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Assessment of water quality using physicochemical and bacteriological parameters in Oued Mchera (Bouregreg Basin, Morocco)

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Abstract: This study examines changes in physicochemical and bacteriological parameters in Oued Mchera water from the Bouregreg Basin to determine their pollution level and the factors responsible for it. Our investigation, conducted in 2021, focused on five specific stations within Oued Mchera. Nine physicochemical parameters were assessed on a spatio-temporal basis to calculate the water quality index (*WQI*). Furthermore, the levels of faecal coliforms (FC), *Escherichia coli*, and total coliforms (TC) were evaluated at these specific stations. The findings indicate that the pH average values vary between 7.59 and 8.78, the electrical conductivity average values range from 923 to 8300 $\mu S \cdot cm^{-1}$, and the dissolved oxygen (*DO*) levels range from 3.13 to 3.06 $mg \cdot dm^{-3}$. It should be noted that the high levels of conductivity, sodium, and temperature have a detrimental impact on the growth of bacteria. Furthermore, elevated salinity hinders the proliferation of FC, *E. coli*, and TC. The presence of *E. coli* is inversely related to the levels of *DO* and NO_3^-. This research's *WQI* demonstrated notable temporal differentiation, clearly indicating differences in various seasons and stations both upstream and downstream. In addition, the *WQI* indicates that the water from all stations is not suitable for drinking throughout the dry and wet periods. The findings underscore the immediate need for coordinated efforts to mitigate the detrimental impacts of pollution on the water quality of Oued Mchera. Urgent implementation of stringent regulatory actions will be needed to curb the release of home and agricultural wastewater into the study area.

Keywords: microbial, Oued Mchera, physio-chemical, pollution, water quality

INTRODUCTION

Water is a vital ingredient for sustaining life, bestowed by nature, and necessary for the survival of all living species, including humans (Mishra, 2023). Nevertheless, water is progressively becoming a limited commodity in several regions around the globe, presenting substantial obstacles to the maintenance of life and economic endeavours. Water resources include surface water (such as lakes and rivers), groundwater, and marine and coastal waters. These resources are essential for supporting living systems (Brusseau, 2019). Surface water is very susceptible to contamination resulting from the fast growth of cities, industrial development, and the increased intensity of agricultural practices (Chowdhary *et al.*, 2020). Moreover, the combination of climate change and population growth worsens the decline of surface water supplies, increasing the strain on groundwater for various purposes such as household, municipal, industrial, and irrigation demands (Mejjad, Rossi and Pavel, 2022).

Groundwater, the most abundant reservoir of potable water, derives its advantages from its extended residence period and inherent filtration via geological elements, making it the predominant water supply for several nations (Zhang, 2023). Nevertheless, it is also vulnerable to pollution caused by both human actions and natural phenomena, such as the deposition of minerals, geological structures, the speed at which groundwater moves, the rate at which water seeps into the ground, the quality of replenishing water, and the influence of other kinds of water (Abanyie *et al*., 2023). This susceptibility is especially evident in dry and semi-dry areas, where the lack of water is a major concern. Water quality has alarmingly deteriorated on a global scale in recent decades, necessitating immediate action. This is primarily due to the widespread use of chemical fertilisers in agriculture and uncontrolled industrial emissions, which induce harmful chemical changes in water bodies (Kumar *et al*., 2024). Studies have demonstrated that industrial and urban discharges have diverse effects on the quality of surface water and the pollution of continental aquatic ecosystems (Elassassi *et al*., 2022). Rivers play a crucial role in numerous human activities, including supplying drinking water, supporting agriculture, fishing, navigation, industry, hydroelectric power generation, and waste disposal (Loucks and Van Beek, 2017). However, the degradation of river water quality due to increased human activity has had adverse effects on both human health and plant development. Polluted water causes disturbances in aquatic ecosystems and facilitates the transmission of waterborne illnesses, such as typhoid fever, which is often associated with the consumption of contaminated agricultural products or fish (Domenico *et al*., 2022).

Water scarcity in Morocco has emerged as a critical problem owing to a prolonged water shortage spanning many years, which poses a significant risk to the country's economic capacity and public health (Hejazi *et al*., 2023). The composition of water, which is governed by its chemical, physical, and biological constituents, is affected by a variety of internal and external influences. The water quality of Oued Mchera has greatly deteriorated as a result of the flow of wastewater and agricultural leftovers from the city of Rommani into the river (Ouharba, Triqui and Moussadek, 2021). Despite the apparent deterioration, a complete assessment of surface water quality in this area has yet to be carried out so far. This study aims to address this gap by investigating the physicochemical and bacteriological parameters of the water in Oued Mchera. The investigation will assess the spatiotemporal fluctuations of these factors in the surface waters of Oued Mchera. The results are expected to highlight the magnitude of surface water pollution problems, motivating key institutions to take appropriate measures. However, the complexity of the issue and the potential for further insights underscore the need for continued research by the scientific communities.

MATERIALS AND METHODS

STUDY AREA

Oued Mchera is part of the Bouregreg Watershed and is one of the major rivers of Morocco. Its area is nearly 1900 km, and its flow is 23 $m^3 \cdot s^{-1}$ (Aoula *et al*., 2021). This basin represents almost the entire Middle Atlas of Morocco, mainly in Wilaya of Rabat Salé and the provinces of Khemisset and Khenifra. It brands its birth in the middle of Atlas and heads across the Moroccan Atlantic coast, passing the Meseta Plateau by the direction NW and SE. Oued Mchera is located in the region of Rabat at the level of the Province of Khemisset in the rural commune of Rommani, which is part of the plain of Zaër of the Meseta Central Moroccan (Mohamed *et al*., 2017). Generally, this Oued is between latitudes 32°18' and 35°8' N and longitudes 1°11' and 5°37' W, characterised by a Mediterranean-type rainfall regime and irregular rains (Addou *et al*., 2023). In general, all streams in the Rommani Basin are non-perennial. The main stream is Oued Mchera, downstream at the level of the commune Nkhila, where it meets Oued Krifla (Fig. 1).

