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Evaluation of the Physico-Chemical and Bacteriological Quality of a Mediterranean Urban Wetland in Algeria (Boussedra Marsh)

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ABSTRACT

As cities grow and demand for land increases, wetlands retreat and degrade. To assess the possible effect of human activity in a Mediterranean urban wetland (Boussedra marsh) in northeastern Algeria, analyses of physico-chemical parameters and faecal contamination indicator germs were carried out over a 12-month period, with 24 samples taken at 2 sampling sites chosen according to their exposure to probable sources of pollution. To compare the results with the World Health Organization's (WHO) guidelines, varieties of physico-chemical and bacteriological characteristics were examined. These included turbidity, electrical conductivity, biological demand for oxygen, pH, hardness, solids in suspension, dry residues, dissolved oxygen, ammonium, potassium, nitrates, nitrites, chloride, phosphate, sulphur dioxide, calcium, and magnesium. Bacteriological parameters such as total mesophilic aerobic flora, total coliforms, faecal coliforms and faecal streptococci were addressed. This wetland's surface water quality was evaluated overall using the water quality index (WQI). Results of physicochemical analyses indicate that several parameters exceed the current standards. The results also revealed a relatively high number of germs indicative of faecal contamination, indicating a high degree of bacteriological pollution. The levels of these pollutants differ from one point to another, and according to the sampling period (rainy or dry). The load of faecal pollution indicator germs was higher in dry periods than in rainy periods. The Boussedra marsh has extremely poor water quality, according to the WQI water quality index (WQI=168.48±29.65). Although the Boussedra wetland is an ideal wintering area and refuge for many species of waterfowl, it has reached a high level of pollution and deterioration. Priority must therefore be given to building capacity to ensure the conservation of this urban wetland.

INTRODUCTION

Wetlands are the cradle of biodiversity on which countless plant and animal species depend on **(Loucif *et al*., 2020a, 2021; Sharma *et al*., 2021)**. Wetlands also contribute to the quality of water resources through their self-cleansing effect, their role in protecting against the devastating effects of flooding, and their retention of nutrients in floodplains **(Scholz, 2024)**. Wetlands continue to be among the world's most threatened ecosystems despite their significance because of drainage, pollution, and drying out **(Ballut *et al*., 2022)**.

In addition to their role in conserving biodiversity by offering protection to the communities that inhabit them, urban and peri-urban wetlands fulfil important functions by improving the local environment **(Ioja *et al*., 2020)**. However, as cities grow and demand for land increases, these wetlands are often encroached upon, degraded, filled in, and eventually replaced by buildings **(Iyoob *et al*., 2022)**.

Urban and peri-urban wetlands, often perceived as ordinary, raise expectations among managers. It is noteworthy that to learn that a large number of wetlands in urban and peri-urban regions have been damaged or are now being damaged by pollution, inadequate waste management, landfill sites and the encroachment of nearby people **(Roy-Basu *et al*., 2020)**. Notably, wetlands that were previously in rural areas including Ramsar sites are becoming more urbanized, raising the possibility of degradation and pollution of these sites **(Loucif*et al*., 2020b)**.

The Boussedra marsh is a periurban wetland situated in the Wilaya of Annaba in the northeast side of Algeria. *Phragmitesaustralis*, *Typhaangustifolia*, and *Scirpusmaritimus* dominate the marsh. There is a dense stand of Tamarixgallica trees surrounding the southern edge **(Boudraa *et al*., 2014; Draidi *et al*., 2023)**. Many species of waterfowl use the Boussedra marsh as a wintering and breeding site **(Boudraa *et al*., 2014; Draidi *et al*., 2023; Hennouni *et al*., 2023)**. Urban, industrial and agricultural expansion, as well as the construction of new buildings, have led to significant degradation and shrinkage of this water body, with a decline in the cover of aquatic vegetation around and within the marsh **(Aouadi*et al*., 2021)**.

Pollution by wastewater from various human activities, whether domestic and/or industrial, remains a public health problem, and the issue of water is an ongoing one, both globally and in countries with scarce water resources (**Negm*et al*., 2020)**. Recently, surface water quality has become one of the main environmental concerns of researchers inmany parts of the world **(Saalidong *et al*., 2022; Adeyemi *et al*., 2023; Chedadi *et al*., 2023; Gule *et al*., 2023; Syeed *et al*., 2023; Wang *et al*., 2023)** and in Algeria **(Zenati *et al*., 2023; Boussaha *et al*., 2024; Loucif & Chenchouni, 2024; Mechouet *et al*., 2024; Rezak *et al*., 2024)**. Water quality is a key factor in wastewater treatment, human and animal health, agriculture, aquaculture, industry, aquatic ecology and many other areas, and it is impossible to meaningfully address the issue of water quality without making extensive use of physicochemical and bacteriological parameters **(Boyd, 2020)**. However, the assessment of the water quality of the Boussedra marsh has been neglected and there is very little data available describing the physico-chemical and bacteriological quality of the water in this peri-urban wetland.

