlands highlights their importance as a wintering area for many species. In addition, the three studied sites are suitable for hosting, and resting for a large and diverse range of migratory birds. The dominance of polyphagous species reflects the abundance and diversity of food resources provided by crops grown in the region, and granivorous birds feed on seeds of herbaceous plants around the sites. Otherwise, the importance of invertebrate feeders reflects the availability of aquatic invertebrates in the studied sites and some fish for piscivorous birds.

Of the 28 species identified, 9 species are protected in Algeria. According to the IUCN Red List, 25 species (89, 29%) are of least concern (LC); one species is near threatened (NT): *Aythya nyroca*; one species is vulnerable (VU): *Aythya ferina*, and one species is endangered (EN): *Oxyura leucocephala* (see **appendix 1**). According to the IUCN Red List (UICN 2024), the studied hillside reservoirs are home to a few worldwide threatened species. Moreover, nine species representing 32.15% of the total recorded waterbird species are considered protected by Algerian law (JORA 2012).

The results of the present study showed that the family of Anatidae is the most abundant. Our results are consistent with other studies that reported the strong representation of Anatidae compared to other families of waterbirds in wetlands (Benzina *et al.* 2022; Khoualdia *et al.* 2014).

3.3. Spatiotemporal variation and distribution patterns of waterbird communities

The Mallard (*Anas platyrhynchos*) and the Eurasian Coot (*Fulica atra*) were the most numerous species, with a maximum of more than 5000 individuals for each species, counted across all three sites during the survey. The Common Moorhen (*Gallinula chloropus*) and the Cattle Egret (*Bubulcus ibis*) were also well represented in number with a maximum of just over 2500 individuals recorded for each species on the three wetlands during one survey. Few species were represented by less than 40 individuals: *Charadrius hiaticula, Podiceps cristatus*, and *Phalacrocorax carbo*.

The highest abundance of waterbird species was recorded at the Sem Labrika wetland with 39.63% of the total individual numbers, followed by Ain Zarga (36.12%), and Bouroumane (24.25%). The highest abundance in the three studied sites was noted in the Rallidae and Anatidae, sometimes reaching 50 % of the total individual number (**Figure 2a**). According to the climatic seasons, the highest abundance of waterbirds was observed during autumn (31.32%), followed by summer (28.13%). The lowest abundance was recorded during spring (19.43%). During winter, the highest abundance of waterbird species was observed in Anatidae and Rallidae in the three studied sites (**Figure 2b**).

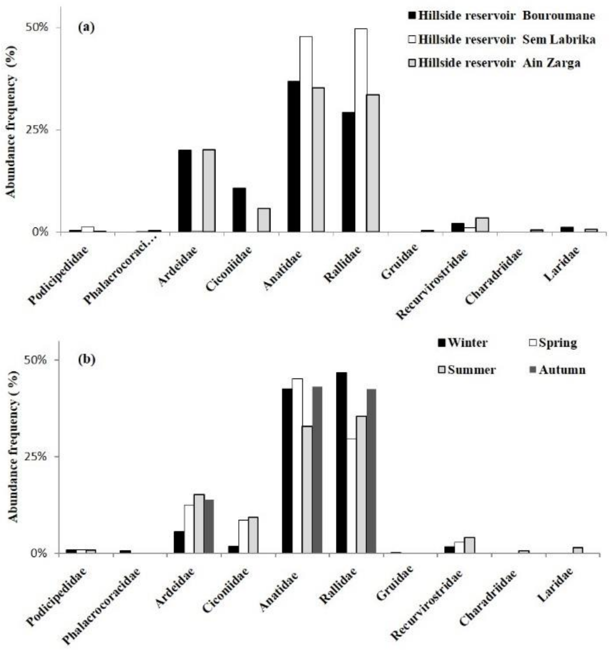


Figure 2. Variation in the abundance of waterbirds families according to sites (a) and seasons (b) in three artificial wetlands.

The CCA analysis applied to examine distribution of waterbirds species according to environmental variables (season, water depth, water temperature and precipitation) revealed that the first two canonical axes explained 84.44% of the variance (Axis 1 = 58.82%, Axis 2 = 25.62%) (**Figure 3**).

The analysis distinguished four distinct seasonal bird assemblages in relation to environmental gradients. The **autumn group** was defined by a **negative correlation with precipitation** and included species such as *Ciconia ciconia* and *Himantopus himantopus*. These species likely benefit from exposed mudflats and shallow zones typical of post-summer low-water conditions. The **winter assemblage** was clearly **negatively associated with air temperature**, and was dominated by *Bubulcus ibis*, a species well adapted to foraging in cool, saturated soils and grasslands (Sbiki *et al.* 2015).