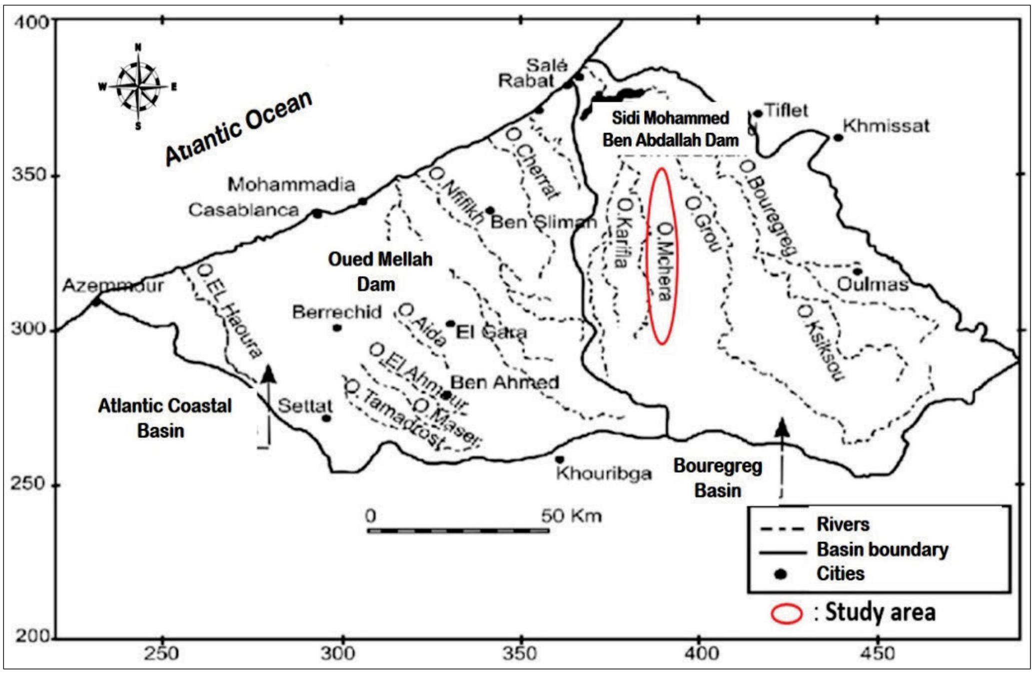

Fig. 1. Oued Mchera's geographical location at the Bouragrag Watershed's level; source: own elaboration

The aquifer in the study area, located in the Zäer Province of Khemisset, is an unconfined aquifer primarily composed of a mixture of sandstone, limestone, clay, and gravel. These geological formations give the aquifer a variable permeability, allowing for the infiltration and movement of groundwater. The aquifer is relatively shallow, with the water table depth typically varying due to seasonal fluctuations and recharge from rainfall and surface water sources like Oued Mchera. The aquifer's hydraulic characteristics indicate moderate to high permeability, making it a significant groundwater resource for local communities and agriculture (Addou *et al.*, 2023). Quality analyses of the aquifer have shown variability in several vital parameters. The pH levels are generally neutral to slightly alkaline, and electrical conductivity (*EC*) indicates moderate mineralisation, typical of groundwater influenced by local geology. Total dissolved solids levels are within acceptable ranges for drinking water, but there are concerns about elevated nitrate concentrations, often linked to agricultural activities in the area. Bacteriological analyses have revealed the presence of *Escherichia coli* and coliform bacteria, indicating contamination from surface runoff or improper sanitation practices. The primary sources of pollution affecting the aquifer include agricultural runoff, which contributes nitrates and pesticides, and domestic wastewater discharges, leading to microbiological contamination.

DESCRIPTION OF SAMPLING STATIONS

The study stations are located in the wet zone of the central Plateau of Morocco, between the Atlas and the Atlantic. Its limits lie between the meridians 6° and 7° W and the parallels 33° and 34° N, with altitudes decreasing from east (300 m) to west (0 m) and covering an area of around 3 860 km^2. During the field trip, the altitude (m) and geographical coordinates (latitude, longitude) of each station were recorded using a GPS (Tab. 1).

Five stations (S1, S2, S3, S4, and S5) were selected along the Oued of Mchera. Water samples were taken during the wet season from January to March and during the dry season from May to July 2021. Sixty (6 sampling at each station and during each study period) water samples were collected. They are chosen for the least durability of their flow, for their representativeness of the watercourses as well as for their accessibility, and for the presence of human activities (Fig. 2) (Auby *et al.*, 2018). For physicochemical variables, water samples were taken from below the surface at a depth of no more than 0.5 m using bottles (polyethylene 1 dm^3), while bacterial sampling was carried out using clean, sterile bottles (polyethylene 500 cm^3).

PHYSICOCHEMICAL, BACTERIOLOGICAL AND STATISTICAL ANALYSES

To establish a diagnosis of surface water pollution along Oued Mchera, water samples were taken at five stations in wet and dry periods during the year 2021. In this investigation, nine physicochemical parameters were determined. Some of these physicochemical parameters were measured in situ, such as temperature, pH, *EC*, and dissolved oxygen (*DO*) measured by the instruments, respectively, thermometer (HANNA), pH meter (HANNA) conductivity meter (model HACH), and oximeter (model HACK). Water samples from each station were collected from bottles (1 dm^3 polyethylene). The other physicochemical parameters (biochemical oxygen demand test run for 5 days (BOD_5), nitrate (NO_3^-), potassium (K^+), sodium (Na^{2+}), and magnesium (Mg^{2+})) indicating pollution were measured in the laboratory.

These samples were stored in coolers at a low temperature (from 4 to −4°C) and were analysed within 24 hours. Samples for bacteriological analyses were taken using pre-autoclaved bottles, and enumeration of *E. coli* and coliform bacteria was carried out according to NM ISO 9308-1:2019 IMANOR (2019) methods. These analyses were carried out according to the methods of Rodier and Afnor (Rodier, Legube and Merlet, 2009) in the laboratory of National Center for Scientific and Technical Research (Fr.: CNRST – Centre National pour la Recherche Scientifique et Technique) in Rabat.