To evaluate the level of contamination in the Boussedra marsh, assess potential health consequences, and understand associated risks, a study was organized with the aim of evaluating the water quality in this peri-urban marsh both physico-chemically and bacteriologically. In addition, the water quality index (WQI) was applied to elucidate seasonal and spatial-temporal changes in water quality

MATERIALS AND METHODS

1. Research zone

Boussedra marsh (36°50′45″ North, 7°43′47″ East) is located 10km from Annaba's town (Fig. 1) and is part of the wetlands of Western Numidia. During periods of heavy rainfall, the lake can cover an area of around 55 hectares. The pond's maximum depth is 1.5 meters during dry period and 2 meters during wet period. It is surrounded to the east by shantytowns.

A large industrial area borders the western limit, which is also traversed by a railway. Urban agglomerations border the east and north shores. The study region has a mild Mediterranean climate, with rainy winters and hot, sub-humid summers. In the Emberger Climagram, the location is considered subhumid bioclimatic zone with temperate winters.

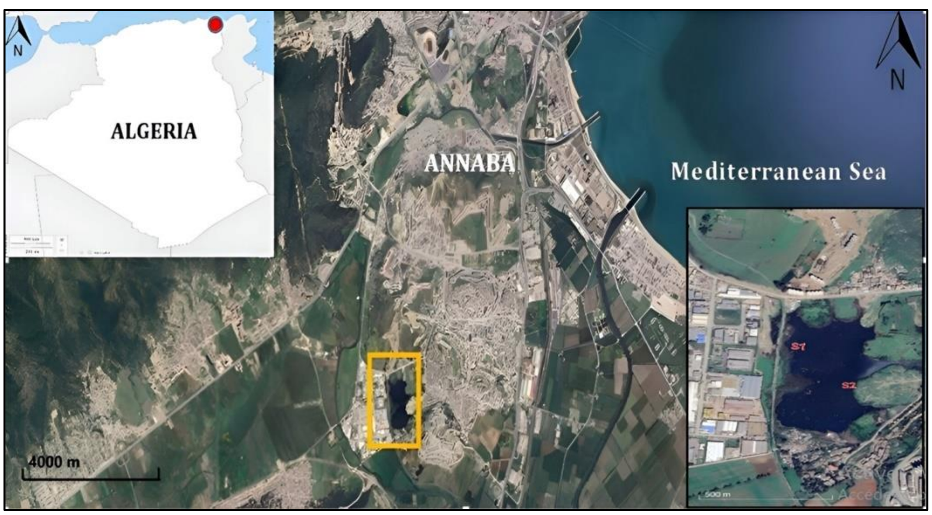

Fig.1. Location of the Boussedra marsh in northeast Algeria. The Boussedra marsh is indicated by a yellow square. At the bottom right is the map of the water body with the location of the two sampling sites, S1 and S2

The Gaussen rainfall diagram for the period 1991-2012 shows that the year is divided into a dry period that extends from April to September and a wet season for the rest of the year **(Boudraa *et al*., 2014; Draidi*et al*., 2023; Hennouni *et al*., 2023)**.

Although it is a small area, the Boussedra marsh provides an excellent wintering and refuge site for many species of waterfowl **(Draidi *et al*., 2023)**.

2. Data collection

For a yearly cycle that extended from November 2021 to October 2022, a monthly sampling was conducted. Samples for the analysis of physico-chemical parameters and the enumeration of faecal contamination indicator germs were taken over a 12-month period, with 24 samples collected from 2 sites at a frequency of one sample per month for each sampling site, which were chosen based on their exposure to likely sources of pollution. Considering the different activities found in these urban wetlands (home, industrial, and agricultural wastewater), two stations (S1 and S2) were selected. Station S1 is located to the west, near the industrial zone. Several wastewater discharge points from neighbouring municipalities are present at S2, which is located to the east of the marsh. Samples for physico-chemical analysis were taken in plastic bottle previously rinsed with water from the pond. These were carefully sealed and stored in a cool box in the field.

In situ measurements of physico-chemical parameters were conducted in the field, including pH, dissolved oxygen (O_2), and electrical conductivity (EC). The other parameters were carried out in the lab, namely biological oxygen demand (BOD_5), turbidity, hardness (TH), total suspended solids (TSS), dry residue (DR), phosphate (PO_4^{3-}), nitrite (NO_2), magnesium (Mg^{2+}), nitrate (NO_3^-), calcium (Ca^{2+}), ammonium (NH_4^+), magnesium (Mg^{2+}), chloride (Cl^-), sulphate (SO_4^{2-}) and potassium (K^+).

