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Assessment of seasonal variations in water quality and pollution sources in the coastal water bodies between Casablanca and Rabat (northwest Morocco)

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ABSTRACT

This study monitored the physicochemical and microbiological quality of six rivers in the coastal Oueds Basin between Casablanca and Rabat, Morocco, to assess seasonal variations in water quality, identify pollution sources, and evaluate the efficacy of water quality indices (CCME-WQI and WGQI) in a Moroccan context. Water quality was assessed during the dry and wet seasons (March and September 2024) using fifteen parameters: Temperature, pH, EC, Turbidity, DO, COD, BOD_5, TP, NH_4^+, TKN, TSS, NO_3-, Cl^-, SO_4^{2-} and FC. Water quality was classified as "poor" to "very poor" across all stations. The dry season showed particularly severe organic pollution (BOD_5 reaching 58.04 mg/L; COD up to 222.58 mg/L) and fecal contamination, primarily from untreated domestic wastewater and industrial discharges. Elevated ionic concentrations (Cl^- 4133 mg/L; SO_4^{2-} 255.3 mg/L) indicated significant agricultural and industrial runoff impacts. Intermittent streams exhibited extreme sediment loads (TSS > 600 mg/L) following seasonal rewetting. This study presents the first comparative analysis of water quality index (WQI) performance in one of Morocco's most heavily polluted downstream reaches. The findings contribute to this growing body of research using WQI, while awaiting the development of a Morocco-specific WQI framework that considers hydro-climatic variability and anthropogenic pressures.

Keywords: water quality, surface water pollution, WQI, monitoring study, Morocco.

INTRODUCTION

Freshwater is a vital resource, providing essential ecosystem services such as drinking water, irrigation, and waste disposal (Pan et al., 2012; Nguyen et al., 2017; Rehman et al., 2024). However, human activities, including urbanization, industrialization, and agricultural practices, have significantly degraded freshwater habitats and reduced water quality worldwide (Nguyen et al., 2017; Gikas et al., 2023). This issue is particularly acute in Mediterranean regions, where rivers and streams face additional pressures from seasonal and inter-annual variability in precipitation, exacerbated by climate change (Grantham et al., 2012; Cid et al., 2017). In Mediterranean areas, intermittent and ephemeral streams are common. These dynamic ecosystems experience three distinct hydrological phases: flowing, non-flowing, and dry (Gallart et al., 2012; Banegas-Medina et al., 2021; Koutalakis et al., 2024). Seasonal changes, such as rising temperatures and reduced rainfall, often lead to increased conductivity, salinity, and reduced dissolved oxygen levels in surface waters (Dhawde et al., 2018; Magand et al., 2020). Irregular rainfall patterns further exacerbate these issues by reducing pollutant dilution and increasing sediment and mineral loads in river systems (Chakrabarty and Sarma, 2011). Understanding the interactions between hydro-climatic stressors and anthropogenic impacts, such as mineral, organic, and nutrient pollution, is crucial for effective water resource management (Stefanidis et al., 2018; Ustaoğlu et al., 2020). Regular monitoring of water quality is essential to adapt management strategies and mitigate the impacts of these combined stressors (Barakat et al., 2016). Water quality indices (WQIs) are valuable tools in this regard, as they transform complex datasets into simplified, unitless numerical values that represent the overall status of water quality, making the data accessible to decision-makers and policymakers (Mourhir et al., 2014).

While water quality indices have been widely studied in the European Mediterranean part (e.g., Santos et al., 2015; Stefanidis et al., 2018; Gikas et al., 2023; Uslu et al., 2024), significant gaps remain in the southern part, in regions like Morocco, where seasonal variations are more severe. The coastal plains between Rabat and Casablanca, for instance, are critical for Morocco's socioeconomic development, yet they face increasing water quality degradation due to rapid urbanization, industrial expansion, and agricultural activities (Barakat et al., 2016).

As this region is set to undergo multiple infrastructure projects along downstream river sections, these developments are expected to substantially alter water quality. This study focuses on the downstream sections of six rivers in the Bouregreg-Chaouia Watersheds along the Atlantic coast between Rabat and Casablanca: Ykem, Cherrat, El Ghbar, Nfifikh, El Maleh, and Hassar. The specific objectives are to: (1) analyze seasonal variations in physicochemical and bacteriological indicators of water quality; (2) evaluate the performance of the Moroccan and Canadian water quality indices (WGQI and CCME-WQI); and (3) investigate the relationships between pollutant types and sampling sites using multivariate analysis.