Table 1. Description and location of different sampling stations (S1–S5)

Station	Latitude (N)	Longitude (W)	Altitude (m)	Riverbed		Current type	Substrate	Riparian zone	Human impact
				width (m)	depth (m)				
S1	33°36'31.7"	6°39'24.0"	288	5	0.4	moderate	coarse materials mixed with fine red clay, moss	oleander	waste discharge, livestock presence, and wheat farming
S2	33°32'17.0"	6°37'35.2"	280	4	0.5	moderate	coarse materials and gravel	aquatic vegetation, although oleander	wastewater discharge, plastics, wheat farming
S3	33°60'54.22"	6°65'72.88"	257	6	0.35	low	fine and coarse materials	aquatic vegetation, while oleander and jujube trees line the banks	waste discharges and livestock grazing
S4	33°45'16.6"	6°43'00.3"	70	5	0.4	low	fine and coarse dirt, clay, gravel, pebbles	oleander and jujube trees	livestock and farming activities
S5	33°76'11.45"	6°72'88.74"	74	7	0.3	low	fine and coarse dirt, clay, rock	oleander and jujube trees	livestock and farming activities

Source: own study.

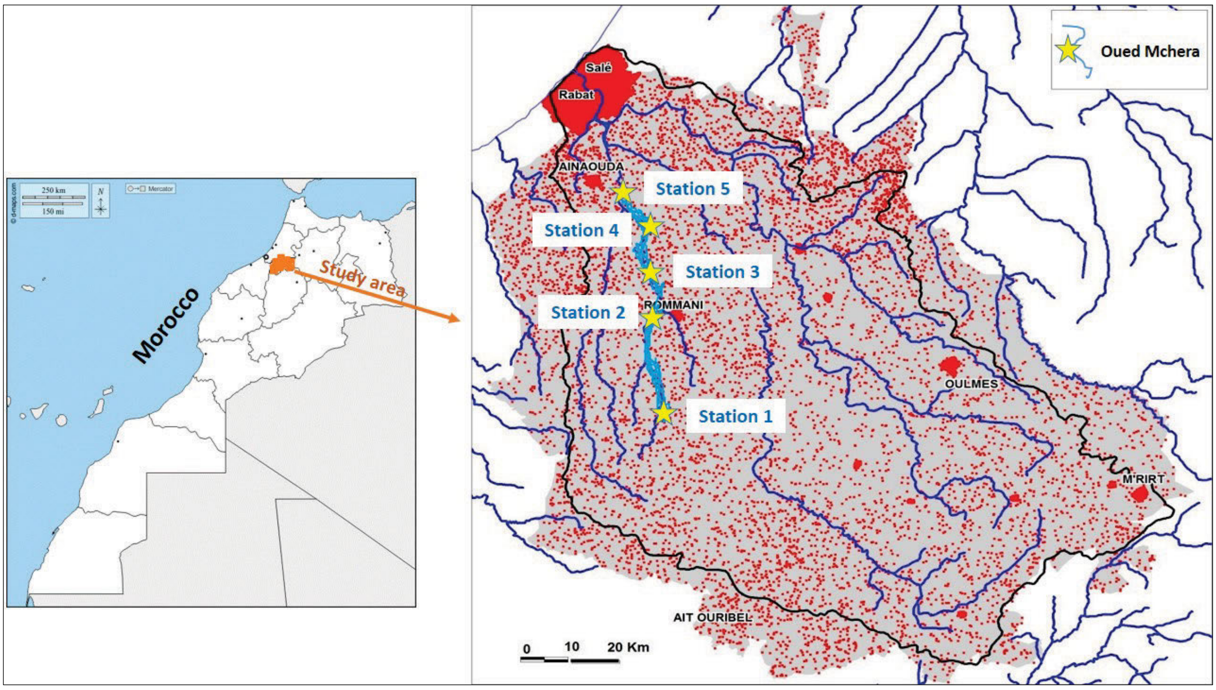

Fig. 2. Geographical location of Oued Mchera and sampling stations; source: own study

Statistical analysis of the data was conducted using statistical package for the social sciences (SPSS) statistics. All data was subjected to analysis of the correlation of Pearson, a significant *F*-test at $p < 0.05$.

WATER QUALITY INDEX

Many researchers widely use the water quality index (*WQI*) technique to assess water quality (Kumar and Krishna, 2021). This index is a water quality classification technique based on comparing water quality parameters with Moroccan national or international standards in this study (Talhaoui *et al.*, 2020). In this study, nine physicochemical parameters are used to calculate the *WQI*. In this approach, a numerical value called relative weight (RW_i), specific to each physicochemical variable (*i*-th parameter) is calculated (Tab. 2); the RW_i is calculated according to the following Equation (1):

$$RW_i = \frac{K}{S_i} \tag{1}$$

where: S_i = maximum value of the Moroccan surface water standard of each (*i*-th) variable (Talhaoui *et al.*, 2020), K = the proportional constant, which is computed in the following way:

$$K = \frac{1}{\sum_{i=1}^{n} \frac{1}{S_i}} \tag{2}$$

where: RW_i = the relative weight, n = number of variables.

The quality score (Q_i) is counted using the Equation (3):

$$Q_i = \frac{C_i}{V_i} \tag{3}$$

where: C_i = each chemical variable's concentration, V_i = the ideal value for the evaluated parameters.