Water pH, electrical conductivity, and dissolved oxygen were measured using a high-precision WTW Multi® multi-parameter hand-held unit with an automatic correction system **(Rodier *et al*., 2009)**. Total hardness was determined by complexometric titration with EDTA. Suspended solids were determined using the gravimetric method after filtration through a glass fibre filter **(Rodier *et al*., 2009)**. Turbidity was measured by nephelometry using a turbidimeter that gives a measurement in nephelometric turbidity units (NTU). The determination of dry residues consisted of gradually evaporating a quantity of water in a beaker. Once the water had evaporated, the capsule was placed in an oven at 105°C for 4h and left to cool for 1/4h in a desiccator **(Rodier*et al*., 2009)**. BOD is an important parameter for assessing the quantity of oxygen required for the self-purification of natural surface waters. BOD_5 was measured using the OxiTop® system based on the pressure principle (measurement by difference) and expressed in mg O_2/ L **(Rodier *et al*., 2009)**. Phosphates, sulphates, nitrates, potassium, ammonium, calcium, magnesium and nitrites were determined by ion spectrophotometry. Chlorides were analyzed by using the flow injection analysis (FIA) **(Rodier *et al*., 2009)**.

Total mesophilic aerobic flora (TMAF) was counted using the TGEA agar incorporation method. Bacteria were kept dispersed in a solid medium, giving rise under favorable conditions to colonies that were isolated from each other and can therefore be counted directly **(Rodier *et al*., 2009)**. Indicator germs for faecal contamination (Total coliforms, faecal coliforms, and faecal streptococci) were counted using the most probable number (MPN). The methods used to determine all the parameters recommended by **Rodier *et al*.(2009)**.

3. The water quality index (WQI)

Water quality index (WQI) simplifies detailed data on water quality into a format that the public can easily understand and allows results to be compared to national or international guidelines **(Li *et al*., 2014; Loucif & Chenchouni, 2024)**. Managers and decision-makers can readily comprehend this index **(Uddin *et al*., 2021)**. Each physicochemical parameters was assigned a weight *wi* based on its potential impact on health and the environment. This index is obtained using the weighted arithmetic index approach**(Bouderbala, 2017; Loucif & Chenchouni, 2024)**.

Thirteen (13) significant parameters were chosen for calculating the water quality index (WQI): Potential hydrogen 'pH', turbidity, electrical conductivity, 'NO_3^-'', 'NO_2^-', 'NH_4^+', 'PO_4^{3-}', 'Ca^{2+}' 'Mg^{2+}', 'Cl^-', K^+', 'SO_4^{2-}' and hardness. This method uses the following formula to determine a numerical value, known as relative weight (Wi) (Table1), unique to each physico-chemical parameter,

$$W_i = w_i / \sum_{i=1}^{n} w_i$$

where, Wi represents the relative weight; wi represents the weight of each parameter, and nindicates the number of parameters. Table(1) presents the assigned weight (wi), relative weight (Wi), and **WHO (2011)** standards for each parameter.

Table 1. Relative weight of chemical parameters and the WHO water quality standards **(Loucif&Chenchouni, 2024)**

Physicochemical parameter	WHO standards	Weight (w_i)	Relative weight (W_i)
Potential hydrogen 'pH'	8.5	3	0.0682
Ammonium 'NH_4^+' [mg/L]	0.5	5	0.1136
Phosphate 'PO_4^{3-}' [mg/L]	5	4	0.0909
Calcium 'Ca^{2+}' [mg/L]	200	3	0.0682
Nitrates 'NO_3^-' [mg/L]	50	5	0.1136
Nitrites 'NO_2^-' [mg/L]	0.1	5	0.1136
Potassium 'K^+' [mg/L]	12	1	0.0227
Magnesium 'Mg^{2+}' [mg/L]	50	3	0.0682
Chloride 'CL^-' [mg/L]	250	4	0.0909
Sulphate 'SO_4^{2-}' [mg/L]	250	3	0.0682
Hardness [°F]	300	3	0.0682
Turbidity [NTU]	5	2	0.0455
Electrical conductivity [µS/cm]	2000	3	0.0682
		$\sum w_i = 44$	$\sum W_i = 1$

Each of the parameters has a quality rating scale (qi) that is derived utilizing the equation that follows:

$$q_i = C_i/S_i \times 100$$

Where, qi is the quality index; Ci is each chemical parameter's concentration (mg/L), and Si is the **WHO (2011)** guideline of each parameter. The SI is initially determined for each parameter and used to calculate the WQI utilizing the equation that follows:

$$SI = W_i q_i$$

The water quality index was determined by summing the SI of n parameters.

$$WQI = \sum_{i=1}^{n} SI_i$$

The water quality index level and type of water were categorized in five classes (Table 2)**(Li *et al*, 2014; Loucif & Chenchouni, 2024)**.

Table 2. Water quality classifcation based on WQI values

WQI values	Water quality classifcation
WQI<25	Excellent water quality
25<WQI<50	Good water quality
50<WQI<100	Moderate water quality
100< WQI < 150	Poor water quality
WQI>150	Extremely poor water quality

4. Data analysis

The average, the mean's standard deviation, and range were the descriptive statistics used to summarize the data for each parameter. The degree of the potential relationship between the various categories of faecal pollution indicator bacteria was evaluated using Pearson's correlation coefficient (r). Throughout the study period, Pearson correlation coefficients (r) were determined between the four groups of faecal pollution indicators, which were taken in pairs. The results were performed using IBM SPSS 25 Software.

