# Physicochemical and Bacteriological Quality of Surface Water Resources Receiving Common Wastewater Effluents in Drylands of Algeria

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## Contents



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**Abstract** The assessment of water quality and pollution of surface water resources is crucial to maintain the integrity of aquatic environments. This study aims at characterizing water physicochemical and bacteriological quality of Wadis of Biskra (northeastern Algeria). Water samples were collected monthly from three different Wadis receiving common wastewater effluents from the city of Biskra. Using standard methods, each sample underwent several analyses to determine physicochemical parameters (temperature, pH, electrical conductivity, turbidity, biological and chemical oxygen demand "$BOD_5$ and COD", and concentrations of suspended solid materials, dissolved oxygen, phosphate, nitrites, nitrates, and ammoniacal nitrogen) and bacterial quality (total coliforms, faecal coliforms, faecal streptococci, and sulfite-reducing *Clostridia*). Most of the measured physicochemical parameters reached unsuitable quality limits according to FAO and WHO standards. The water of Wadis of Biskra are characterized by slightly alkaline water pH (7–7.79), electrical conductivity >1,500 μS/cm, turbidity >5 FTU, very low level of suspended solid materials (1–1.33 mg/L), dissolved oxygen <5–8 mg/L, phosphates >2 mg/L, $BOD_5$ > 5 mg/L, COD >30 mg/L, nitrite >0.1 mg/L, and $NH_3$–N > 0.5 mg/L. Our findings emphasized the high contamination load of bacterial groups studied that exceeded WHO standards: total coliforms (56,917–76,167 CFU/100 mL), faecal coliforms (457–6,100 CFU/100 mL), faecal streptococci (1,432–5,217 CFU/100 mL), and sulfite-reducing *Clostridia* (886–5,217 CFU/100 mL). These results revealed a significant faecal pollution in the water of study Wadis. The spatiotemporal trend of different physicochemical and bacterial parameters, as well as the relationships between bacteria densities and physicochemical parameters were tested and discussed. The discharge of untreated wastewater into natural Wadis of drylands results in high and potential pollution risk with serious health and environmental issues. Therefore, the appropriate water treatment prior to wastewater discharge is needed urgently to prevent aquatic ecosystem pollution and degradation.

**Keywords** Algeria, Bacteriological indicators, Drylands, Eutrophication, Faecal pollution, Surface water resources, Urban wastewater effluents, Water physicochemical parameters, Water quality

## Abbreviations

| | |
|---|---|
| ANOVA | Analysis of variance |
| $BOD_5$ | 5-Day biological oxygen demand |
| CFU | Colony-forming unit |
| COD | Chemical oxygen demand |
| DO | Dissolved oxygen |
| EC | Electrical conductivity |
| FC | Faecal coliforms |
| FS | Faecal streptococci |

| | |
|---|---|
| GLM | Generalized linear model |
| MPN | Most probable number |
| SD | Standard deviation |
| SRC | Sulfite-reducing *Clostridia* |
| SSM | Suspended solid material |
| TC | Total coliforms |
| WBK | Wadi of Biskra |
| WHO | World Health Organization |
| WRB | Wadi of Chaabet Roba |
| WZM | Wadi of Zemer |

## 1 Introduction

Water is a rare and precious resource in hot arid regions. In these regions, groundwater plays crucial roles for developing countries as it is often the only source of drinking and irrigation water. This water is therefore vital for the socioeconomic development of these countries [1–3]. However, this water is highly exposed to alteration and seriously threatened by different human activities [4, 5]. Population growth and lack of awareness among people accompanied by rapid urbanization and intensive industrialization and agriculture are causing widespread degradation in natural habitats and disturbances in ecosystem integrity [2, 6], because these activities generate various pollutants that affect the physicochemical and biological quality of water and soil and consequently biota [7–9].

Nature and living beings are increasingly suffering the consequences of pollution generated from industrial development and population growth [10, 11]. Water pollution affecting rivers, seas, groundwater, and lakes is the result of the discharge of wastewater in nature without or with insufficient treatment, thus causing degradation of habitat and disturbance of ecosystem balance [8, 9]. The problem is even more serious in the case of industrial effluents containing toxic pollutants. Generally, effluents require a more or less simple treatment, depending on the degree of water alteration, before their release into the natural environment [3, 8, 12].

Water pollution is one of the serious problems of modern civilization as it continuously concerns people and governments. Increasing pollution is spreading and threatening development efforts and the health of humans and their environment, mainly water resources [5, 6, 12–14]. It is therefore necessary to use wisely these water resources and find the best conditions of their protection. It is also important to delineate the risks of pollution to eliminate or mitigate their harmful effects [6]. One of the negative aspects of the population explosion associated to urban centers and industrial development is the considerable increase in the volume of wastewater (domestic and industrial), which is systematically discharged freely and almost without control in nature [3, 10]. Domestic wastewater generally contains human feces, hospital discharges, and slaughterhouse wastewater. Industrial discharges, in addition to their organic matter load, may also contain toxic substances such as heavy metal salts, arsenic, radioactive particles, etc. [4, 9, 10, 15].

Urbanization, growth of industry, and intensification of agriculture have increased, chronically and/or accidentally, watercourse pollution by affecting its physicochemical and biological quality [11, 15]. Half of the world's rivers are polluted [15]. This chemical, organic, and microbiological pollution comes from, among others, synthetic fertilizers and pesticides used in agriculture and toxic discharges from industrial and mining activities [6]. Rainfall runoff and infiltration into the soil result in pollution of streams and seas/oceans [7, 16]. Microbiological pollutants come mainly from domestic wastewater and landfills [4, 15]. These pollutants are drivers of waterborne diseases that can cause epidemics [13].

Agriculture is currently ranked as the leading source of water pollution in several regions in the developed industrialized world [11], but especially in arid countries where, for adverse climatic reasons, irrigation with sometimes poor quality water is an unavoidable technical imperative [17]. One of the major environmental consequences of the current agriculture intensification is the degradation of water quality. The latter is reflected, for both surface water and groundwater, by pollution linked to the dissemination of agricultural inputs such as phytosanitary products, nitrogenous and phosphate mineral fertilizers, or livestock manure [11]. On the other hand, the reuse of wastewater in crop irrigation [18, 19] and its byproducts such as sewage sludge in land fertilization [20], provided using adequate treatments and pollutant removal [21], may solve partially issues related to water shortage in arid agriculture and food insecurity at drylands [17, 18].

The Wadis of North Africa, Algeria included, have become dumps as they carry all kinds of liquid and solid discharges and trashes [16]. For example, the Wadis of Seybouse, Medjerda, and Kebir receive sewage discharged by the localities and industries located along these rivers [9, 10]. This wastewater contributes to the deterioration of Wadis water quality and the integrity of the ecosystem [7, 8]. It should be noted that this contaminated water is used for irrigation, which leads to the displacement of pollutants toward the soil of crop fields and the surface layers flooded by Wadis [7, 16], but these can also transmit diseases to humans through contaminated agricultural products [22].

Water as a biotope is characterized by its physicochemical and hydrodynamic features [16]. Thus the quality of river water depends on various factors that can be altered and degraded [7, 23]. These factors help to draw up a diagnosis of the watercourse to evaluate the need or not of water resource management. For example, the temperature of water is considered an important abiotic factor since it determines the dissolved oxygen content in the water. Also saturation level of the water in dissolved oxygen is inversely proportional to its temperature [9]. In addition, the most important indicators of water pollution include 5-day biochemical oxygen demand ($BOD_5$), chemical oxygen demand (COD), nitrogen products (nitrates, nitrites and ammoniacal nitrogen), phosphates, heavy metals concentration, faecal contamination status [4, 7, 15, 23].

Studies on the characterization of surface water in arid regions and the environmental factors that determine the quality of this water are deeply neglected given the scarcity of water and also their ephemeral nature. This study focuses on the physicochemical and biological quality of the surface water of Wadis of Biskra (Algeria's No. 1 agricultural hub [24]). It determines the microbiological quality and investigates how the physicochemical factors of water influence the microbiological characteristics of Wadi water.

## 2 Materials and Methods

### 2.1 *Study Area*

The province "Wilaya" of Biskra covers an area of 21.671 km$^2$ and has a population of 73 k inhabitants with a density of 34 inhabitants/km$^2$. Located in northeastern of Algeria, it is bounded by the following wilayas: Batna to the north, M'sila to the northwest, Djelfa to the southwest, El-Oued to the south, and El-Oued and Khenchela to the northeast (Fig. 1).