Table 2. Weight of physicochemical parameters and Moroccan surface water quality standard (Ministère de l'équipement, Ministère chargé de l'aménagement du territoire, de l'urbanisme, de l'habitat et de l'environnement, 2002)

Parameter	S_i	$1/S_i$	RW_i
pH	9	0.11111111	0.16530747
T (°C)	30	0.03333333	0.04959224
EC (μS·cm^{-1})	2,700	0.00037037	0.00055102
DO (mg·dm^{-3})	5	0.2	0.29755345
Nitrate (mg·dm^{-3})	50	0.02	0.02975534
Sodium (mg·dm^{-3})	250	0.004	0.00595107
Potassium (mg·dm^{-3})	12	0.08333333	0.1239806
BOD_5 (mg·dm^{-3})	5	0.2	0.29755345
Magnesium (mg·dm^{-3})	50	0.02	0.02975534
Total		0.67214815	1

Explanations: pH = potential of hydrogen, T = temperature, EC = electrical conductivity, DO = dissolved oxygen, BOD_5 = biochemical oxygen demand test run for 5 days, RW_i = relative weight, S_i = maximum value standard, Morocco.
Source: own study.

The quality score for pH and *DO* (Q_{pH} and Q_{DO}) has been counted based on the following Equation (4):

$$Q_i = \frac{S_i - V_i}{S_i - v_i} 100 \tag{4}$$

where: v_i = the lower permissible limit or critical threshold for the parameter, S_i = the maximum value of Moroccan surface water standard of each variable in mg·dm^{-3} except for pH, T (°C), and *EC* (Tab. 3), the ideal value for V_i is 7.0 for pH and 14.6 for *DO* (Ameen *et al.*, 2023). Five water quality categories can be determined according to the value of the index *WQI* (Tab. 3).

Table 3. Classification and possible use of water according to the water quality index (*WQI*) (Akinbile and Omoniyi, 2018)

WQI	Water quality	Possible uses
[0–25]	excellent	drinking water, irrigation, and industries
(25–50]	good	drinking water, irrigation, and industries
(50–75]	bad	irrigation and industries
(75–100]	terrible	irrigation
>100	non-drinking	appropriate treatment is required before the use

Source: own study.

Lately, the overall *WQI* has been calculated using the following formula:

$$WQI = \frac{\sum_{i=1}^{n} Q_i \cdot RW_i}{\sum_{i=1}^{n} RW_i} \tag{5}$$

CRITERIA FOR METHOD SELECTION

The criteria that led to the choice of methods used in this study were carefully designed to ensure comprehensive and representative sampling of water quality along the Oued Mchera. The selection of five stations was based on factors such as flow durability, representativeness of different watercourses, accessibility, and the presence of human activities, which are critical in influencing water quality. These stations were strategically chosen to cover areas with varying levels of human impact, from wastewater discharge points near urban areas to more rural settings, providing a holistic view of water pollution sources. The study also utilised a combination of *in-situ* measurements and laboratory analyses to capture both immediate and more stable water quality indicators. Parameters such as temperature, pH, *EC*, and *DO* were measured on-site to prevent changes due to sample handling. In contrast, other parameters like BOD_5, nitrates, and various ions were analysed in the laboratory for higher precision and accuracy.

LIMITATIONS OF THE STUDY

The reliance on spot sampling during specific wet and dry periods might not fully capture the temporal variability of water quality, potentially overlooking transient pollution events or seasonal variations. Additionally, the use of *in-situ* instruments, while practical for real-time measurements, can be subject to calibration errors and environmental interferences.

RESULTS

THE PHYSICOCHEMICAL VARIABLES OF WATER QUALITY

The results demonstrate significant average temperature changes over time, highlighted by a subtle variation in average temperature across several geographical areas, as seen in Figure 3. The highest surface temperatures occur during the summer, ranging from 26.98°C to 34°C. The lowest temperatures occur during the winter, ranging from 14.97°C to 18.05°C. The pH levels at all stations (S1–S5) consistently suggest mildly to moderately alkaline conditions, with all values over 7 during both wet and dry times (Fig. 3). The pH levels at stations S1, S2, and S3 are higher during the dry period (8.55, 7.6, and 7.99, respectively) compared to the wet period (8.72, 8.22, and 8.29, respectively), indicating a more alkaline environment during dry times. In contrast, stations S4 and S5 exhibit a decline in pH values from the rainy period (8.78 and 8.69, respectively) to the dry period (7.59 and 7.65, respectively).

In our study, the spatiotemporal evolution of dissolved oxygen (*DO*) shows slight variations in concentrations at four stations (S1, S3, S4, S5) in the wet period compared to those in the dry period (Fig. 3). The levels recorded vary between 3.13 mg·dm^{-3} (S1) and 3.06 mg·dm^{-3} (S3 and S4). In addition, the data shows an increase in *DO* levels at S3, S4, and S5 during the dry period compared to the wet period, while S2 did not follow this trend. Several factors can influence this variation in *DO* between the wet and dry periods. The nitrate levels across all stations vary significantly between wet and dry periods, indicating different environmental conditions affecting nitrate concentrations (Fig. 3). At S1, nitrate levels decrease from 1.28 mg·dm^{-3} in the wet period

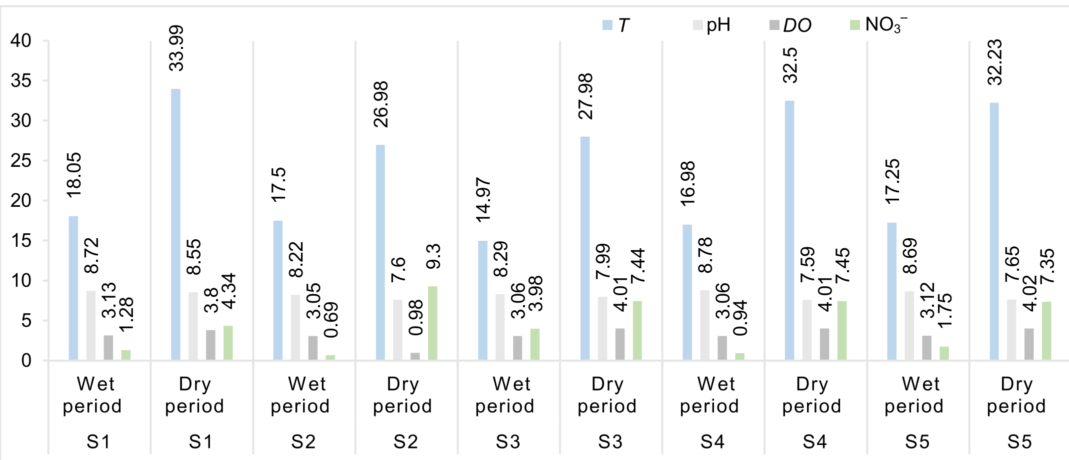

Fig. 3. Spatiotemporal variations in temperature (*T*, °C), pH, dissolved oxygen (*DO*, mg·dm^{-3}), and NO_3^- (mg·dm^{-3}) levels in five stations (S1–S5); source: own study