RESULTS

1. Boussedra marsh's physicochemical characteristics

Physicochemical properties of the water sampled at the Boussedra marsh are shown in Table (3) with their respective mean ± standard deviation values. The surface waters of the Boussedra marsh were characterized by an average turbidity of 9.28±1.25 NTU (Interval: 7.02-12. 33), a mean pH of 7.29±0.25 (Interval: 7.02-7.83), a mean EC of 1605.39±478.31µs/cm (Interval: 1024-2354), mean DO was 0.73±0.13mg O_2/L (Interval: 0.42-0.96), mean TSS was 12.22±0.60 (Interval: 10.52-13.00mg/L). DR had a mean of 1127.94±312.83 (Interval: 126.55-1324.55mg/L). Nitrate NO_3^- averaged 8.43±0.68

(Interval: 7.52-10.55mg/L). Nitrite NO_2^- had an average concentration of 0.80±0.23 (Interval: 0.33-1.52mg/L).NH_4^+ had a mean value of 2.41±0.76 (Interval: 1.20-4.50mg/L), PO_4^{3-} had a mean value of 4.34±2.41 (Interval: 1.30-8.66mg/L). BOD_5 with an average of 3.77±0.76 (2.70-5.30mg O_2/L), and an average total hardness TH of 57.35±5.82 (Interval: 45.55-69.75°F). Calcium Ca^{2+} had an average value of 77.67±6.21 (56.88-87.52mg/L). Mg^{2+} had an average value of 83.66±45.86 (Interval: 19.25-193.33mg/L). Cl^- had an average value of 794.42±384.80 (Interval: 154-1425mg/L). K^+ showed an average concentration of 72.83±9.78 (Interval: 51-88mg/L). SO_4^{2-} had an average concentration of 140.96±24.78 (Interval: 102-220mg/L) (Table 3).

2. Bacteriological characteristics

Our research found that a large number of germs, indicating faecal contamination, colonizes the waters of the Boussedra marsh. The average total mesophilic aerobic flora (TMAF) was 315× 10^3±67.40× 10^3 colony forming units/100mL (varying 230× 10^3-455×10^3). The average total coliform count (TC) was270.00× 10^3±52.75× 10^3 colony forming units/100mL (Interval: 210×10^3-368×10^3); the average (FC) count was 231.37×10^3±55.18×10^3 colony forming units/100mL (Interval: 120×10^3-320×10^3) and the average FS count was 49.79×102±18.00×102 CFU/100mL (21×10^2 -76×10^2).

Station S2 was more colonized by fecal pollution germs than Station S1. The TMAF load for Station S2 was 344.92×10^3 ± 73.63×10^3 colony forming units/100 mL (Interval: 251×10^3 - 455×10^3). Total coliforms (TC) were 286.00×10^3 ± 54.15×10^3 colony forming units/100mL (Interval: 210×10^3 - 368×10^3). Fecal coliforms (FC) were 249.00×10^3 ± 52.16×10^3 colony forming units/100 mL (Interval: 180×10^3 - 320×10^3), and fecal streptococci (FS) were 52.58×10^2 ± 14.67×10^2 colony forming units/100mL (Interval: 33×10^2 - 76×10^2).

Compared to rainy seasons, the load of bacteria that indicate faecal pollution was higher during dry periods. During the dry season, the following was the load of indicator bacteria for faecal pollution: TMAF was 340.58×10^3±54.00×10^3 colony forming units/100mL (Interval: 264×10^3 – 447×10^3). Total coliforms 298.33×10^3 ±45.09 ×10^3 colony forming units/ 100mL (Interval: 210×10^3-368). Fecal coliforms were 265.42×10^3 ± 40.19 colony forming units/100mL (Interval: 190×10^3 - 320×10^3), and fecal streptococci were 59.42×10^2 ± 13.32×10^2 colony forming units/100 mL (Interval: 33×10^2 - 75×10^2) (Tables 3, 4, 5).

Table 3. Descriptive statistics for physico-chemical (mg/L) and bacteriological (CFU/mL) parameters of the two sampling stations for the period from November 2021 to October 2022 at the Boussedra marsh (Annaba) (mean ± SD and [min-max] interval).