The 41-year climate data (1973–2013), provided from Biskra weather station, and which were retrieved from the TuTiempo.net database (https://en.tutiempo.net/climate/ws-605250.html), indicate an average annual temperature of 21.6°C with a maximum in July of 41.7°C and a minimum of 6.6°C in January. Precipitation is low and irregular reaching 125 mm/year. The wettest month is September with

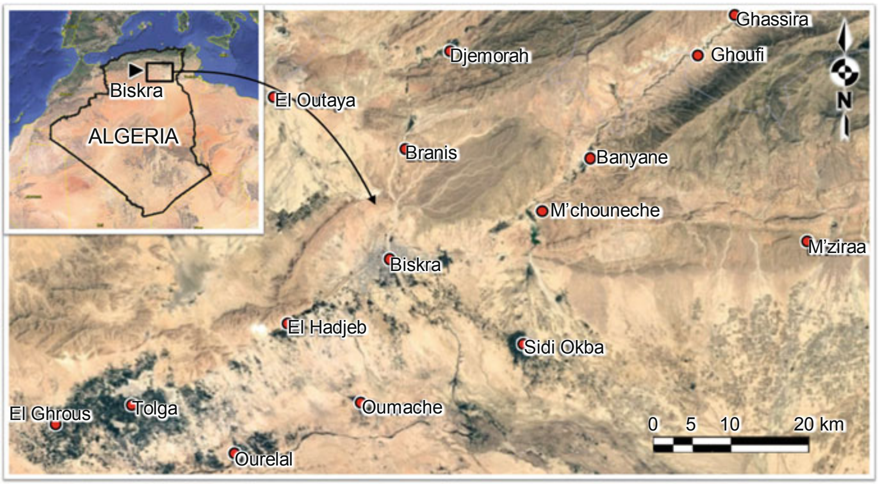


**Fig. 1** Location of the region of Biskra "study area" in northeastern Algeria

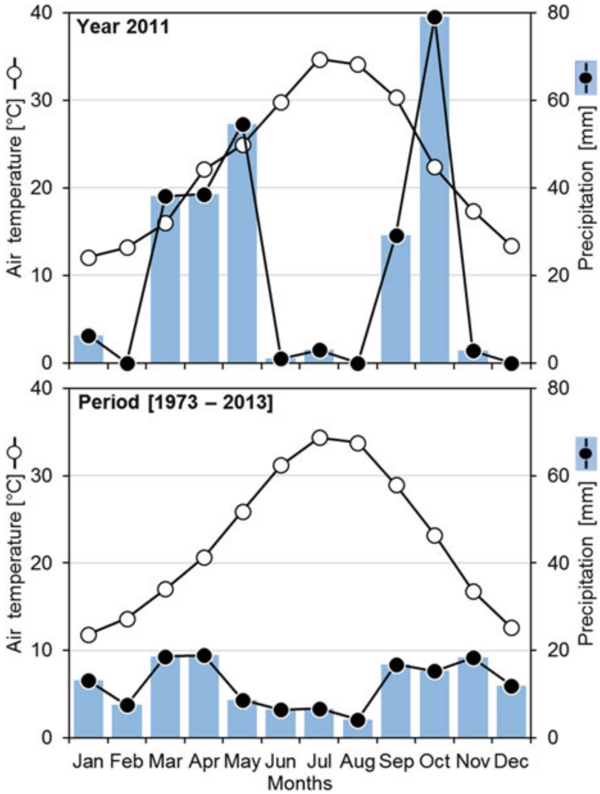


**Fig. 2** Ombrothermic diagrams of Gaussen and Bagnouls of the region of Biskra, northeastern Algeria, applied for the study year "2011" (top plot) and the period (1973–2013) (bottom plot)

an average of 20.1 mm, while the least rainy month is July with 2 mm (Fig. 2). According to Köppen classification, the climate is hot desert type "BWh," with an evaporation rate of 99.8% and a runoff of 0.2%. The water deficit is about 1,062 mm/year (Tables 1 and 2). Biskra is classified hyperarid according to De Martonne aridity index ($I_{DM} = 4$). The Gaussen and Bagnouls diagram indicates a dry period that lasts 12 consecutive months (Fig. 2).

## 2.2 *Study Wadis*

This study was conducted in three sites that represent the main wastewater outfalls from the city of Biskra in the hydrographic network.

*Site 1*: Wadi of Biskra (WBK). It takes its source at the confluence of Oued El Hai and Djamoura. It is fed upstream by several Wadis, viz., Oued Branis, Oued Lefrahi, Oued El Besbas, and Oued Lakhdar. It is the most important site, characterized by 1.5 m diameter wastewater discharge pipes and a slope of 2.5%, collecting wastewater from the northern zone and the city center of Biskra.

**Table 1** Long-term monthly climatic data of the city of Biskra (latitude, 34.85 N; longitude, 5.73 E; altitude, 87 m; WMO station, 60525) in northeastern Algeria

| Parameters | January | February | March | April | May | June | July |
|---|---|---|---|---|---|---|---|
| Mean temperature [°C] | 11.6 ± 2.49 | 13.3 ± 3.04 | 16.1 ± 3.17 | 20.2 ± 3.88 | 24.8 ± 4.56 | 30.1 ± 5.2 | 33.4 ± 5.7 |
| Maximum temperature [°C] | 16.1 ± 4.39 | 18.2 ± 4.36 | 21.7 ± 4.26 | 26.1 ± 4.02 | 30.5 ± 4.11 | 36 ± 4.2 | 41.7 ± 4.95 |
| Minimum temperature [°C] | 6.6 ± 5.35 | 7.8 ± 5.5 | 11.1 ± 5.69 | 14.3 ± 5.9 | 18.2 ± 5.75 | 23.8 ± 6.06 | 26.7 ± 5.88 |
| Precipitation [mm] | 9 ± 12.42 | 8 ± 8.13 | 12 ± 11.16 | 10 ± 8.48 | 13 ± 9.71 | 6 ± 6.97 | 2 ± 3.47 |
| Potential evapotranspiration [mm] | 33.6 ± 11.5 | 47 ± 11.31 | 80.1 ± 16.43 | 109.3 ± 16.45 | 138.9 ± 21.54 | 154.7 ± 21.9 | 169.1 ± 23.64 |
| Water vapor pressure [hPa] | 9.5 ± 1.2 | 9.2 ± 1.92 | 10.3 ± 2.62 | 10.8 ± 3.24 | 14 ± 4.64 | 16.1 ± 5.59 | 16.1 ± 4.15 |
| Wind speed [km/h] | 2.16 ± 3.78 | 2.16 ± 4.58 | 2.16 ± 4.93 | 2.16 ± 4.89 | 2.16 ± 4.61 | 2.16 ± 4.45 | 1.8 ± 2.83 |
| Sunshine frequency [%] | 60 ± 8.18 | 67 ± 10.34 | 69 ± 7.22 | 70 ± 8.45 | 70 ± 4.66 | 69 ± 3.62 | 76 ± 3.97 |
| Day length [h] | 10:04 | 10:53 | 11:56 | 13:01 | 13:56 | 14:23 | 14:10 |
| Sunshine hours [h] | 06:02 | 07:17 | 08:14 | 09:06 | 09:45 | 09:56 | 10:46 |
| Ground frost frequency [%] | 5 | 2 | 0 | 0 | 0 | 0 | 0 |
| Effective rain [mm] | 9 | 8 | 12 | 10 | 13 | 6 | 2 |
| Effective rain ratio [%] | 99 | 99 | 98 | 98 | 98 | 99 | 100 |
| Rainy days | 2 | 1 | 2 | 1 | 2 | 1 | 0 |
| Solid precipitation ratio [%] | 2 | 1 | 0 | 0 | 0 | 0 | 0 |
| Parameters | August | September | October | November | December | Average / sum | |
| Mean temperature [°C] | 32.5 ± 5.12 | 27.6 ± 4.14 | 22.1 ± 3.34 | 16.2 ± 2.63 | 12.1 ± 2.4 | 21.67 ± 3.81 | |
| Maximum temperature [°C] | 40.5 ± 4.38 | 34.4 ± 3.7 | 27.7 ± 4.31 | 21.1 ± 4.3 | 16.7 ± 4.44 | 27.56 ± 4.29 | |
| Minimum temperature [°C] | 26.1 ± 5.9 | 22.7 ± 5.87 | 17.2 ± 6.26 | 11.6 ± 5.98 | 7.1 ± 5.6 | 16.1 ± 5.81 | |
| Precipitation [mm] | 6 ± 5.23 | 20 ± 7.87 | 16 ± 10.33 | 18 ± 9.98 | 8 ± 12.02 | 10.67 ± 8.81 | |
| Potential evapotranspiration [mm] | 159.6 ± 20.99 | 126.3 ± 14.65 | 85.7 ± 13 | 51.1 ± 14.2 | 34.8 ± 10.26 | 99.18 ± 16.32 | |
| Water vapor pressure [hPa] | 19 ± 6.02 | 18.5 ± 3.97 | 14.5 ± 2.34 | 11.2 ± 2.39 | 9.2 ± 1.25 | 13.2 ± 3.28 | |
| Wind speed [km/h] | 1.8 ± 2.62 | 2.16 ± 2.26 | 2.16 ± 2.85 | 2.16 ± 2.71 | 2.16 ± 3.06 | 2.1 ± 3.63 | |
| Sunshine frequency [%] | 76 ± 5.33 | 77 ± 5.64 | 68 ± 5.67 | 61 ± 6.18 | 61 ± 11.13 | 68.67 ± 6.7 | |
| Day length [h] | 13:23 | 12:21 | 11:16 | 10:18 | 09:48 | 12:07 | |
| Sunshine hours [h] | 10:10 | 09:31 | 07:40 | 06:17 | 05:59 | 08:24 | |
| Ground frost frequency [%] | 0 | 0 | 0 | 0 | 4 | 1 | |
| Effective rain [mm] | 6 | 19 | 16 | 17 | 8 | 125 | |
| Effective rain ratio [%] | 99 | 97 | 97 | 97 | 99 | 98 | |
| Rainy days | 1 | 2 | 2 | 3 | 1 | 18 | |
| Solid precipitation ratio [%] | 0 | 0 | 0 | 0 | 2 | 0 | |

**Table 2** Location and climatic information (classifications and indices) of the province "Wilaya" of Biskra in northeastern Algeria

| Climatic information | Value/class |
|---|---|
| *Location* | |
| Latitude (North) | 5.733° |
| Longitude (East) | 34.817° |
| Altitude [m] | 240 |
| WMO station code | 60,525 |
| *Climate characteristics* | |
| Köppen class: | BWh |
| | B = Arid climate |
| | D = Desert |
| | h = hot |
| Budyko climate | Desert |
| Radiational index of dryness | 10.562 |
| Budyko evaporation [mm/year] | 128 |
| Budyko runoff [mm/year] | 0 |
| Budyko evaporation [%] | 99.8 |
| Budyko runoff [%] | 0.2 |
| Aridity | Arid |
| Aridity index | 0.11 |
| Moisture index [%] | −89 |
| De Martonne index | 4 |
| Precipitation deficit [mm/year] | 1,062 |
| Climatic NPP[a] | 244 |
| NPP (Temperature) | 2,339 |
| NPP (Precipitation) | 244 |
| NPP is precipitation limited | |
| Gorczynski continentality index | 44.5 |

[a]NPP: Climatic net primary production in g(DM)/$m^2$/year

*Site 2*: Wadi of Chaabet Roba (WRB). Located east of Biskra city, it receives all wastewater from the El-Alia area. It is characterized by the presence of domestic wastewater discharge pipes with a diameter of 1.2 m.