to 0.69 mg·dm^{-3} in the dry period; S2 shows a similar trend with a decrease from 0.98 mg·dm^{-3} in the wet period to 0.94 mg·dm^{-3} in the dry period. At S3, nitrate levels increase slightly from 0.98 mg·dm^{-3} in the wet period to 1.75 mg·dm^{-3} in the dry period; S4 also indicates an increase from 1.75 mg·dm^{-3} in the wet period to 7.35 mg·dm^{-3} in the dry period. Similarly, S5 indicates a substantial increase from 0.94 mg·dm^{-3} in the wet period to 7.35 mg·dm^{-3} in the dry period.

According to Figure 4, the electrical conductivity (*EC*) values at all stations (S1–S5) exhibit clear patterns throughout both wet and dry seasons. At S1, the *EC* experiences a significant increase from 923 μS·cm^{-1} during the wet period to 8300 μS·cm^{-1} during the dry period. At S2, the *EC* declines from 2143 μS·cm^{-1} during the dry period to 1380 μS·cm^{-1} during the wet period. The S3 has a comparable decline in *EC* values, falling from 3543 μS·cm^{-1} during the dry period to 1386 μS·cm^{-1} during the wet period. The S4 exhibits a decrease in *EC* from 2750 μS·cm^{-1} during the dry period to 1346 μS·cm^{-1} during the wet season. The S5 saw a reduction in *EC* from 2152 μS·cm^{-1} during the dry period to 1283 μS·cm^{-1} during the wet period.

The results indicate a significant increase in BOD_5 in the water of Oued Mchera during the dry period, with the highest average value of 650.33 mg·dm^{-3} recorded at S2 in summer and 48.95 mg·dm^{-3} in winter. In contrast, the lowest BOD_5 value during the dry period was observed at S1 (16 mg·dm^{-3}), and during winter, low average values were also recorded at S3 (9.16 mg·dm^{-3}), S4 (9.83 mg·dm^{-3}), S5 (10.33 mg·dm^{-3}), and S1 (11.71 mg·dm^{-3}), showing only slight variations (Fig. 4).

The concentrations of the main elements (potassium, sodium, and magnesium) at all stations exhibit different patterns during rainy and dry times. Potassium (K^+) concentrations exhibit consistent and little variations across all stations and periods, ranging from 4.68 mg·dm^{-3} to 18.02 mg·dm^{-3}. Sodium (Na^{2+}) levels show the most substantial instability, especially at S1. During the dry period, the sodium levels peak drastically at 1678.6 mg·dm^{-3}, compared to 94.06 mg·dm^{-3} during the wet period. There are also considerable increases in sodium levels at other stations, such as 575.17 mg·dm^{-3} at S3 during the dry period. The levels of magnesium ions (Mg^{2+}) remain generally constant but exhibit mild increases over the dry period at various stations. For instance, at S1, the magnesium concentration reaches 121.45 mg·dm^{-3}, while at S4, it reaches 141.91 mg·dm^{-3} (Fig. 5 and Tab. 2).

BACTERIOLOGICAL ANALYSES

The bacteria count is carried out using the colony-forming unit (CFU) method. The NM ISO 9308-1:2019 (IMANOR, 2019) concerned the leading indicators of faecal pollution, name-

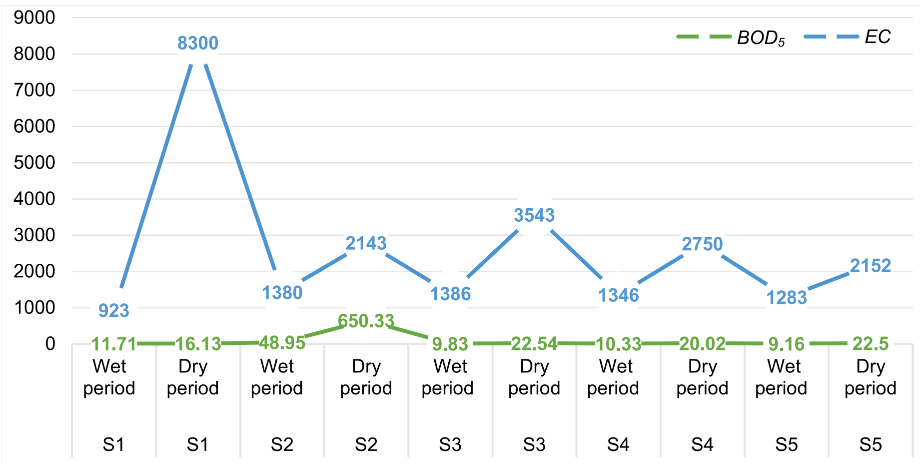

Fig. 4. Spatiotemporal variation of electric conductivity (*EC*, μS·cm^{-1}) and biochemical oxygen demand (BOD_5, mg·dm^{-3}) in five stations (S1–S5); source: own study