Water parameter	**Sampling station: Mean ± SD [min-max]**		**Total**
	S1 (N=12)	**S2 (N=12)**	**(N=24)**
Turbidity	9,89±1,20 [8,62–12.33]	8,67±1,02 [7,02–10.77]	9,28±1,25 [7,02–12.33]
pH	7,42±0,27 [7,02–7,83]	7,17±0,14 [7,03–7,54]	7,29±0,25 [7,02–7,83]
EC (µs/cm)	1949,67±456,27 [1024–2354]	1261,11±107,61 [1132,55–1467,21]	1605,39±478,31 [1024–2354]
DO (mg O_2/L)	0,71±0,10 [0,42–0,86]	0,75±0,15 [0,53–0,96]	0,73±0,13 [0,42–0,96]
TSS (mg/L)	12,34±0,47 [11,45–13,00]	12,11±0,71 [10,52–12,84]	12,22±0,60 [10,52–13,00]
DR (mg/L)	1217,31±67,25 [1087,66–1324,55]	1038,57±427,40 [126,55–1274,55]	1127,94±312,83 [126,55–1324,55]
NO_3^- mg/L	8,05±0,40 [7,52–8,55]	8,82±0,71 [7,98–10,55]	8,43±0,68 [7,52–10,55]
NO_2^- (mg/l)	0,83±0,19 [0,54–1,20]	0,77±0,27 [0,33–1,52]	0,80±0,23 [0,33–1,52]
NH_4^+ (mg/L)	2,05±0,84 [1,20–4,50]	2,76±0,46 [2,30–3,50]	2,41±0,76 [1,20–4,50]
PO_4^{3-} (mg/L)	2,55±1,89 [1,30–6,66]	6,14±1,28 [4,55–8,66]	4,34±2,41 [1,30–8,66]
BOD_5 (mg O2/l)	3,43±0,51 [2,70–4,30]	4,10±0,83 [3,10–5,30]	3,77±0,76 [2,70–5,30]
TH (°F)	59,26±4,83 [54,66–68,66]	55,45±6,30 [45,55–69,75]	57,35±5,82 [45,55–69,75]
Ca^{2+} (mg/L)	78,36±4,78 [72,33–86,77]	76,98±7,54 [56,88–87,52]	77,67±6,21 [56,88–87,52]
Mg^{2+} (mg/L)	85,79±45,07 [19,25–190,51]	81,53±48,55 [46,25–193,33]	83,66±45,86 [19,25–193,33]
Cl- (mg/L)	825,67±410,20 [182–1425]	763,17±373,12 [154–1081]	794,42±384,80 [154–1425]
K^+ (mg/L)	69,83±11,51 [51–88]	75,83±6,93 [66–88]	72,83±9,78 [51–88]
SO_4^{2-} (mg/L)	137,25±14,96 [110–162]	144,67±32,09 [102–220]	140,96±24,78 [102–220]
TMAF (UFC/1000 mL)	285,08±46,08 [230–368]	344,92±73,63 [251–455]	315,00±67,40 [230–455]

TC (UFC/1000 mL)	254,00±48,24 [210–320]	286,00±54,15 [210–368]	270,00±52,75 [210–368]
FC (UFC/1000 mL)	231,37±55,18 [120–280]	249,00±52,16 [180–320]	231,37±55,18 [120–320]
FS (UFC/100 mL)	47,00±21,11 [21–75]	52,58±14,67 [33–76]	49,79±18,00 [21–76]

Table 4. Bacteriological characteristics (CFU/ml) of Boussedra marsh water

Station	Month	TMAF (UFC/1000 mL)	TC (UFC/1000 mL)	FC (UFC/1000 mL)	FS (UFC/100mL)
S1	November	255	210	180	68
	December	244	210	180	25
	January	234	220	180	27
	February	230	210	150	21
	March	245	210	120	21
	April	336	320	280	38
	May	368	320	280	37
	June	312	302	255	54
	July	322	288	240	58
	August	324	304	280	66
	September	287	244	230	74
	October	264	210	190	75
S2	November	290	260	180	76
	December	265	212	200	41
	January	251	220	190	42
	February	266	210	188	44
	March	402	310	250	45
	April	455	308	270	34
	May	447	320	290	33
	June	402	368	320	66
	July	387	350	310	65
	August	366	324	310	56
	September	321	300	260	58
	October	287	250	220	71

Table 5. Descriptive statistics for bacteriological parameters (CFU/mL) distributed according to season (rainy and dry) in the Boussedra marsh (Annaba) (mean ± SD and [min-max] interval)

Bacteriological parameter	Season : Mean ± SD [min-max]		Total (N=24)
	Rainy season (N=12)	Dry season (N=12)	
TMAF (UFC/1000 mL)	289,42±71,79 [230–455]	340,58±54,00 [264–447]	315,00±67,40 [230–455]
TC (UFC/1000 mL)	241,67±45,10 [210–320]	298,33±45,09 [210–368]	270,00±52,75 [210–368]
FC (UFC/1000 mL)	197,33±47,15 [120–280]	265,42±40,19 [190–320]	231,37±55,18 [120–320]
FS (UFC/100 mL)	40,17±17,27 [21–76]	59,42±13,32 [33–75]	49,79±18,00 [21–76]

3. Evaluating water quality in Boussedra wetland with the water quality index

With an average value of 168.48± 29.65, the WQI reveals that the Boussedra marsh's water quality is extremely poor. Moreover, station S1 shows more polluted water with an average WQI value of 174.01±37.07 (Interval: 113.12-222.51) compared with 162.94±19.93 (Interval: 114.86-184.30) at station S2. According to the WQI, the water is more polluted in dry period than in the rainy season, with an average WQI value of 181.88± 14.03 (Interval: 167.87-219.94) in the dry season compared with 155.07±35.34 (Interval: 113.12-222.51) in the wet season. The water has a poor quality during the rainy season from December to February, and it is extremely poor throughout the rest of the rainy season. During the dry season, both sample stations exhibit an extremely poor water quality (Table6).