*Site 3*: Wadi of Zemer (WZM). Located west of Biskra city, crosses the El-Corab mountains at a location called Foum Mawya. It is fed along its course by the Wadis of Hammam, Hassi Mabrouk, El Tera, and Leham. It is characterized by discharging ducts with a diameter of 1.5 m and a slope of 1.5%. It collects wastewater from the western sector of Biskra city, which includes the industrial zone, the training center, and the city of 726 housing units.

## 2.3 Water Sampling

Water samples were collected monthly from January to June 2011. For each site, water sampled from several sampling points was kept in two sterilized glass bottles of 500 mL capacity. Put in isothermal boxes at a temperature of 4°C, samples were immediately transported to the laboratory for carrying out physicochemical and microbiological analyses [19].

## 2.4 Water Physicochemical Analyses

Water quality was determined by measuring several physicochemical parameters using standard water analysis procedures [19, 23, 25]. Water samples have undergone the following measurements: temperature, pH, electrical conductivity (EC), turbidity, suspended solid material (SSM), dissolved oxygen (DO), 5-day biological oxygen demand ($BOD_5$), chemical oxygen demand (COD), and concentrations of nitrite ($NO_2$), nitrate ($NO_3$), and ammoniacal nitrogen ($NH_3$–N). Analytical procedures of these physicochemical parameters are summarized in Table 3.

## 2.5 Bacteriological Analyses

The detection of total coliforms (TC), faecal coliforms (FC), faecal streptococci (FS), and sulfite-reducing *Clostridia* (SRC) was carried out using standard microbiological methods [23]. Bacteriological parameters were determined by the most probable number (MPN) method. This method consists of inoculating, using appropriate decimal dilutions of the sample to be analyzed, a series of tubes containing the nutrient medium for detecting total flora [27]. After incubation at 37°C for 24 h, the turbid tubes were considered positive. Faecal contamination was assessed by counting FC and FS.

FCs were determined and enumerated after culture in a double concentration of lactose bromocresol purple with Durham. Incubation was done at 37°C for 24 h (presumptive test). The detection of FS was carried out on Rothe medium at 37°C for 24 h (presumptive test). From the positive Rothe tubes, a subculture was then performed on Litsky medium at 37°C for 24 h (confirmatory test) (Table 3). For FC and FS, presumptive testing and counting were performed using the MPN method. This number was determined after the culture a certain number of samples and/or dilution of these samples, while the estimate was based on the principle of dilution until extinction [27]. The SRC species were detected on agar medium containing meat, liver, and mineral additives (ammonium iron(III) sulfate dodecahydrate and iron sulfate) [23]. After 24–48 h of incubation, these bacteria give typical colonies and reduce the sodium sulfite ($Na_2SO_3$) of the medium into sulfide which reacts with $Fe^{2+}$ and gives FeS (iron sulfide) with black color [26].

**Table 3** Methods used in water physicochemical and bacteriological analyses of Wadis receiving urban wastewater from the city of Biskra, northeastern Algeria

| Water parameter | Method | Reference |
|---|---|---|
| Temperature | Electrode V10 | CONSORT 535 |
| pH | Electrode storage bottle KK2SP 10 B | CONSORT 535 |
| Electrical conductivity (EC) | Electrode | EC meter |
| Turbidity | Spectrometry at $\lambda = 450$ nm | ISO 7027\1994<br>NA 746 |
| Orthophosphate | Spectrometry at $\lambda = 430$ nm | ISO 6378\1983 |
| Dissolved oxygen (DO) | Spectrometry at $\lambda = 535$ nm | NA 1654<br>ISO 5814\1994 |
| Suspended solid material (SSM) | Spectrometry at $\lambda = 810$ nm | NA 6345 |
| 5-day biological oxygen demand ($BOD_5$) | Dilution and seeding | ISO 5815\1989 |
| Chemical oxygen demand (COD) | Oxidation by excess of $KMNO_4$ in sulfuric acid medium at boiling temperature | ISO 6060\1984 |
| Nitrites ($NO_2$) | Spectrometry at $\lambda = 420$ nm | ISO 7890\1986 |
| Nitrates ($NO_3$) | Molecular absorption spectrometry ($\lambda = 640$ nm) | ISO 6777\1984 |
| Ammoniac nitrogen ($NH_3$–N) | Manual spectrophotometry ($\lambda = 425$ nm) | ISO 7150\1984 |
| Total coliforms | Standard membrane filter colimetry | [23, 26] |
| Faecal coliforms | Presumptive medium: double concentration of lactose bromocresol purple with Durham; incubation at 37°C for 24 h<br>Confirmative medium: MacKenzie test; peptone water free of indole; incubation at 40°C | [23] |
| Faecal streptococci | Presumptive medium: Rothe (D/C); Rothe (S/C) | [23] |
| Sulfite-reducing *Clostridia* | Agar medium containing meat, liver, and mineral additives (ammonium iron(III) sulfate dodecahydrate and iron sulfate) | [23] |

## 2.6 Statistical Analysis

In order to compare values of different variables (water physicochemical parameters and bacterial loads) between study sites, means ± standard deviations (SD) are computed based on monthly raw data that were considered replications per site [10]. The spatiotemporal variation of water physicochemical parameters and bacterial load values of TC, FC, FS, and SRC between study sites and months were tested using two-way ANOVA at a significance level $P \leq 0.05$. When ANOVA test is significant ($P \leq 0.05$), Tukey's post hoc test was applied to distinguish heterogeneous site groups. Interrelationships between water physicochemical parameters were analyzed using Pearson's correlation tests. Using the R package "corrplot" [28], the obtained correlation matrix was visualized in a single plot, in which correlation coefficients (*r*) and *P*-values were included. Because the growth of one bacterial group can either reduce or inhibit the growth of other bacteria as it changes water characteristics [29], interrelationships between densities of bacterial groups (TC, FC, FS, and SRC) were investigated using linear regressions and correlation tests. The effects of measured water parameters on the variation of bacterial loads of each of the four bacteria groups were tested using a generalized linear model (GLM). Bacterial load data "count data" were fitted to a Poisson distribution error and log link function. The statistical software R [30] was used to conduct all statistical analyses of the current study.

## 3 Results

### *3.1 Spatial Patterns of Water Physicochemical Parameters*

Figure 3 shows the spatial variation of the different physicochemical parameters of the water analyzed. The Wadi of Biskra (WBK) is characterized by surface water with EC of 3,075 ± 1,344 μS/cm (range: 1,200–5,400 μS/cm) at an average temperature of 19.3 ± 4.7°C, turbidity was 150 ± 25.84 FTU (range: 118–180), phosphate content averaged 20.6 ± 8 mg/L (range: 10.5–28.8), and DO concentration was on average 3.2 ± 1.2 mg/L (range: 1.8–4.7 mg/L). SSM recorded 1.3 ± 0.4 mg/L (range: 0.7–1.9). The $BOD_5$ averaged 139 ± 46.67 mg/L (range: 85–220), and COD was 172.5 ± 46.8 mg/L (range: 120–240). The nitrites averaged 1.6 ± 1.2 mg/L (range: 0.1–3.8). The nitrates averaged 4.7 ± 2.5 mg/L (range: 0.51–7.75), and the ammoniacal nitrogen was 15.5 ± 4.9 mg/L (range: 9.5–22.1) (Fig. 3).

Water of the Wadi of Chaabet Roba (WRB) recorded the following characteristics: the temperature was 19.8 ± 5°C (range: 14–25°C), and pH averaged 7.6 ± 0.3 (range: 7–8). The EC was 2,825 ± 1,300 μS/cm (range: 1,280–5,200). Water turbidity was 192.7 ± 108 FTU (range: 120–401 FTU). Phosphates averaged 18.07 ± 15.07 mg/L (range: 1.8–40). DO was 3.8 ± 1.9 mg/L (range: 1.7–6.3). SSM averaged 1.3 ± 0.5 mg/L (range: 0.7–2.1). $BOD_5$ was 220.8 ± 152.2 mg/L (range: 40–400). The COD was 281.4 ± 139.1 mg/L (range: 162.8–480). $NO_2$ concentration averaged 2.7 ± 2.5 mg/L (range: 1.3–7.7), and $NO_3$ was 4.9 ± 3.1 mg/L (range: 2.3–10.7). $NH_3$–N was 4.7 ± 5.0 mg/L (range: 8.6–23.8) (Fig. 3).

At the Wadi of Zemer (WZM), water temperature averaged 20.2 ± 5°C (range: 13–26°C). The pH was 7.6 ± 0.4 (range: 7.01–8). Water EC was 3,611 ± 2,220 μS/cm (range: 1,400–7,700). The turbidity was 124.3 ± 36.5 FTU (range: 87–170 FTU). Phosphate concentration was 16.20 ± 15.44 mg/L (range: 1.7–43.5 mg/L). DO averaged 4 ± 2.9 mg/L (range: 1.9–9.8). The SSM was 1 ± 0.7 mg/L (range: 0.3–2.1), $BOD_5$ was 140 ± 69.5 mg/L (range: 45–250), COD was 160.8 ± 63.9 mg/L (range: 90–270), $NO_2$ was 1.5 ± 1 mg/L (range: 0.1–4.8), $NO_3$ was 4.2 ± 3.8 mg/L (range: 0.3–11.1), and $NH_3$–N averaged 16.2 ± 1.7 mg/L (range: 14–18.6) (Fig. 3).