Meanwhile, the **summer assemblage** showed a **positive correlation with air temperature** and a **negative correlation with precipitation**, and was represented most notably by *Tadorna tadorna*. This species appears well adapted to arid conditions, exploiting habitats with declining water levels and limited vegetation (Bezzalla *et al.* 2019). The **spring assemblage**, conversely, exhibited a **positive association with rainfall** and a **negative one with temperature**, with *Anas platyrhynchos* being the most abundant species. This species often takes advantage of newly inundated, nutrient-rich areas that emerge during spring flooding, feeding on abundant aquatic invertebrates.

Interestingly, **water depth appeared to be a relatively stable factor across seasons** in this artificial reservoir, unlike precipitation and temperature, which exerted stronger seasonal control over species assemblages. This suggests that natural climatic variables, rather than hydrological regulation, are the primary drivers of waterbird community composition.

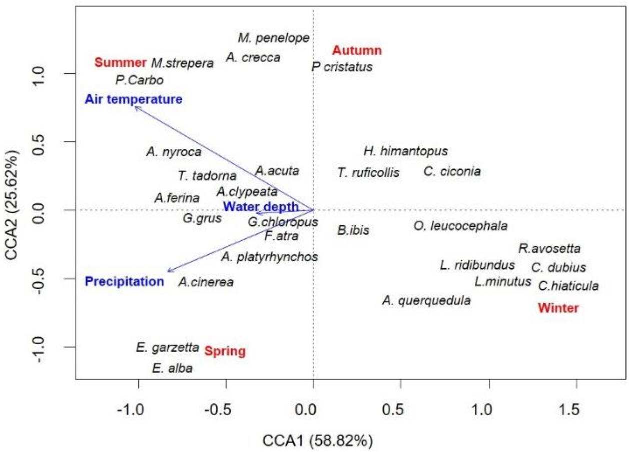


Figure 3. Canonical correspondence analysis (CCA) biplot showing the relationship between the studied environmental variables and the assemblage of waterbird communities. (Species are listed in Appendix 1).

Temperature and precipitation not only influence habitat structure but also impact bird behavior and physiology. Studies such as those by Vaitkuviene *et al.* (2015) and Sokos *et al.* (2016) have demonstrated that a one standard deviation increase in days with temperatures above 25 °C leads to a reduction in overall bird abundance (-2.5%) and species richness (-1.7%) annually. However, in spring and summer, elevated temperatures can promote insect emergence and aquatic productivity, increasing food availability for insectivorous and omnivorous birds. This seasonal resource surge explains the presence of species such as *A. platyrhynchos* and *T. tadorna* during warmer periods, as also supported by Bensaci *et al.*

(2013), who reported increased species richness in Algerian wetlands under warm spring conditions. In addition, the increasing water levels during spring and autumn may be better understood not only as seasonal norms but also as part of more frequent or intense precipitation extremes, which influence wetland structure and bird habitat use (Li and Lei 2024; Lei and He 2025).

Rainfall plays a complementary role, particularly in raising water levels during spring and autumn, which in turn affects habitat suitability for diving birds like grebes and certain ducks. These birds often require specific depth thresholds for foraging, as shown by Fan *et al.* (2021), Amininasab *et al.* (2022), and Krajewski *et al.* (2023). In contrast, shorebirds and waders may avoid such deep conditions, leading to seasonal shifts in community structure.

Overall, the plot demonstrates distinct ecological niches shaped by hydrological and climatic factors, highlighting how artificial wetlands support a functionally diverse avifauna adapted to seasonal variability. This underlines the ecological importance of such reservoirs, particularly in semi-arid contexts where natural wetland availability is limited.

4. Conclusions

Our study highlights the crucial role that artificial water reservoirs play in providing essential alternative habitats for waterbird species in the context of the ongoing loss and degradation of natural sites. The artificial wetlands can support numerous waterbird communities, sometimes of significant heritage value, and therefore, their conservation value should not be underestimated. To this end, these artificial wetlands should be a key element for biodiversity conservation and management efforts should be recommended, including optimizing wetland design to offer diverse habitats, regulating water levels seasonally to match bird migration and breeding needs, and implementing species-specific actions such as installing nesting platforms or controlling human disturbance. Additionally, integrating regular biodiversity monitoring and raising awareness among local communities can support long-term conservation and multifunctional use of these wetlands.