MATERIALS AND METHODS

Study area and sampling sites

The study area encompasses the watercourses along the Atlantic coast between the Bou Regreg and Oum Er Rbia basins, located in the Rabat-Salé-Kénitra and Casablanca-Settat regions of Morocco. This area includes six rivers, Ykem (S1), Cherrat (S2), El Ghbar (S3), Nfifikh (S4), El Maleh (S5), and Hassar (S6), which flow into the Atlantic Ocean between Rabat and Casablanca. Collectively, these rivers drain a basin area of 5.415 km² (ABH BC, 2012).

The region experiences a Mediterranean climate with semi-arid bioclimatic characteristics

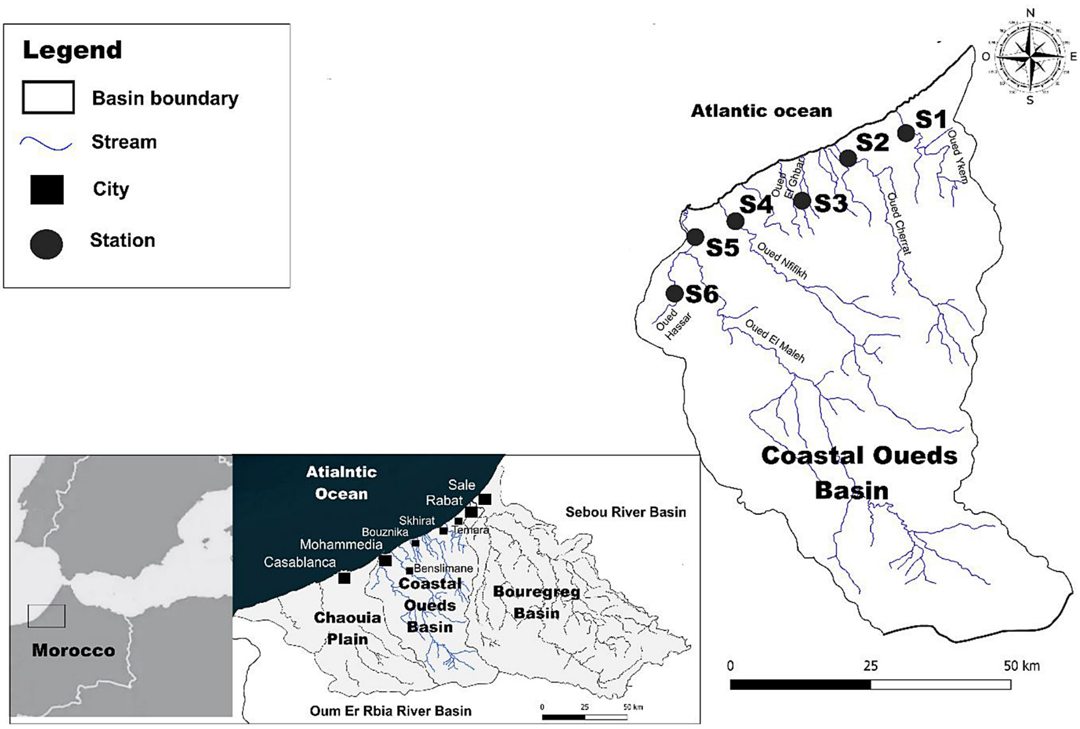

Figure 1. Location of the Coastal Oueds basin and the sampling sites

and strong oceanic influence. Summers are typically hot and dry, with average temperatures ranging from 15 °C to 26 °C, while winters are mild and humid, with temperatures averaging between 8 °C and 17 °C (El Morabet et al., 2024). Annual precipitation averages around 600 mm but varies significantly, ranging from 250 mm to 800 mm (Zouahri et al., 2015).

Geomorphologically, the study area is part of the northern coastal Meseta. It consists of small watersheds whose hydrographic networks originate in the central plateau, traverse the Chaouia plains, and discharge into the Atlantic Ocean. The region's topography is generally low-lying, with elevations in the downstream sections of the basins being minimal and not exceeding 600 m in the interior areas (Boussalim et al., 2022).

Situated between Morocco's administrative capital, Rabat, and its economic hub, Casablanca, the study area is characterized by significant urban development and serves as a focal point for a substantial portion of the country's economic activities. Key urban centers include Skhirat, Ben Slimane, Bouznika, Mediouna, and Mohammedia (Hara et al., 2021) (Fig. 1).

Water samples for physicochemical and bacteriological analysis were collected once per season in March (wet season) and September (dry season) 2024 at six sampling sites. At each station, a single sampling point was selected. The selection of these stations was based on various criteria such as accessibility, pollution sources, and hydrological regime (permanent, or intermittent) (Table 1).