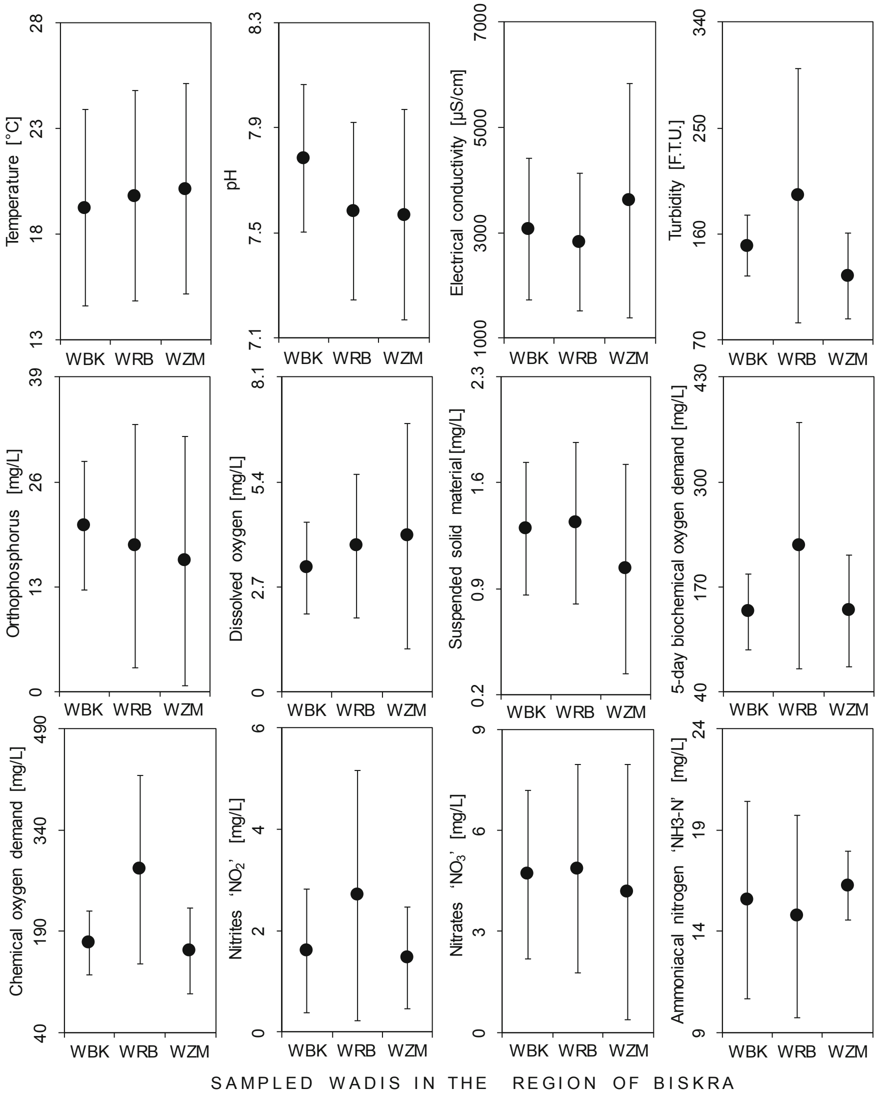


**Fig. 3** Spatial variation of the physicochemical parameters of water collected in Wadis receiving wastewater from the city of Biskra, northeastern Algeria. The values displayed are the mean (solid circle) ± standard deviation (vertical bars) (*WBK* Wadi of Biskra, *WRB* Wadi of Chaabet Roba, *WZM* Wadi of Zemer)

### 3.2 Relationships Between Water Physicochemical Parameters

The pair relationships between water physicochemical parameters revealed many significantly positive correlations at $P < 0.001$ and $P < 0.01$ (Fig. 4). These significant correlations included phosphates–pH ($P = 0.048$), phosphates–EC ($P = 0.046$), temperature–DO ($P = 0.031$), DO–EC ($P = 0.002$), DO–phosphates ($P = 0.005$), turbidity–SSM ($P = 0.012$), COD–$BOD_5$ ($P < 0.001$), $NO_2$–$BOD_5$ ($P = 0.004$), $NO_3$–$BOD_5$ ($P = 0.020$), $NO_3$–COD ($P = 0.043$), $NO_2$–$NO_3$ ($P < 0.001$), and $NH_3$–N–$NO_2$ ($P = 0.049$).

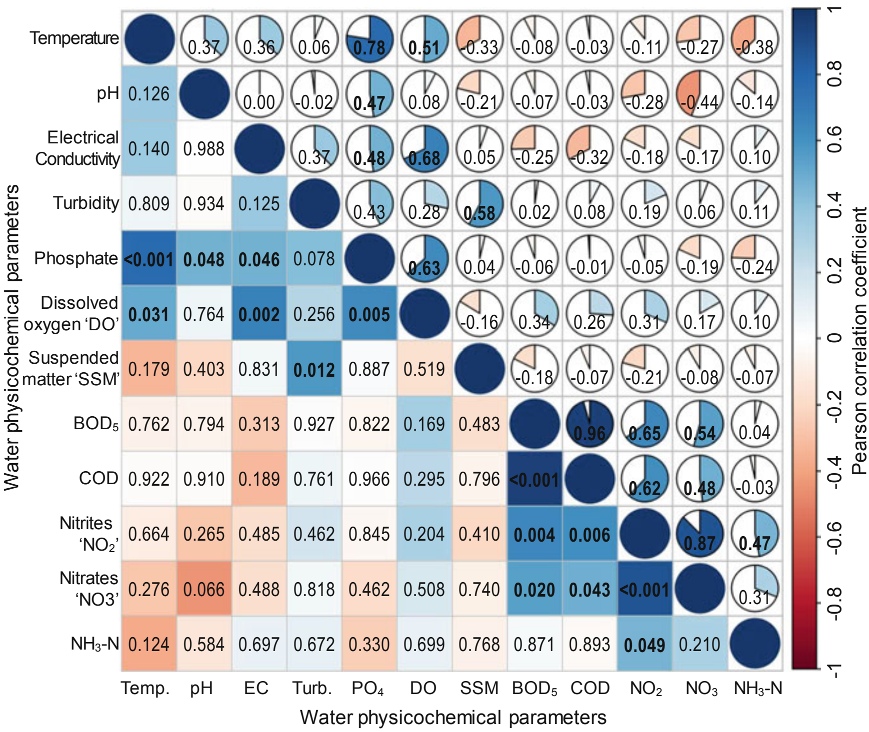


**Fig. 4** Correlation matrix displaying interrelationships between physicochemical parameters of wastewater discharged into Wadis of the region of Biskra, northeastern Algeria. Pearson correlation tests are given as correlation coefficient values (above the diagonal) and the *P*-value (below the diagonal). Significant correlations ($P \leq 0.05$) are indicated in boldface type. Shading and intensity colors in pie charts and squares also visualize Pearson coefficient values

### 3.3 Spatial Variations of Bacterial Loads

The Wadi of Biskra (WBK) recorded a load of total coliforms of 76,167 ± 14,784 CFU/100 mL (range: 60,000–98,000), faecal coliforms of 457 ± 191.20 CFU/100 mL (range: 225–760), faecal streptococci of 1,492 ± 174.40 CFU/100 mL (range: 1,200–1,700), and sulfite-reducing *Clostridia* of 5,217 ± 3,563 CFU/100 mL (range: 1,600–9,600) (Fig. 5). At Wadi of Chaabet Roba, the density of TC reached 62,767 ± 12,540 CFU/100 mL (range: 48,000–80,500). The FC averaged 628 ± 186 CFU/100 mL (range: 400–860), FS were 7,830 ± 2,026.38 (range: 5,200–9,880), and SRC were 1,702 ± 712.36 CFU/100 mL (range: 760–2,460). The Wadi of Zemer recorded a TC density of 56,917 ± 22,330 CFU/100 mL (range: 21,000–80,000), FC averaged 6,100 ± 2,552 CFU/100 mL (range: 2,800–8,900), FS averaged 4,332 ± 1,807 CFU/100 mL (range: 1,500–6,300), and SRC averaged 886 ± 861 CFU/100 mL (range: 390–2,600).

### 3.4 Interrelationships Between Bacterial Groups

The growth of TC was correlated negatively with FS (linear regression: TC = −0.5659 × FC + 66,639). The density of FS was positively associated to the increase of TC and FC loads (TC = 0.2611 × FS + 64,100, FC = 0.0783 × FS + 2,039). However, the increase of faecal bacteria (FC and FS) loads in water deemed to be negatively correlated with SRC density (FC = −0.4025 × SRC + 3,442, FS = −0.3906 × SRC + 5,567). A positive relationship was observed between TC and SRC (TC = 3.9230 × SRC + 55,078), where the correlation was statistically significant ($r = 0.61$, $P = 0.007$). The other correlation tests between bacteria densities were nonsignificant (Fig. 6).