Conflicts of interest

The authors declare no conflict of interest.

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Appendix 1. Systematic list of bird species recorded in the region of Tebessa with its distribution by phenological status and trophic status. Site number: 1: Bouromane wetland; 2: Sem labrika wetland; 3 Ain Zarga wetland. Phenological status (PhS): PM: passing migrant; W: wintering; SB: sedentary breeding; SNB: sedentary non–breeding; SN: summer nesting Trophic status (TS): I: InverteSbrate consumer. P Piscivorous. Pp: Polyphagous; G: Granivorous. Protection categories: * = species protected in Algeria; IUCN Red List categories (LC: least concern, NT: near threatened, VU: vulnerable, EN: endangered).

Order	Family	Species	Scientific name and conservation statutes	Maximum individual number	Site number	Phenological status	Trophic status
Podicipediformes	Podicipedidae	Great Crested Grebe	*Podiceps cristatus* (Linnaeus, 1758) LC	33	1, 2, 3	W	I
		Little Grebe	*Tachybaptus ruficollis* (Pallas, 1764) LC	144	1, 2, 3	W	I
Suliformes	Phalacrocoracidae	Great Cormorant	*Phalacrocorax carbo** (Linnaeus, 1758) LC	39	2, 3	W	P
Pelecaniformes	Ardeidae	Cattle Egret	*Bubulcus ibis* (Linnaeus, 1758) LC	2512	1, 2, 3	SB	I
		Grey Heron	*Ardea cinerea* (Linnaeus, 1758) LC	183	1, 3	W	P
		Great Wihte Heron	*Egretta alba** Linnaeus, 1758 LC	59	3	PM	P
		Little Egret	*Egretta garzetta** (Linnaeus, 1766) LC	140	3	PM	P
Ciconiiformes	Ciconiidae	White Stork	*Ciconia ciconia** (Linnaeus, 1758) LC	1032	1, 3	SN	I
Anseriformes	Anatidae	Northern Shoveler	*Anas clypeata* (Linnaeus, 1758) LC	169	1, 2, 3	W	Pp
		Common Teal	*Anas crecca* Linnaeus, 1758 LC	101	1, 2, 3	W	G
		Garganey	*Anas querquedula* (Linnaeus, 1758) LC	100	1,3	PM	Pp
		Eurasian Wigeon	*Mareca penelope* (Linnaeus, 1758) LC	64	1, 2, 3	PM	Pp
		Mallard	*Anas platyrhynchos* Linnaeus, 1758 LC	5836	1, 2, 3	SB	Pp
		Gadwal	*Mareca strepera* (Linnaeus, 1758) LC	41	1, 2, 3	PM	Pp
		Northern Pintail	*Anas acuta* Linnaeus, 1758 LC	110	1, 3	W	Pp
		Common Pochard	*Aythya ferina* (Linnaeus, 1758) VU	222	1, 2, 3	W	Pp
		Ferruginous Duck	*Aythya nyroca** (Güldenstädt, 1770) NT	153	1, 2, 3	W	Pp
		Common Shelduck	*Tadorna tadorna** (Linnaeus, 1758) LC	1149	1, 2, 3	W	Pp
		White-headed Duck	*Oxyura leucocephala* (Scopoli, 1769) EN	197	1, 3	PM	Pp
Gruiformes	Rallidae	Eurasian Coot	*Fulica atra* Linnaeus, 1758 LC	5011	1, 2, 3	SNB	Pp
		Common Moorhen	*Gallinula chloropus* (Linnaeus, 1758) LC	2820	1, 2, 3	SNB	Pp
	Gruidae	Common Crane	*Grus grus** (Linnaeus, 1758) LC	54	3	W	Pp
Charadriiformes	Recurvirostridae	Black-winged Stilt	*Himantopus himantopus** (Linnaeus, 1758) LC	392	1, 2, 3	W	I
		Pied Avocet	*Recurvirostra avosetta* *Linnaeus, 1758 LC	90	1, 3	PM	I
	Charadriidae	Little Ringed Plover	*Charadrius dubius* Scopoli, 1786 LC	47	3	PM	I
		Common Ringed Plover	*Charadrius hiaticula* Linnaeus, 1758 LC	26	3	PM	I
	Laridae	Black-headed Gull	*Larus ridibundus* (Linnaeus, 1766) LC	53	1,3	PM	Pp
		Mediterranean Gull	*Ichthyaetus melanocephalus* (Temminck, 1820) LC	55	1,3	PM	Pp