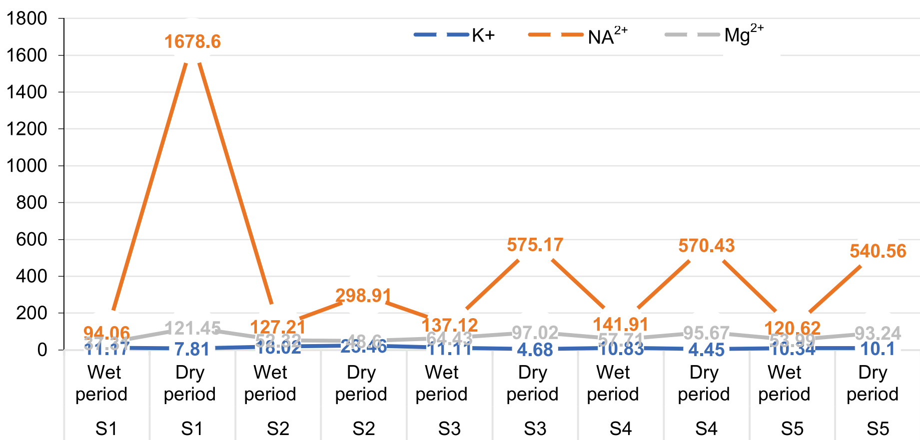

Fig. 5. Spatiotemporal fluctuation of main elements (in mg·dm^{-3}) in five stations (S1–S5); source: own study

ly faecal coliforms (FC), and *E. coli* (Holcomb and Stewart, 2020). The results of this study show the presence of coliforms and *E. coli* along Oued Mchera (Tab. S1). In addition, during the wet period, FC levels varied from 2700 CFU·100 cm^{-3} (S1) to 3600 CFU·100 cm^{-3} (S2, S3, S4, and S5), while *E. coli* concentrations were recorded as follows: S1 – 2300 CFU·100 cm^{-3}, S2 – 1600 CFU·100 cm^{-3}, S3 – 1600 CFU·100 cm^{-3}, S4 – 2000 CFU·100 cm^{-3}, S5 – 1800 CFU·100 cm^{-3}. Conversely, in the dry period, FC counts ranged from 81 CFU·100 cm^{-3} (S1) to 4500 CFU·100 cm^{-3} (S3, S4, and S5), with *E. coli* levels observed at S1 – 0 CFU·100 cm^{-3}, S2 – 9700 CFU·100 cm^{-3}, S3 – 100 CFU·100 cm^{-3}, S4 – 100 CFU·100 cm^{-3}, S5 – 100 CFU·100 cm^{-3}.

During the dry period, all stations (S1, S2, S3, S4, and S5) show a significant decrease in *E. coli* concentrations compared to the wet period. For example, *E. coli* levels drop from 2300 to 0 CFU·100 cm^{-3} in S1, from 1600 to 970 CFU·100 cm^{-3} in S2, and from 1600 to 100 CFU·100 cm^{-3} in S3. This consistent decline across all stations can be attributed to reduced surface runoff during the dry period, which limits the transport of contaminants, including *E. coli*, from various sources like agricultural lands, urban areas, or untreated sewage into the water bodies. Additionally, lower water flow and higher evaporation rates during dry conditions might also reduce bacterial survival and proliferation, contributing to the observed decrease in *E. coli* levels.

STATISTICAL ANALYSES, CORRELATION OF ESTIMATED VARIABLES

The correlation matrix (Tab. S2) illustrates significant relationships among various environmental variables. Temperature shows a strong positive correlation with *EC* (r = 0.698) and nitrate NO_3^- (r = 0.731), indicating that higher temperatures are associated with increased ion concentration and nitrate levels. The pH has a strong negative correlation with nitrate (r = –0.869) and a positive correlation with *E. coli* (r = 0.672), suggesting that lower pH levels are linked to higher nitrate concentrations and lower bacterial counts. The *EC* is highly positively correlated with Na^{2+} (r = 0.986) and magnesium (r = 0.821), reflecting their contribution to overall ion concentration in water. In addition, Mg^{2+} and Na^{2+}, show significant positive correlations with temperature (r = 0.828 and r = 0.780, respectively), indicating a temperature-dependent increase in these elements. There are notable negative correlations between *E. coli* and *T* (r = –0.938) and *EC* (r = –0.681), suggesting that higher temperatures and ionic strength are associated with lower *E. coli* presence. Finally, the strong negative correlations between coliform counts and both temperature (r = –0.938) and *EC* (r = –0.681) emphasise the inverse relationship between these microbial indicators and warmer, more conducive conditions.

WATER QUALITY INDEX ANALYSIS

The water quality index (*WQI*) values for the stations (S1, S2, S3, S4, and S5) indicate significant variation between wet and dry periods. The *WQI* at S1 marginally increases from 123 during the wet period to 153, suggesting a marginal decline in water quality. The water quality of S2 has significantly declined, as evidenced by a significant increase in *WQI* from 378 in the wet period to 4385 in the dry period. Stations 3, 4, and 5 exhibit moderate increases in *WQI* from wet to dry periods, with values increasing from 100 to 188, 109 to 181, and 105 to 194, respectively (Fig. 6).

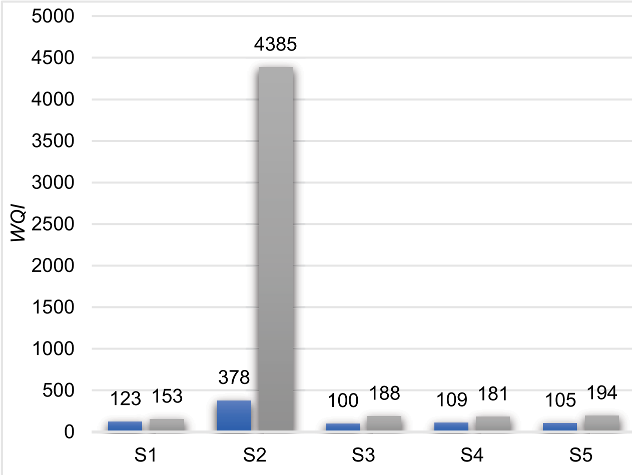

Fig. 6. Spatiotemporal evolulution of water quality index (*WQI*) of the study region; source: own study

DISCUSSION

PHYSICOCHEMICAL AND BACTERIOLOGICAL PARAMETERS

The data reveal notable temporal and regional fluctuations in mean temperature, implying considerable shifts throughout time. When compared with the studies by Khan and Butt (2023) and Chedadi *et al.* (2023), these findings align with the observed trends in temperature variability noted in similar climatic regions. These changes are a consequence of seasonal cycles, with summer seeing more intense solar radiation, leading to higher temperatures, while winter has lower solar input, resulting in colder temperatures (Thompson *et al*., 2023). The variations seen in different places indicate that local variables also influence the modulation of temperature patterns, emphasising the need to take into account both the temporal and spatial elements in climate research.