### 3.5 Spatiotemporal Variation of Water Parameters

Regarding the spatial variation of the physicochemical parameters of water, although different values were observed between the sites studied, no significant statistical difference (ANOVA: $P > 0.05$) was detected between the studied Wadis, except for nitrates ($F_{(2,10)} = 4.39$, $P = 0.043$). The temporal variation, i.e., between study months, was significant for water temperature ($F_{(5,10)} = 33.28$, $P < 0.001$), pH ($F_{(5,10)} = 8.40$, $P = 0.002$), EC ($F_{(5,10)} = 17.40$, $P < 0.001$), orthophosphate ($F_{(5,10)} = 7.91$, $P = 0.003$), nitrites ($F_{(5,10)} = 14.58$, $P < 0.001$), and nitrates ($F_{(5,10)} = 6.25$, $P = 0.007$). For these latter six parameters, the general ANOVA model testing spatiotemporal variation "Sites + Months" demonstrated that the

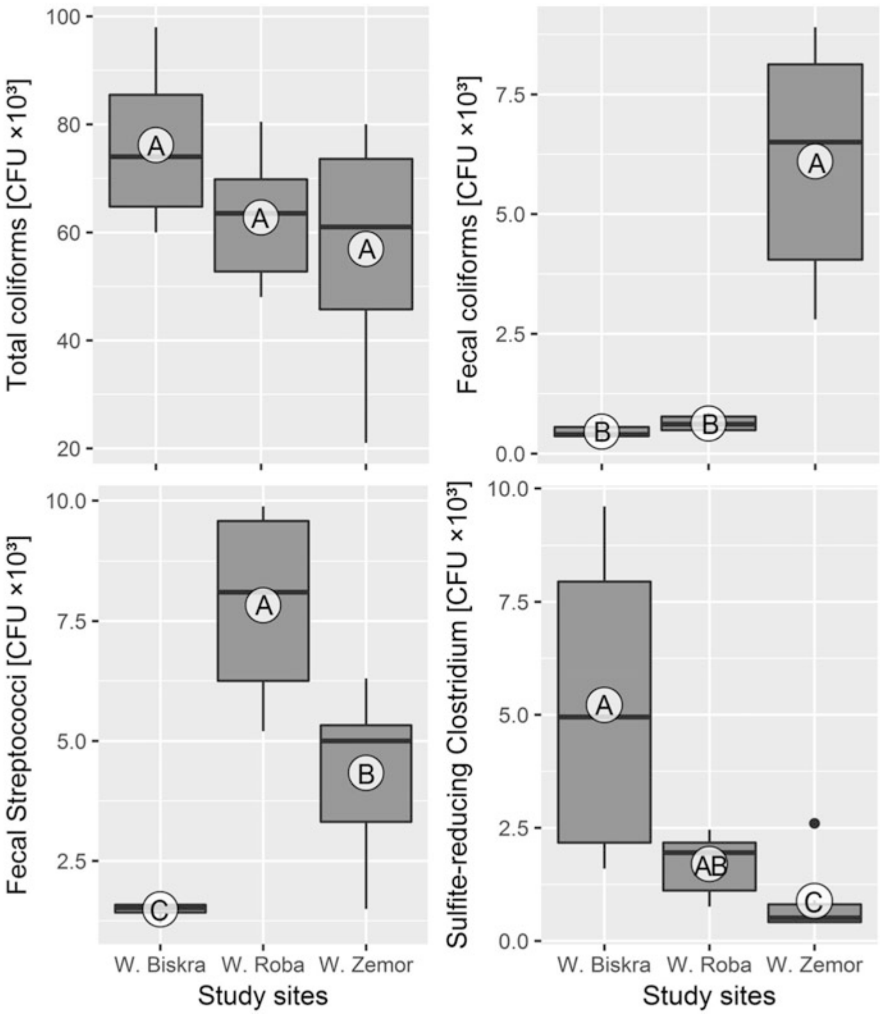


**Fig. 5** Boxplots displaying the variation of bacterial loads (in CFU/100 mL) of total and faecal coliforms, faecal streptococci, and sulfite-reducing *Clostridia* measured in three Wadis receiving urban wastewater from of the city of Biskra in northeastern Algeria. The same letters associated with average values (white circles) are significantly not different at $P \leq 0.05$ following Tukey's post hoc test

variability of the values recorded monthly in each site was statistically significant (Table 4).

Statistically, ANOVAs revealed a significant difference between the three Wadis for faecal coliform populations ($F_{(2,10)} = 31.92$, $P < 0.001$), faecal streptococci ($F_{(2,10)} = 43.87$, $P < 0.001$), and sulfite-reducing *Clostridia* ($F_{(2,10)} = 5.92$, $P = 0.020$). No difference was observed for spatial variation in total coliforms

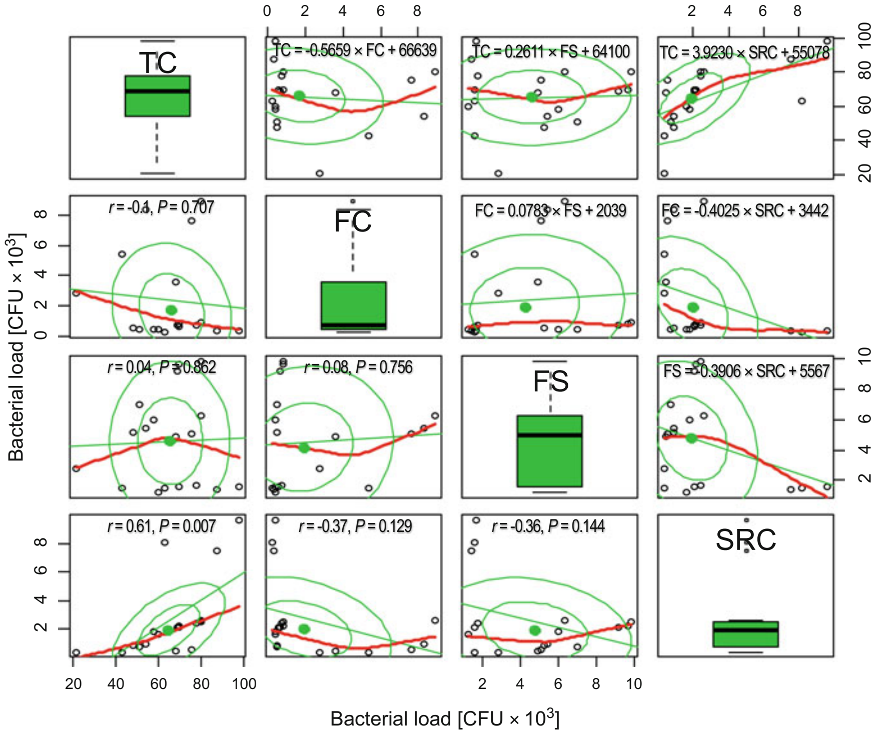


**Fig. 6** Scatterplot matrix between all pairs of bacterial groups (TC, total coliforms; FC, faecal coliforms; FS, faecal streptococci; and SRC, sulfite-reducing *Clostridia*) screened in Wadis of Biskra (northeastern Algeria) receiving common wastewater effluents. Red curves are LOWESS smoothers. Green lines represent linear regressions with the equations given at the top of plots above the diagonal. Pearson correlation tests between bacteria density are displayed in plots below the diagonal where $r$ = correlation coefficient value and $P$ = $P$-value. Green ellipses represent 40 and 80% concentration levels of observations with the center in solid green circle

($F_{(2,10)} = 2.76$, $P = 0.111$) (Table 5). The bacterial load of faecal streptococci varied significantly between the studied months ($F_{(5,10)} = 3.37$, $P = 0.048$). Tukey tests showed significantly higher bacterial loads of FC in WZM, FS in WRB, and SRC in WBK (Table 6).

## 3.6 *Effects of Water Characteristics on Bacterial Loads*

The GLMs revealed that the bacteria respond differently to water parameters of polluted Wadis (Table 7). While the decrease in temperature, pH, EC, SSM, $BOD_5$, and $NO_2$ caused a significant increase ($P < 0.001$) in total coliforms, turbidity, orthophosphate, DO, COD, $NO_3$, and $NH_3$–N were deemed correlated positively

**Table 4** Two-way analyses of variance (ANOVA) testing the spatiotemporal variations of water physicochemical parameters of Wadis receiving wastewater in the region of Biskra, northeastern Algeria

| Variables | Df | SS | MS | *F* | *P* | Sig. | SS | MS | *F* | *P* | Sig. | SS | MS | *F* | *P* | Sig. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Temperature | | | | | pH | | | | | Electrical conductivity (EC) | | | | |
| Sites | 2 | 2.48 | 1.24 | 0.61 | 0.561 | NS | 0.18 | 0.09 | 2.59 | 0.124 | NS | 1.9E+06 | 9.7E+05 | 2.23 | 0.158 | NS |
| Months | 5 | 337.02 | 67.40 | 33.28 | <0.001 | *** | 1.42 | 0.28 | 8.40 | 0.002 | ** | 3.8E+07 | 7.6E+06 | 17.40 | <0.001 | *** |
| Model | 7 | 339.51 | 48.50 | 23.94 | <0.001 | *** | 1.60 | 0.23 | 6.74 | 0.004 | ** | 4.0E+07 | 5.7E+06 | 13.06 | <0.001 | *** |
| Error | 10 | 20.26 | 2.03 | | | | 0.34 | 0.03 | | | | 4.3E+06 | 4.3E+05 | | | |
| Total | 17 | 359.76 | | | | | 1.94 | | | | | 4.4E+07 | | | | |
| | | Turbidity | | | | | Orthophosphate | | | | | Dissolved oxygen (DO) | | | | |
| Sites | 2 | 14,297 | 7,149 | 1.97 | 0.190 | NS | 57.6 | 28.8 | 0.54 | 0.599 | NS | 2.14 | 1.07 | 0.42 | 0.668 | NS |
| Months | 5 | 32,063 | 6,413 | 1.77 | 0.207 | NS | 2,111.8 | 422.4 | 7.91 | 0.003 | ** | 40.86 | 8.17 | 3.22 | 0.055 | NS |
| Model | 7 | 46,361 | 6,623 | 1.83 | 0.187 | NS | 2,169.4 | 309.9 | 5.80 | 0.007 | ** | 43.00 | 6.14 | 2.42 | 0.099 | NS |
| Error | 10 | 36,237 | 3,624 | | | | 534.2 | 53.4 | | | | 25.38 | 2.54 | | | |
| Total | 17 | 82,598 | | | | | 2,703.6 | | | | | 68.38 | | | | |
| | | Suspended solid material (SSM) | | | | | Biological oxygen demand ($BOD_5$) | | | | | Chemical oxygen demand (COD) | | | | |
| Sites | 2 | 0.33 | 0.16 | 0.50 | 0.621 | NS | 26,463 | 13,232 | 1.35 | 0.303 | NS | 5.3E+04 | 2.7E+04 | 3.03 | 0.093 | NS |
| Months | 5 | 1.48 | 0.30 | 0.90 | 0.516 | NS | 52,810 | 10,562 | 1.08 | 0.429 | NS | 4.1E+04 | 8.2E+03 | 0.93 | 0.500 | NS |
| Model | 7 | 1.80 | 0.26 | 0.79 | 0.614 | NS | 79,274 | 11,325 | 1.15 | 0.405 | NS | 9.4E+04 | 1.3E+04 | 1.53 | 0.261 | NS |
| Error | 10 | 3.28 | 0.33 | | | | 98,151 | 9,815 | | | | 8.7E+04 | 8.7E+03 | | | |
| Total | 17 | 5.08 | | | | | 177,424 | | | | | 1.8E+05 | | | | |
| | | Nitrites ($NO_2$) | | | | | Nitrates ($NO_3$) | | | | | Ammoniacal nitrogen ($NH_3$–N) | | | | |
| Sites | 2 | 5.46 | 2.73 | 4.39 | 0.043 | * | 1.61 | 0.81 | 0.22 | 0.806 | NS | 6.85 | 3.43 | 0.26 | 0.779 | NS |
| Months | 5 | 45.41 | 9.08 | 14.58 | <0.001 | *** | 114.25 | 22.85 | 6.25 | 0.007 | ** | 124.22 | 24.84 | 1.85 | 0.190 | NS |
| Model | 7 | 50.88 | 7.27 | 11.67 | <0.001 | *** | 115.86 | 16.55 | 4.53 | 0.016 | * | 131.07 | 18.72 | 1.40 | 0.305 | NS |
| Error | 10 | 6.23 | 0.62 | | | | 36.56 | 3.66 | | | | 134.07 | 13.41 | | | |
| Total | 17 | 57.11 | | | | | 152.42 | | | | | 265.14 | | | | |