Table 6. WQI values and surface water quality class of the Boussedra marsh (Annaba) for individual water samples (mean ± SD and interval [min-max])

Rainy season	WQI value	Classification
S1	189,25	extremely poor water quality
S1	123,68	poor water quality
S1	113,12	poor water quality
S1	114,83	poor water quality
S1	181,07	extremely poor water quality
S1	222,51	extremely poor water quality
S2	167,79	extremely poor water quality
S2	142,02	poor water quality

S2	142,23	poor water quality
S2	114,86	poor water quality
S2	167,79	extremely poor water quality
S2	181,75	extremely poor water quality
Total	155,07±35,34	extremely poor water quality
Dry season	WQI value	Classification
S1	219,94	extremely poor water quality
S1	187,83	extremely poor water quality
S1	186,83	extremely poor water quality
S1	182,16	extremely poor water quality
S1	179,72	extremely poor water quality
S1	187,25	extremely poor water quality
S2	172,91	extremely poor water quality
S2	169,68	extremely poor water quality
S2	172,27	extremely poor water quality
S2	184,30	extremely poor water quality
S2	167,87	extremely poor water quality
S2	171,85	extremely poor water quality
Total	181,88±14,03	extremely poor water quality

4. Interrelationships between groups of bacteria

Pearson correlation coefficients were calculated between the 4 groups of faecal pollution indicators, taken in pairs, for the 2 sampling stations throughout the study period. Analysis of the Pearson correlation matrix data showed highly significant positive correlation values (r) for the TMAF-TC pairs (r=0.874; $P<0.001$). TMAF- FC (r=0.842; $P<0.001$) .FC -TC (r=0.936; $P< 0.001$). However, between the FS group and the other groups of faecal contamination indicators, we could not find any significant relation (Table7).

Table 7. Correlation matrix showing the interrelationships between the bacteriological parameters of the Boussedra marsh waters. Pearson correlation tests are given as correlation coefficient (r) values and *P*

		TMAF	TC	FC	FS
TMAF	Correlation coefficient (r)	1	0,874***	0,842***	0,082^{ns}
	P		0,000	0,000	0,705
TC	Correlation coefficient (r)	0,874***	1	0,936***	0,218^{ns}
	P	0,000		0,000	0,306
FC	Correlation coefficient (r)	0,842***	0,936***	1	0,292^{ns}
	P	0,000	0,000		0,166
FS	Correlation coefficient (r)	0,082^{ns}	0,218^{ns}	0,292^{ns}	1
	P	0,705	0,306	0,166	

***$P < 0,001$. **$P < 0, 01$. *$P < 0, 05$. ^{ns} $P > 0,05$.

DISCUSSION

1. Physicochemical parameters

The results reveal that several physicochemical parameters of the waters of the Boussedra marsh largely exceed the international standards. The turbidity of water is due to the presence of particles in suspension: clays, silts, grains of silica, organic matter. Assessing the abundance of these particles measures its degree of turbidity **(Rodier*et al*., 2009)**.The average value in the Boussedra marsh was 9.28±1.25 NTU, with a range of 7.02–12.33 NTU. This value generally fluctuates between 10 and 50 NTU in surface waters**(Boyd, 2020)**. Moreover, this property is strongly influenced by heavy rainfall **(Rodier*et al*., 2009)**.

During the study period, the pH at Boussedra marsh was slightly alkaline, with an average of 7.29±0.25 (range: 7.02-7.83). The pH of the Boussedra marsh falls within the range of 6.5-8.5 established by the **WHO (2017)**. The electrical conductivity of the Boussedra marsh is greater than 1500µS/ cm, with a mean value of 1605.39±478.31 (range: 1024-2354), which is higher than the accepted quality standard, indicating high mineralization of the water in this wetland **(WHO, 2017)**. These high values of electrical conductivity are due either to an increase in the contributions of dissolved substances coming from the agricultural land surrounding the site, or to organic substances of various origins (discharges from the neighboring industrial zone, wastewater, public discharges from neighboring municipalities), which are directly dumped into this marsh **(Loucif *et al*., 2020b)**.

Water's dissolved oxygen concentration is a crucial factor, as it is used by living organisms to respire. Low dissolved oxygen levels can stress and even kill aquatic organisms **(Braz-Mota & Almeida- Val, 2021)**. Our findings reveal an anoxic state in the Boussedra marsh, with a mean DO level of 0.73±0.13mg/L (fluctuate 0.42-0.96mg/L), considerably lower than the **WHO (2017)** guidelines of 5-8mg/L. This significant dissolved oxygen deficit is probably linked to an abnormally high input of nutrients from untreated wastewater from neighbouring agglomerations **(Guemmaz*et al*., 2020)**. The increase in nutrients in the lake water also allows phytoplankton to proliferate, which increases the turbidity of the water. The plants at the bottom of the lake are then deprived of light and photosynthesis becomes impossible, leading to a situation of anoxia **(Ngodhe *et al*., 2013)**.