The pH levels exhibit geographical and temporal changes, with elevated values seen during the rainy period. Conversely, somewhat lower values are observed during the dry period. These findings align closely with the results reported by Fiouz *et al.* (2024). This indicates that the water becomes more alkaline during the wet season, most likely because of a higher volume of water that dilutes acidic substances, hence increasing the water's ability to resist changes in pH. On the other hand, the little decline in pH during the dry season might be attributed to reduced water quantities, leading to the concentration of acidic chemicals and a drop in alkalinity (Xia *et al*., 2024).

The sampling stations indicate a significant seasonal variation in dissolved oxygen (*DO*) levels between the wet and dry periods. This could be attributed to the increased runoff and sediment burden, which have resulted in reduced aeration and higher water turbidity. Conversely, the levels of *DO* experienced a substantial rise during the dry period. This increase in *DO* during the dry season is likely the result of reduced water volumes, which facilitate oxygen diffusion, and potentially increased photosynthetic activity from aquatic plants. These results are in agreement with those obtained by Khan and Butt (2023). The influence of hydrological changes on the availability of oxygen in the water, which is essential for the preservation of aquatic life, is underscored by the variation in *DO* levels between seasons. In addition, one crucial element that causes these differences is the impact of water temperature, as colder water often contains more *DO* than warmer water. In the wet season, lower temperatures dominate, which increases the ability of oxygen to dissolve in water and leads to increased quantities of *DO* (Mahaffey *et al*., 2023). On the other hand, during the dry season, higher water temperatures decrease the ability of oxygen to dissolve, resulting in lower quantities.

In this study, NO_3^- levels reveal distinct variations between the wet and dry periods across the sampling stations. During the wet period, nitrate concentrations are typically lower. This decrease can be attributed to the dilution effect caused by increased water flow, which disperses nutrients more widely. Controversly, during the dry period, nitrate levels rise significantly with concentrations. These findings are in alignment with those reported by Ajiyel *et al.* (2021) and Elassassi *et al.* (2022). The rise in nutrient levels is probably caused by the accumulation of nutrients when water levels decline, together with decreased absorption of nutrients by plants under dry circumstances. The increased nitrate levels seen during the dry season suggest the buildup of agricultural runoff or other nutrient sources that become more concentrated in times of water scarcity. This emphasises the immediate requirement for efficient management approaches to address nutrient pollution in freshwater ecosystems (Chowdhary *et al*., 2020).

The disparity in electrical conductivity (*EC*) levels during wet and dry seasons can be ascribed to the impact of precipitation. During periods of rain, the comparatively pure rainwater dilutes the conductivity of surface waters, leading to decreased *EC* values (Varol and Tokatlı, 2023). In contrast, at low rainfall, surface waters become more concentrated due to evaporation and less dilution, resulting in elevated *EC* values (Zhang *et al*., 2018). Furthermore, the measured *EC* values indicate the substantial presence of minerals in the natural water sources in the Oued Mchera Basin. The leaching of minerals from geological formations increases the water's concentration of different ions, contributing to the baseline *EC* values.

The BOD_5 data indicate notable spatiotemporal differences across the sample stations (S1 to S5) during both wet and dry seasons. This significant pollution at S2 aligns with findings from previous research by Varol and Tokatlı (2023), which also highlighted the impact of urban wastewater discharge on water pollution in the region. The elevated BOD_5 levels, especially at 650.33 mg·dm^{-3}, are so high that nitrification, an essential process for removing nitrogen compounds from water, is not feasible. This extreme BOD_5 value is attributed to sporadic discharges of untreated wastewater rather than the average characteristics of the situation.

The results show a notable rise in K^+, Na^{2+}, and Mg^{2+} ion levels in the waters of Oued Mchera at all sites throughout the dry period. This significant change indicates the impact of human activities, such as industrial operations, on the increased quantities of ions in the water. Regarding ion predominance, the Oued Mchera consistently exhibits a pattern where sodium ions are the most prevalent, followed by potassium and magnesium ions. These findings are consistent with prior studies undertaken by Zaghloul *et al.* (2020), Khadija *et al.* (2021) and Ustaoğlu *et al.* (2021) providing more evidence for the observed patterns in ion concentrations within the watershed. The consistent nature of these findings highlights the enduring influence of human activities on water quality.

The results for faecal coliforms (FC), *E. coli*, and total coliforms (TC) show significant variation between wet and dry periods across the different sampling stations. Similar results were obtained by Hamadou *et al.* (2023). The proliferation of microbes can explain the increase of these germs in dry periods at these stations due to the discharge of organic matter and nitrogen nutrients from the agricultural activities that are installed during this period, however, the decrease of FC and *E. coli* in Oued Mchera (S1), is explained by the *EC* (8300 ±100 mS·cm^{-1}), and sodium (1678.6 mg·cm^{-3}), the high salinity is a stress factor that causes the release of these germs (Fouad *et al*., 2013). Indeed, at S1, the more basic pH is more significant than 8.5 causing a decrease in FC survival (Elassassi *et al*., 2022). General and the reduction of these germs in wet periods can be explained by the phenomenon of self-purification after the fall of rain (Aminirad *et al*., 2021), with an increase in FC levels at S2 during wet periods; this pollution could be explained by discharges directly to this station from tributaries which are loaded by wastewater, domestic discharges, and a sewerage network in the municipality of Rommani (Saab *et al*., 2007).

STATISTICAL ANALYSES, CORRELATION OF ESTIMATED VARIABLES

The results obtained show the Pearson correlation coefficient between physicochemical parameters and microbial water characteristics of Oued Mchera, the average temperature values are strongly correlated positively with that of *EC* (0, 698), strongly correlated with *E. coli* and FC (−0, 938). The positive correlation between temperature and *EC* is from a study conducted by Ameen *et al.* (2023), indicating a consistent association between these two variables. Moreover, a significant positive link was seen between temperature and nitrate levels, with a correlation coefficient of 0.731 (Andrade Costa De *et al*., 2020). This association suggests a positive relationship between temperature and nitrate concentrations, meaning that when temperature increases, nitrate concentrations also tend to grow.