*Df* degrees of freedom, *SS* sum squares, *MS* mean squares, *F* *F*-statistics, *P* *P*-value, *Sig*. statistical significance, ***: $P < 0.001$, **: $P < 0.01$, *: $P \leq 0.05$, NS: $P > 0.05$

**Table 5** Two-way ANOVAs testing the effects of sites and months on the variation of water bacterial loads of total and faecal coliforms, faecal streptococci, and sulfite-reducing *Clostridia* measured in three Wadis receiving wastewater effluents in the region of Biskra, northeastern Algeria

| Variables | Df | SS | MS | *F* | *P* | Sig. | SS | MS | *F* | *P* | Sig. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total coliforms | | | | | Faecal coliforms | | | | |
| Sites | 2 | 1.2E+09 | 5.8E+08 | 2.76 | 0.111 | NS | 1.2E+08 | 6.2E+07 | 31.92 | <0.001 | *** |
| Months | 5 | 2.3E+09 | 4.5E+08 | 2.13 | 0.145 | NS | 1.4E+07 | 2.7E+06 | 1.40 | 0.304 | NS |
| Model | 7 | 3.4E+09 | 4.9E+08 | 2.31 | 0.112 | NS | 1.4E+08 | 2.0E+07 | 10.12 | <0.001 | *** |
| Error | 10 | 2.1E+09 | 2.1E+08 | | | | 1.9E+07 | 1.9E+06 | | | |
| Total | 17 | 5.5E+09 | | | | | 1.6E+08 | | | | |
| | | Faecal streptococci | | | | | Sulfite-reducing *Clostridia* | | | | |
| Sites | 2 | 1.2E+08 | 6.0E+07 | 43.87 | <0.001 | *** | 6.4E+07 | 3.2E+07 | 5.92 | 0.020 | * |
| Months | 5 | 2.3E+07 | 4.6E+06 | 3.37 | 0.048 | * | 1.6E+07 | 3.2E+06 | 0.60 | 0.704 | NS |
| Model | 7 | 1.4E+08 | 2.1E+07 | 14.94 | <0.001 | *** | 8.0E+07 | 1.1E+07 | 2.12 | 0.136 | NS |
| Error | 10 | 1.4E+07 | 1.4E+06 | | | | 5.4E+07 | 5.4E+06 | | | |
| Total | 17 | 1.6E+08 | | | | | 1.3E+08 | | | | |

*Df* degrees of freedom, *SS* sum squares, *MS* mean squares, *F* *F*-statistics, *P* *P*-value, *Sig*. statistical significance, ***: $P < 0.001$, *: $P \leq 0.05$, NS: $P > 0.05$

**Table 6** Results of Tukey's post hoc tests

| Water variables | Study sites | | | Months | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | WBK | WRB | WZM | January | February | March | April | May | June |
| Physicochemical parameters | | | | | | | | | |
| Temperature | A | A | A | c | c | a | b | ab | a |
| pH | A | A | A | ab | c | ab | bc | a | ab |
| Electrical conductivity (EC) | A | A | A | bc | bc | b | bc | c | a |
| Turbidity | A | A | A | a | a | a | a | a | a |
| Orthophosphate | A | A | A | b | b | ab | ab | ab | a |
| Dissolved oxygen (DO) | A | A | A | a | a | a | a | a | a |
| Suspended solid material (SSM) | A | A | A | a | a | a | a | a | a |
| Biological oxygen demand ($BOD_5$) | A | A | A | a | a | a | a | a | a |
| Chemical oxygen demand (COD) | A | A | A | a | a | a | a | a | a |
| Nitrites ($NO_2$) | A | A | A | b | b | b | a | b | b |
| Nitrates ($NO_3$) | A | A | A | b | ab | b | a | b | b |
| Ammoniacal nitrogen ($NH_3$–N) | A | A | A | a | a | a | a | a | a |
| Bacteriological group | | | | | | | | | |
| Total coliforms | A | A | A | a | a | a | a | a | a |
| Faecal coliforms | B | B | A | a | a | a | a | a | a |
| Faecal streptococci | C | A | B | a | a | a | a | a | a |
| Sulfite-reducing *Clostridia* | A | AB | B | a | a | a | a | a | a |

Different letters represent significant differences ($P \leq 0.05$) in parameter values between sites (uppercase) and months (lowercase) in multiple pairwise comparisons of means

*WBK* Wadi of Biskra, *WRB* Wadi of Chaabet Roba, *WZM* Wadi of Zemer

**Table 7** Generalized linear models (Poisson GLMs) testing the effects of water physicochemical parameters on the variation of bacterial loads of total and faecal coliforms, faecal streptococci, and sulfite-reducing *Clostridia* measured in three Wadis receiving wastewater effluents in the region of Biskra, northeastern Algeria

| | Total coliforms | | | | | Faecal coliforms | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Goodness of fit: $\chi^2_{17} = 94{,}003$ | | | | | Goodness of fit: $\chi^2_{17} = 55{,}622$ | | | | |
| Water parameters | Estimate | SE | *Z* | *P* | Sig. | Estimate | SE | *Z* | *P* | Sig. |
| Intercept | 12.940 | 0.044 | 293.2 | <0.001 | *** | 11.430 | 0.310 | 36.9 | <0.001 | *** |
| Temperature | −0.023 | 0.001 | −40.5 | <0.001 | *** | 0.220 | 0.005 | 44.4 | <0.001 | *** |
| pH | −0.236 | 0.005 | −47.6 | <0.001 | *** | −1.436 | 0.041 | −34.7 | <0.001 | *** |
| Electrical conductivity | −0.000 | 0.000 | −36.3 | <0.001 | *** | −0.001 | 0.000 | −53.4 | <0.001 | *** |
| Turbidity | 0.001 | 0.000 | 36.1 | <0.001 | *** | 0.001 | 0.000 | 2.4 | 0.016 | * |
| Phosphate | 0.025 | 0.000 | 95.7 | <0.001 | *** | −0.042 | 0.002 | −21.1 | <0.001 | *** |
| Dissolved oxygen | 0.012 | 0.002 | 6.5 | <0.001 | *** | 0.797 | 0.012 | 66.1 | <0.001 | *** |
| Suspended materials | −0.608 | 0.005 | −118.7 | <0.001 | *** | −0.428 | 0.035 | −12.3 | <0.001 | *** |
| $BOD_5$ | −0.005 | 0.000 | −82.5 | <0.001 | *** | −0.001 | 0.000 | −3.2 | 0.001 | ** |
| COD | 0.005 | 0.000 | 95.1 | <0.001 | *** | −0.002 | 0.000 | −4.6 | <0.001 | *** |
| Nitrites ($NO_2$) | −0.215 | 0.004 | −56.1 | <0.001 | *** | −1.559 | 0.034 | −46.4 | <0.001 | *** |
| Nitrates ($NO_3$) | 0.057 | 0.002 | 37.6 | <0.001 | *** | 0.477 | 0.013 | 38.0 | <0.001 | *** |
| $NH_3$–N | 0.028 | 0.001 | 49.9 | <0.001 | *** | 0.307 | 0.006 | 53.4 | <0.001 | *** |
| $\Phi$ | 0.806 | | | | | 0.892 | | | | |
| AIC | 34,567 | | | | | 18,517 | | | | |
| | Faecal streptococci | | | | | Sulfite-reducing *Clostridia* | | | | |
| | Goodness of fit: $\chi^2_{17} = 35{,}586$ | | | | | Goodness of fit: $\chi^2_{17} = 41{,}289$ | | | | |
| Water parameters | Estimate | SE | *Z* | *P* | Sig. | Estimate | SE | *Z* | *P* | Sig. |
| Intercept | 15.350 | 0.203 | 75.6 | <0.001 | *** | 6.905 | 0.231 | 29.9 | <0.001 | *** |
| Temperature | −0.025 | 0.002 | −10.8 | <0.001 | *** | −0.048 | 0.003 | −16.3 | <0.001 | *** |
| pH | −0.897 | 0.022 | −41.0 | <0.001 | *** | −0.085 | 0.028 | −3.1 | 0.002 | ** |
| Electrical conductivity | −0.000 | 0.000 | −2.2 | 0.027 | * | −0.001 | 0.000 | −16.8 | <0.001 | *** |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Turbidity | 0.007 | 0.000 | 32.4 | <0.001 | *** | 0.004 | 0.000 | 17.4 | <0.001 | *** |
| Phosphate | −0.001 | 0.001 | −0.6 | 0.553 | ns | 0.033 | 0.001 | 23.2 | <0.001 | *** |
| Dissolved oxygen | 0.108 | 0.009 | 12.3 | <0.001 | *** | 0.037 | 0.009 | 4.0 | <0.001 | *** |
| Suspended materials | −1.343 | 0.026 | −51.8 | <0.001 | *** | −0.835 | 0.030 | −27.6 | <0.001 | *** |
| $BOD_5$ | −0.016 | 0.000 | −57.5 | <0.001 | *** | −0.008 | 0.000 | −28.0 | <0.001 | *** |
| COD | 0.019 | 0.000 | 64.1 | <0.001 | *** | 0.012 | 0.000 | 37.9 | <0.001 | *** |
| Nitrites ($NO_2$) | −0.137 | 0.019 | −7.2 | <0.001 | *** | −0.733 | 0.020 | −35.9 | <0.001 | *** |
| Nitrates ($NO_3$) | −0.086 | 0.007 | −11.8 | <0.001 | *** | 0.130 | 0.008 | 15.8 | <0.001 | *** |
| $NH_3$–N | −0.002 | 0.003 | −0.6 | 0.558 | ns | 0.160 | 0.003 | 58.32 | <0.001 | *** |
| $\Phi$ | 1.074 | | | | | 0.448 | | | | |
| AIC | 9,953.9 | | | | | 27,269 | | | | |