The average dry residue concentration of the Boussedra marsh is 1127.94±312.83mg/ L. This concentration is lower than the **WHO's (2017)** maximum limit of 2000mg/ L. Suspended matter such as clays, sands, silts, products of the decomposition of organic matter, bacteria, plankton, and algae are responsible for water turbidity. In the Boussedra marsh we recorded an average value of suspended solids of 12.22mg/L (limits: 10.52- 13mg/ L). Suspended solids levels in lakes and marshes are variable and sometimes high, these values are linked to the nature of the soil, precipitation, and discharges **(Bourrier & Selmi, 2011)**. Salts of magnesium and calcium, as well as chlorides and bicarbonates, are the primary contributing factors of water hardness **(Haritash*et al*., 2016)**.

Our results show that the water in the Boussedra marsh recorded a significant hardness of 57.35±5.82 (range: 45.55-69.75).Water hardness can be ascribed to multiple factors, as the soil's composition, pollution from domestic and industrial wastewater discharges, and chemical pollution from the usage of fertilizers **(Madhav*et al*., 2020; Akhtar *et al*., 2021)**. Concentration of eutrophying elements (NH_4^+ and PO_4^{3-}, NO_3^-, NO_2^-) varies from one element to another. The primary sources of phosphorus in rivers and lakes are drainage from fertilized agricultural land and the use of detergents **(Rejsek, 2002)**. Eutrophication of water bodies results from an abundance of nutrients causing excessive growth of plants and algae **(Tiwari & Pal, 2022)**.

According to **Chadli and Boufala (2021)**, ammonium in water typically indicates inadequate decomposition of organic materials. Ammonium is an ideal indicator of organic discharges from home, industrial, or agricultural sources that contaminate water since it is formed when iron combine with nitrates **(Dey *et al*., 2021)**. The ammonium concentration in the Boussedra marsh is 2.41± 0.76mg/L (range: 1.20– 4.50mg/L, and it is well above the standard of the WHO (0.5mg/L).The ammonium ion (NH4+), which is found in water and soil, is nitrified to produce nitrates (NO3-) and nitrites (NO2-). Nitrates are then transformed into nitrites **(Spataru, 2022)**. Nitrite is considered a toxic element. Human activity is the main cause of nitrates and nitrites found in water, resulting from the decomposition of animal and plant substances, the use of artificial fertilizers and manure, and intense agricultural practices **(Riaz *et al*., 2024)**.

At the study site, nitrite concentrations were 0.80± 0.23mg/L (range: 0.33-1.52), exceeding the **WHO (2017)** threshold of 0.1mg/L. The ortho-phosphate concentration in Bousedra marsh is 4.34± 2.41mg/L (range: 1.30-8.66) which does not exceed the threshold recommended by **WHO (2017)**, with a value limit of 5mg/L. Calcium, potassium, sodium and magnesium are the main mineral elements found in lake and river water, and the concentration of calcium and magnesium is an indicator of water hardness **(Amankwaa *et al*., 2020)**. The Boussedra marsh's water contains 77.67± 6.21mg/L of calcium, which is below the guideline implemented by **WHO (2017)** of 200mg/ L. According to our results, the magnesium level in the Boussedra marsh is 83.66± 45.86mg/ L, which is considered to be high, thus favoring interactions with Na^+, which can be dangerous for crop irrigation **(Bouaroudj *et al*., 2019)**.

The chloride value recorded in the study area is 794.42± 384.80mg/ L, which represents a very high value that exceeds the current standards indicated by the **WHO (2017)**. The presence of chlorides in surface water can be attributed to the dissolution of salt deposits, effluents from chemical plants, sewage, irrigation runoff, and waste leachate **(Loucif *et al*., 2020b, Laskar *et al*., 2022)**.

For sulphate, an average concentration of 140.96± 24.78mg/L was noted in the Boussedra marsh, which is below the threshold set by the **WHO (2017)**. According to **Boyd (2020)**, the BOD_5 of natural waters is generally between 1 and 10mg/ L, and domestic wastewater has a much higher BOD_5 generally between 100 and 300mg/L. At Boussedra marsh, we recorded a BOD_5 of 3.77± 0.76mg O_2/L.

2. Bacteriological parameters

All the results obtained show that the water in the Boussedra marsh is heavily contaminated. Total mesophilic aerobic flora (TMAF), coliforms (Total and faecal) and intestinal enterococci indicate a very poor bacteriological quality of the water. The results also show that point S2, located to the east of the marsh, has the highest values due to the presence of several wastewater discharge points at this level.

These values decrease as you move towards the S1 points located to the west of the marsh, but in general, all of the values obtained are higher than the norm, indicating a very high degree of contamination.

Our analyses show that the germ load indicating faecal contamination increases considerably during the dry season. Dilution is probably responsible for the difference in bacterial loads between the rainy and dry seasons. Rainfall can act as a diluting agent for bacterial contamination by increasing the flow rate in the water body **(Yasmin *et al*., 2023; Loucif & Chenchouni, 2024)**.