In domestic wastewater, the predominant nitrogen-containing pollutant is ammonium (NH_4^+), not nitrate (NO_3^-), because the process of nitrification, which converts ammonium to nitrites and subsequently to nitrates, is often limited or absent in raw wastewater. Therefore, wastewater treatment strategies often prioritise the removal of NH_4^+ through biological processes, such as nitrification followed by denitrification, to mitigate its environmental impact. The interconnections among pH, *DO*, and BOD_5 in aquatic environments are intricate and diverse. The positive correlation (0.045) between pH and *DO* indicates that changes in pH levels tend to align with fluctuations in *DO* concentrations. Still, the extent of this relationship is relatively tiny. This correlation supports the notion that pH can affect the solubility of oxygen in water. Higher pH values are typically linked to higher oxygen levels because the solubility of CO_2, a consequence of respiration, decreases, leading to increased oxygen availability (Elassassi *et al*., 2022). In contrast, the negative correlation (−0.449) between pH and BOD_5 indicates an inverse association. This means that higher pH values are associated with lower levels of BOD_5, which suggests a decrease in organic pollutant concentrations. The pH is a highly responsive indicator of environmental conditions, and changes can influence both physicochemical parameters and biological processes in aquatic habitats (Elassassi *et al.*, 2022). The interaction between biological and physicochemical factors highlights the dynamic character of pH control in aquatic environments.

The EC values are strongly correlated positively with that of temperature (0.638), sodium (0.780), and magnesium (0.828). The value of the EC increases with the increase of the Na^{2+} and Mg^{2+} ions. This is related to the geological nature of the rocks of the Oued Mchera area that belongs to the central Moroccan Plateau (El Haissoufi *et al.*, 2017), which consists of a Paleozoic sedimentary substrate (Ordovician to Carboniferous). Generally, shale with intercalations of sandstone and quartzite banks, a granite massif of Zaër, a Triassic detrital complex composed of alternating clays, gypsy-saliferous and basaltic mass and Cenozoic superficial formations (Laouina and Mahé, 2013). The indicated oxygen values demonstrate a significant negative association with BOD_5 readings (correlation coefficient of 0.869), consistent with the findings of Medeiros *et al.* (2017). There is a negative significance between most physicochemical parameters and the development of bacteria; note the elevated rate of the EC (−0.672), Na^{2+} (−0.750), NO_3^- (−0.770), and the temperature (−0.938), which act fastly on the bacterium development (TC and *E. coli*) and also the high salinity inhibits the growth of FC, this is observed at S1 during the dry period, where there is a total absence of *E. coli* (Tab. S2). *E. coli* correlates negatively with the DO (−0.434) and NO_3^- (−0,7). Those results are consistent with these results (*E. coli* and DO (−0.49), *E. coli* and NO_3^- (−0.6) obtained by Andrade Costa De *et al.* (2020).

WQI ANALYSIS

The findings of the water quality index (WQI) indicate notable geographical and temporal fluctuations across the study area during both wet and dry periods. During the wet season, the WQI readings tend to be lower, which suggests improved water quality. However, during periods of low rainfall, there is a significant rise in WQI values at many stations, particularly at S2, where the WQI soars to 4385, indicating deficient water quality (Rahman *et al.*, 2020). The considerable increase suggests a significant decline in water quality during the dry season, most likely caused by variables such as decreased water volume, elevated pollutant concentrations, and reduced ability to dilute. These results emphasise the need to monitor and control water quality, especially in areas prone to substantial seasonal variations, to guarantee the safeguarding of aquatic ecosystems and human health.

The decline in water quality throughout the gradient from upstream to downstream of Oued Mchera is primarily due to agricultural operations, specifically the typical farming practices in the region. During the rainy season, the growing of grains, and during the dry season, the planting of fruit crops, mainly at stations S1, S3, S4, and S5, result in a significant input of artificial mineral and organic contaminants into the water body. These operations result in transferring fertilisers, herbicides, and organic matter from agricultural fields into surface waters, worsening nutrient pollution and undermining water quality. The proximity of agricultural operations to the communes of Rommani exacerbates the impact, as these practices are frequently linked to deficient management practices and insufficient regulatory supervision. The combined effect of these human-induced inputs decreases water quality as it flows downstream in Oued Mchera.

CONCLUSIONS

The study conducted on the water quality of Oued Mchera has shown considerable fluctuations in the water quality index over time, with distinct variances seen between different seasons and between the upstream and downstream stations. The results suggest that the water from all stations is not fit for consumption throughout both the dry and wet seasons. The research emphasises the immediate effect of pollution, mainly caused by the release of home and agricultural sewage from the rural commune of Rommani. This pollution introduces several chemicals that provide significant hazards to both aquatic ecosystems and human health. The presence of these impurities may deteriorate the quality of water, rendering it suitable for irrigation or other urgent use with sufficient treatment. In order to successfully tackle these difficulties, it is necessary to have a complete management plan. This encompasses routine surveillance of water quality to swiftly identify any alterations, stringent regulatory interventions to manage the release of pollutants, and active engagement from local populations to cultivate a feeling of accountability and collaborative effort. These actions are vital for effectively controlling pollution levels and preventing lasting harm to the water body. Subsequent investigations should prioritise several crucial domains to expand upon these discoveries. Further research should investigate innovative and economical water treatment techniques specifically designed for local conditions to restore usability to contaminated water. Furthermore, examining both the immediate and indirect effects of polluted water on human well-being and local farming may provide a more thorough comprehension of the socio-economic repercussions.

SUPPLEMENTARY MATERIAL

Supplementary material to this article can be found online at https://www.jwld.pl/files/Supplementary_material_Habchaoui.pdf

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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