*SE* standard error, *Z* *z*-statistics, *P* *P*-value, $\Phi$ dispersion (deviance/degree of freedom), *AIC* Akaike information criterion, *Sig*. statistical significance, ***: $P < 0.001$, **: $P < 0.01$, *: $P \leq 0.05$, ns: $P > 0.05$

($P < 0.001$). The faecal coliforms were positively correlated with water turbidity ($P = 0.016$), temperature, DO, $NO_2$, and $NO_3$ ($P < 0.001$), but negatively correlated with the rest of water's physicochemical parameters ($P < 0.001$). Faecal streptococci were negatively correlated ($P < 0.001$) with temperature, pH, EC, orthophosphates, SSM, $BOD_5$, $NO_2$, $NO_3$, and $NH_3$–N and positively correlated with turbidity, DO, and COD. SRC increased significantly ($P < 0.001$) with the increase of water turbidity, orthophosphates, DO, COD, $NO_3$, and $NH_3$–N, but load of SRC decreased significantly when water temperature, pH, EC, SSM, $BOD_5$, and $NO_2$ increased (Table 7).

# 4 Discussion

## *4.1 Physicochemical Proprieties of Wadi Water*

Physicochemical parameters of water determine surface water quality, which is also conditioned by the presence and intensity of microbial activities, in particular faecal coliform bacteria (FC) [23, 31]. Values and quality of water parameters are affected by external and internal factors that are interrelated in a very complex way. External factors include meteorological conditions, substrate factors (soil and/or sediment), and pollution sources, while internal factors are generated by biochemical reactions occurring in water [32].

The analyses of water at Wadis of Biskra revealed a temperature that ranges between 19.25 and 20.15°C. Temperature has less importance in pure water due to the wide temperature tolerance range in aquatic life-forms [32, 33]. However, in polluted water, temperature can induce significant effects on dissolved oxygen and biological oxygen demand as well as other physical, chemical, and biological characteristics of water. Temperature influences especially the solubility of salts and gases, density, viscosity, dissociation of dissolved salts, chemical and biochemical reactions, development, growth and behavior of aquatic and amphibiotic living organisms, and particularly the activity of aquatic microorganisms [34–36]. As with all surface water, the temperature depends on seasonal variations [37], varying from 2°C in winter to 30°C in summer [25], geographical location [33], and hot wastewater discharges [23, 38].

Water pH at the Wadis of Biskra fluctuates between 7.57 and 7.79, revealing a neutral to slightly alkaline patterns (6.5–8.5) [38, 39]. This alkalinity is attributed to the presence of carbonates associated mainly with calcium and to a lesser extent with magnesium, sodium, and potassium [40], thus buffering the runoff that flows into the Wadis. Slightly alkaline water inhibits the toxicity of heavy metals in the form of carbonate or bicarbonate precipitates, making these heavy metals unavailable [33]. The water of Wadis of Biskra are characterized by electrical conductivity ranging between 2,825 and 3,611 μS/cm, that is greater than 1,500 μS/cm [39] and 2,000 μS/cm, which represents an abnormal situation [23]. EC values indicate decomposition and mineralization of the organic matter [23, 41, 42], associated with wastewater emanating from the city and neighboring residents. The quality of water is classified poor, when EC > 4,000 μS/cm [43].

The turbidity of water samples averaged between 124 and 192 FTU (range 50–200 FTU). According to the [44], water samples belong to class 4 of turbidity, equivalent to African surface water (extremely colored). Although the standards for this parameter are quite different, it must be less than 5 FTU for drinking water [45]. The recorded values indicate the presence of suspended solids caused by the flow of water or the discharge of wastewater highly loaded with particles [46], although the SSM was very low in this study (1.03–1.33 mg/L). According to Afri-Mehannaoui [47], the SSM level is relatively low except during periods of high watercourses. Natural water is never free from SSM and content of less than 30 mg/L is allowed.

The surface water in the region of Biskra has a dissolved oxygen level of 3.18–4.01 mg/L. These values are below 5–8 mg/L [39], characterizing the water quality as passable (3–5 mg/L) [43]. The low levels of dissolved oxygen observed are due to the high organic load in urban discharges emanating from the city of Biskra without any prior treatment and the consumption of it by biodegradable bacteria. The increase in water and air temperatures promotes microbial activity and thus oxygen consumption [48]. It is well known that hot water contains less dissolved oxygen than cold water [23], but according to [32], the concentration of this element depends on several physical, chemical, and microbiological processes. The low oxygen level observed in the Wadi of Fes (Morocco) [49] was attributed to water pollution by urban discharges from the city of Fes. The high and rapid decomposition of organic matter reduces substantially the solubility of oxygen in water [50], reflecting heavy organic pollution. The DO in water represents a reliable indicator factor of the pollution status in aquatic systems [51]. Oxygen deficiency in water protects anaerobic bacteria and other pathogens, which are harmful to human health [50], by stimulating bioaccumulation and biomagnification process [32].

Phosphate concentration in Wadis of Biskra ranges from 16 to 20 mg/L, exceeding 2 mg/L [39] and the Algerian standards (<4 mg/L). The availability of orthophosphates can be explained by leaching and urban discharges from neighboring agglomerations and the release of phosphorus trapped in large quantities in the sediment [52]. Eutrophication can occur at relatively low concentrations of phosphates (~50 μg/L) [52, 53]. This state initially reduces the biodiversity of the environment by favoring the rapid and important proliferation of eutrophic algae which, at the end of their growth, accumulates in large deposits of organic matter that consume most of the dissolved oxygen of the habitat during their putrefaction. This process transforms the habitat into an anaerobic ecosystem leading consequently to the elimination of plants, animals, and aerobic microorganisms [54].

The $BOD_5$ recorded in surface water at Wadis of Biskra ranged between 139 and 220 mg/L, which was much higher compared to the standard value of 5 mg/L [39]. Water samples are qualified as very poor as $BOD_5$ exceeds 25 mg/L [43], which is the result of the discharge of untreated wastewater, rich in organic matter and nutrients (leaching organic fertilizer) from urban agglomerations, resulting in a considerable increase in organic load in surface water [49], affecting even Saharan wetlands such as ephemeral salt lakes "Sabkhas and Chotts" [55]. In conjunction with $BOD_5$, the COD is an indicator of toxic conditions and the presence of bioresistant organic substances [56]. The obtained values vary between 160 and 281 mg/L, which are 6–9 times higher than the limit of 30 mg/L established by the WHO [39]. The water studied is of very poor quality [43] as it exceeds 80 mg/L and is saturated with less or non-biodegradable pollutants [23, 57]. When the values of $BOD_5$ and COD are high, it means that wastewater has a high pollution potential and should therefore be treated before releasing into the environment [58]. The use of adequate depollution techniques is necessary to prevent environmental contaminations and preserve aquatic systems safe [21].

In this study, the nitrite content (1.46–2.69 mg/L) far exceeds the WHO standard ($<$0.1 mg/L) [39]. High concentrations of nitrites often reflect the presence of toxic materials [53], indicating pollution above 1 mg/L [38]. On the other hand, nitrates (4.15–4.85 mg/L) are very negligible compared to the reference value of 50 mg/L for drinking water [39]. The values measured in the study area could be attributed to untreated wastewater and agricultural discharges [59]. These values also reflect consumption by bacteria during periods of low oxygenation, thus avoiding anaerobiosis. The pattern of ammonia ($NH_3$–N) of the analyzed water shows that the concentrations (4.73–16.24 mg/L) are higher than the norm of 0.5 mg/L [39], indicating the absence of dilution and poor oxygenation of water, which leads to the non-oxidation of nitrogen. The presence of this element in water is an indicator of organic pollution by microorganisms, including faecal pollution [49]. Interpretation of nitrogen content is very difficult due to the instability of nitrification/denitrification/ammonification reactions. Knowing that nitrogen is in the organic form of ammonium ($NH_4^+$) and nitrate ($NO_3^-$) in wastewater, each of the previous reactions is dependent on the availability of dissolved oxygen. The presence of $NH_4^+$ with high concentrations leads to a high oxygen consumption due to bacterial nitrification, i.e., transformation of $NH_4^+$ into $NO_2^-$ and $NO_3^-$ [14, 54].