3. Evaluating water quality in Boussedra wetland with the water quality index

According to the WQI, the Boussedra marsh's water quality is extremely poor at station S1, which is bordered by an important industrial zone, recording the highest level of pollution. During the rainy season from December to February, the water is of poor quality, and for the rest of the season, it is extremely poor. The declining quality of the water in this wetland is principally a consequence of industrial and urban wastewater discharges, as well as the impact of agricultural practices. In fact, Boussedra marsh receives untreated wastewater discharged directly from urban communities and the neighboring industrial zone.

Seasonal variation is also very clear. They show a clear increase during the hot dry season. The increase in the degree of pollution during the dry period is mainly linked to the reduction in flows from the marsh, while the inflow of effluent laden with domestic and industrial wastewater from the various urban centers remain high.

We recorded highly significant positive correlations (r) for the TMAF-TC peers (r=0.874; P<0.001). TMAF- FC (r=0.842; P< 0.001).FC -TC (r=0.936; P<0.001), similar interactions between the different groups of bacteria indicating faecal contamination of water have already been documented by **Guemmaz*et al*. (2020)** and **Loucif *et al*. (2020b)**.

CONCLUSION

Our research aimed at evaluating the water quality in the Boussedra marsh. While many species of waterbirds use the Boussedra wetland as a wintering area and an optimal habitat for reproduction, this marsh receives a high load of domestic and industrial wastewater coming from different urban centers. Encroachment, urban expansion, pollution, inadequate waste management, and landfill sites are deteriorating the Boussedra wetland, as observed during our monitoring.

Water quality has a major influence on all aspects of the health and the well-being of ecosystems and people. Addressing the water quality of the Boussedra marsh would help better guide prevention strategies against water-borne diseases and identify sources of pollution in this wetland area. Consequently, in terms of management priorities, small urban and peri-urban wetlands therefore deserve to have the same conservation interest as larger wetlands. In this respect, effective management measures and innovative solutions must be taken to solve these pollution problems. It is recommended to (i) ensure a better understanding of water quality management, (ii) make decisions based on scientific data, (iii) improve legal and institutional frameworks to promote better management of water quality; and (iv) promote innovative approaches to water and wastewater quality management.

Therefore, priority must be given to strengthening the capacities which make it possible to guarantee the conservation and rational use of this wetland. The Ramsar listing of sites close to urban centers constitutes a fundamental contribution to safeguarding these important ecosystems against urban encroachment and pollution.

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ARABIC SUMMARY

تقييم جودة المياه الفيزيو-كيميائية والبكتريولوجية لمنطقة رطبة حضرية متوسطية في الجزائر (مستنقع بوسدرة)

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مع نمو المدن وزيادة الطلب على الأراضي، تتراجع الأراضي الرطبة وتتدهور. لتقييم التأثير المحتمل للنشاط البشري في منطقة رطبة حضرية متوسطية (مستنقعات بوسدرة) في شمال شرق الجزائر، تم إجراء تحليلات للمعايير الفيزيائية الكيميائية وجراثيم مؤشر التلوث البرازي على مدى 12 شهراً، حيث تم أخذ 24 عينة في موقعين تم اختيارها وفقاً لتعرضهما لمصادر التلوث المحتملة. لمقارنة النتائج مع المعايير المرجعية لمنظمة الصحة العالمية، تم فحص العديد من الخصائص الفيزيوكيميائية والبكتريولوجية. وشملت هذه المعايير (التعكر،الموصلية الكهربائية، الطلب البيولوجي على الأكسجين، الأس الهيدروجيني، العسر، مجموع المواد الصلبة المذابة، المخلفات الجافة، الأكسجين المذاب، الأمونيوم، البوتاسيوم، النترات، النتريت، الكلوريد، الفوسفات، ثاني أكسيد الكبريت، الكالسيوم، المغنيسيوم). المعايير البكتريولوجية (مجموع الكائنات المجهرية المتباينة التغذية، القولونيات الكلية، القولونياتالبرازية والمكورات العقدية البرازية). تم تقييم جودة المياه السطحية لهذه الأراضي الرطبة بشكل عام باستخدام مؤشر جودة المياه (WQI). تشير نتائج التحاليل الفيزيوكيميائية إلى أن العديد من المعايير تتجاوز المواصفات المعمول بها حالياً. كما كشفت النتائج أيضاً عن وجود عدد كبير نسبياً من الجراثيم التي تدل على التلوث البرازي مما يشير إلى درجة عالية من التلوث البكتريولوجي. وتختلف مستويات هذه الملوثات من نقطة إلى أخرى، ووفقًا لفترات أخذ العينات (ممطرة أو جافة). كانت نسبة الجراثيم الدالة على التلوث البرازي أعلى في الفترات الجافة منها في الفترات الممطرة. يتميز مستنقع بوسدرة بجودة مياه رديئة للغاية، وفقاً لمؤشر جودة المياه (wqi=168.48±29.65) .WQI. وعلى الرغم من أن المنطقة الرطبة بوسدرة هي ملجأ للعديد من أنواع الطيور المائية، إلا أنها وصلت إلى مستوى عالٍ من التلوث والتدهور. لذلك يجب إعطاء الأولوية لضمان الحفاظ على هذه المنطقة الرطبة الحضرية.