Nutrient (nitrogen and phosphate) pollution depends on the supply of agricultural land with fertilizers (livestock manures and chemical fertilizer amendments) and the discharge of wastewater. The most commonly used fertilizers are ammonium nitrate, phosphorus and potassium urea, superphosphates, potassium chloride, and to a lesser extent ammonium sulfate, sodium, calcium nitrate, and sulfate of potassium [60].

Regarding the correlations between the different parameters studied, the statistical analysis found positive correlations between many physicochemical parameters (phosphates–pH, P–EC, P–DO, DO–temperature, and DO–EC, SSM–turbidity, $BOD_5$–COD, $NO_2^-$–$BOD_5$, $NO_3^-$–$BOD_5$, $NO_3^-$–COD, $NO_2^-$–$NO_3$, $NH_4^+$–$NO_2^-$, and $NO_3^-$–$NO_2^-$). Generally, the pollution elements are strongly linked: turbidity–SSM, COD–$BOD_5$, $BOD_5$–$NO_2^-$, $BOD_5$–$NO_3^-$, $NO_3^-$–COD, $NO_3^-$–$NO_2^-$, and $NH_4^+$–$NO_2^-$. The positive correlation between COD and $BOD_5$ is explained by the setup of the conditions of organic matter degradation by microorganisms whose activity and multiplication require oxygen [61]. The same is true for the significant interrelationships between temperature, phosphates, and the abundance of faecal germs, which are connected to domestic discharges and the availability of nitrogen and phosphate nutrients (i.e., the eutrophication stimulators)

[38]. EC is positively related to temperature, which is a catalyst for chemical reactions that accelerate the dissolution of minerals constituting the geological environment [62]. Water pH and EC are also temperature-dependent, as are carbon biodegradation processes [63].

Positive correlations are reported in the Bizerte lagoon (Tunisia) between temperature, salinity, and coliforms and inversely with dissolved oxygen [64]. Our results are consistent with water analyses of Boufekrane and Ouislane Wadis in Morocco [65], where it has been noted that bacterial loads increased with the increase of water temperature since indigenous bacteria are the dominant component of populations at polluted rivers [66]. A positive correlation was reputed between bacterial loads in water and faecal pollutant loads in the Bizerte lagoon in Tunisia [67], thus explaining the large influx of faecal pollutants by leaching from the center of agglomeration.

It is accepted that cold water is more oxygenated than hot water [9]. However, and contrary to this rule, a positive correlation is established in this study between DO–temperature and DO–EC. These positive correlations may be explained by (1) changes in Wadi water temperature by that of domestic effluents which are independent of climatic conditions. This can be considered as thermal pollution of water; (2) the study period "January–June" coincides with the cold and slightly hot seasons; during this period, the bacterial activity can be qualified as low or moderate to reach the point of significantly reducing the DO level. Indeed, GLMs indicated that water temperature negatively affects the abundance of bacterial groups studied, but "thermotolerant" faecal coliforms were positively affected, and (3) the case of this study is a water receiving heavy pollution load in the form of domestic wastewater, while previous studies reporting the negative correlation between DO and temperature investigated mainly non-polluted or slightly polluted natural surface water. This is the case of the Bizerte lagoon in Tunisia [67], where negative correlation was found between DO and temperature. Similarly, the relationship was negative in the Gulf of Annaba in Algeria [9].

When DO concentration in water is $<1$ mg/L, it indicates conditions close to anaerobiosis, which occur when the oxidation processes of mineral wastes, organic matter, and nutrients consume more oxygen than is available. Low DO content causes an increase in the solubility of the toxic elements that are released from the sediments [9, 23]. Also, the DO available is limited by the maximum solubility of oxygen (9 mg/L at 20°C), which decreases with the increase of temperature and the presence of pollutants in watercourses [23].

Bacteriologically, the enumeration of total and faecal coliforms is the most widely used bacteriological procedure for assessing water quality [68]. They are good indicators of the microbiological quality of water [32], their abundance reflects organic pollution because they cannot survive in clean water beyond a limited time [29]. Apart from total coliforms, faecal streptococci and faecal coliforms represent signs of recent faecal contamination [50, 69] since their survival in water can be very short, whereas *Clostridium* sulfito-reducers are indicators of old faecal contamination because of their resistance to adverse environmental conditions [46]. This is the case of *Clostridium perfringens* which can survive in water for a longer period compared to other faecal bacteria [68]. The high numbers of total coliforms (56,917–76,167 CFU/100 mL), faecal coliforms (457–6,100 CFU/100 mL), faecal streptococci (1,432–7,830 CFU/100 mL), and sulfite-reducing *Clostridia* (886–5,217 CFU/100 mL) come from the wastewater, rich in nitrogenous nutrients, emanating from the neighboring city ensuring their proliferation. These indicators of faecal contamination have been reported in the surface water of Silver Lake (Delaware, Iowa) [70].

When surface water is constantly contaminated by faecal pollution germs, it is no longer an alarm signal, but an assessment of the importance of faecal pollution, originating from the discharges of urban wastewater with a relatively constant faecal coliform concentration in the order of 106 CFU/100 mL [23]. A similar observation was reported in M'sila in Algeria [71] and in Beni Aza (Blida, northern Algeria) [37].

## 4.2 *Effect of Water Physicochemical Factors on Bacteria Populations*

The physicochemical properties of water influence the survival, decomposition, and/or growth rates of coliform bacteria [72, 73]. In the case of Wadis of Biskra TC responded positively to the increase in water temperature, pH, EC, SSM, $BOD_5$, and $NO_2^-$ and negatively to the increase in turbidity, phosphates, DO, COD, $NH_3$–N, and $NO_3^-$. Faecal coliform populations increase when turbidity, temperature, $NO_2^-$, DO, $NO_2^-$, and $NO_3^-$ increase, but FC load decreases with the increase of water pH, EC, SSM, $BOD_5$, phosphates, and $NH_3$–N. Faecal streptococci increase with the decrease of temperature, pH, EC, phosphates, SSM, $BOD_5$, $NO_2^-$, $NO_3^-$, and $NH_3$–N, while they are associated negatively to water turbidity, DO, and COD. SRC increases with the increase of turbidity, phosphates, DO, COD, $NO_3^-$, and $NH_3$–N, whereas their abundances are deemed negatively related to water temperature, pH, EC, SSM, $BOD_5$, and $NO_2^-$.

Water temperature is the most important factor that determines the abundance of coliform bacteria [69]. TC are facultative aerobic-anaerobic bacteria, but they proliferate optimally at 30°C [74]; while FC is thermotolerant, differing from TC in their proliferation temperature that is about 44°C [75]. The temperature was positively correlated with the survival and/or growth of coliforms [76]. However, the mortality rate of coliforms increases with a rise in water temperature [77]. Moreover, low temperatures (~6°C) promote FC survival in seawater [78]. In fact, at low temperature, the bacterial cell limits its energy loss by reducing its metabolic activity, which allows the bacterium to survive much longer compared to high-temperature conditions [79]. Though at 40°C, the survival FC is critically affected than other temperatures [78]. Mancini [80] suggests that temperature is the major factor involved in the disappearance of faecal bacteria in freshwater. Other studies (e.g., [81]) demonstrated that FCs undergo sublethal stress within a week after their introduction into an aquatic environment. The same is true for salinity where high salinity levels reduce the rate of FC in water [78, 82].

As for pH conditions, according to Mayo [83] and Chedad and Assobhei [78], alkaline pHs induce a clear decrease in FC survival, whereas Curtis et al. [84] and Van der Steen et al. [85] argue that TC increases in acidic pHs. Similarly, SSM may facilitate the survival or growth of TC through adsorbing and protecting them from adverse factors such as UV radiations, metal toxicity, and bacteriophage attacks [72]. In all cases, the survival of coliform bacteria can be prolonged, or sometimes even they can grow under certain environmental conditions such as optimum pH, temperature, rich nutrients, and abundant suspended particles [86].

## 5 Conclusion

This study determined water quality of arid Wadis receiving wastewater in the region of Biskra. The results of water physicochemical and bacteriological analyses revealed that the values of several parameters exceed the standards established by FAO and WHO, which indicate large faecal pollution. In effect, the high level of bacterial loads indicates faecal pollution of all the study Wadis. Our findings show that wastewater effluents pose serious environmental contamination issues and health risks that can affect human communities, agricultural lands, crop products, and aquatic life-forms that rely on water of Wadi system. The main risk is associated with exposure to pathogenic biological agents, including pathogenic bacteria, helminths, protozoa, and enteric viruses. High faecal contamination induces drastic changes and deterioration in water characteristics that causes the collapse of aquatic ecosystems.

## 6 Recommendation

In perspective, in order to limit the risks of Wadi water pollution, it is recommended to (1) install wastewater treatment plants before releasing it into the environment in order to preserve water quality in the natural environment and thus sustain life-forms and ecosystem integrity; (2) divert sewage collectors and discharges sites away from agricultural lands to reduce the risk of soil contamination and thus produce healthy agricultural products; and (3) periodically monitor water quality to prevent events of high contamination of hydrosystems receiving polluted water. Under conditions of water scarcity in drylands, a wise water management policy needs to promote the increase agricultural production with less water. This can be achieved through the rationalization of irrigation and drinking water use and improvement of irrigation systems with cutting-edge techniques of water saving. The reuse of adequately treated wastewater in agriculture irrigation is a promoting practice to save natural water resources for other healthy uses. Since arid agriculture is often associated with land degradation and soil salinization, biosolids produced by wastewater treatment plants are indicated to increase soil fertility with organic matter and improve several soil proprieties and also alleviate the negative effects of soil salinity and water stresses on the crop plant.

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