Water analysis

Water samples and analyses were conducted in six rivers along the Atlantic coast of Morocco, located between Rabat and Casablanca, twice a year during both the wet and dry seasons (March and September 2024). The physicochemical and bacteriological analyses were based on the measurement of fifteen parameters. Water temperature (T), pH, turbidity (NTU), electrical conductivity (EC), and dissolved oxygen (DO) were measured in the field using a Bante900P Portable Multiparameter Water Quality Meter. The other parameters (COD, BOD_5, TKN, NH_4^+, TP, TSS, NO_{3-}, Cl^-, and SO_4^{2-}) and fecal coliforms (FC) were analyzed in the Regional Laboratory of the Environment of the Urban Municipality of Tétouan following the protocols established by Rodier (2009).

Water quality and pollution index assessment

We employed the weighted global quality index (WGQI), a recent tool developed by Morocco's Water Research and Planning Department (DRPE) (SEEE, 2008). Adapted from the French System for Evaluation of the Quality of Rivers (SEQ-Eau) (SEQEAU, 2003), this index is derived through a weighting process, and generates a score that reflects its classification within a range of categories according to Moroccan surface water quality standards (SEEE, 2002). Specifically, the interval values defined by the new water quality assessment grids are transformed into numerical values ranging from 0 (very poor quality) to 100 (excellent quality), resulting in a score across five quality categories: excellent, good, medium, poor, and very poor. The overall quality score corresponds to the lowest index obtained from all the considered alterations.

The formula for calculating the weighted index is expressed as:

$$WIap = Li + [\frac{(Hi - Li)}{(ub - lb)}]\, x\,(ub - ap) \quad (1)$$

where: $WIap$ – weighted index of the analyzed parameter, Li – lower index, Hi – higher index, lb – lower limit, ub – upper limit, ap – analyzed parameter.

Table 1. Location of study area and the six sampling sites

Sampling code	Stream name	Locality	Hydrological feature	Altitude (m)	Latitude (N)	Longitude (E)
S1	Oued Ykem	Skhirat	Permanent	14	33.85592	-6.993240
S2	Oued Cherrat	Cherrat	Intermittent	10	33.80096	-7.097304
S3	Oued El Ghbar	Bouznika	Permanent	49	33.78373	-7.142010
S4	Oued Nfifikh	El Mansouria	Intermittent	10	33.70726	-7.332443
S5	Oued El Maleh	Mohammedia	Permanent	11	33.66323	-7.399752
S6	Oued Hassar	Tit Mellil	Permanent	98	33.58064	-7.436899

The CCME-WQI was created in 2001 by a committee formed within the Canadian Council of Ministers of the Environment (CCME) (Halder et al., 2014). This index calculation method combines three factors (Scope, Frequency, and Amplitude) derived from the selected objectives to produce a single numerical score ranging from 0 to 100 (with 1 representing the lowest quality and 100 indicating the highest water quality). Within this scale, water quality is classified into five categories: poor, marginal, fair, good, and excellent (CCME, 2001). The water quality classification was carried out according to Moroccan surface water quality standards (SEEE, 2002). The various mathematical equations of CCME WQI are given below:

1. F1 (scope): represents the percentage of failed variables that do not meet their objectives to the total number of variables measured.

$$F1 = \left(\frac{Number\,of\ failed\,variables}{Total\,number\,of\ variables} \right) \times 100 \quad (2)$$

2. F2 (frequency): represents the percentage of the individual (failed tests) that do not meet objectives.

$$F2 = \left(\frac{Number\,of\ failed\,tests}{Total\,number\,of\ variables} \right) \times 100 \quad (3)$$

3. F3 (amplitude): measures the extent to which failed test values do not meet their objectives and calculated in three steps.

The number of times by which an individual concentration exceeds (or falls below, when the objective is a minimum) the objective is nominated an "excursion" and is calculated by.

$$excursioni = \left(\frac{Objective\ j}{Failed\,Test\ Valuei} \right) - 1 \quad (4)$$

$$excursioni = \left(\frac{Failed\,Test\ Valuei}{Objective\ j} \right) - 1 \quad (5)$$

The normalized sum of excursions (NSE): is calculated by summing the excursions calculated for all individual tests that are out of compliance divided by the total number of tests and is expressed as:

$$F3 = \left(\frac{nse}{0{,}01nse + 0{,}01} \right) \quad (6)$$

$$nse = \left(\frac{\sum_{i=1}^{n} excursioni}{Number\,of\ tests} \right) - 1 \quad (7)$$

Once F1, F2, and F3 have been calculated, the WQI is given by the following form:

$$CCME\text{-}WQI = 100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732} \right) \quad (8)$$

Statistical analysis

The Kolmogorov-Smirnov test was used to assess whether the parameters analyzed across the sampling sites followed a normal distribution. Since normality was not achieved, Spearman's rank correlation was employed to evaluate the degree of association between the various physicochemical and bacteriological parameters.

Component analysis (PCA) was applied to extract the association between the studied sites and the applied parameters. Moreover, a hierarchical cluster analysis (HCA) was used to group the sampling sites according to their causative physicochemical and bacteriological pollutants based on their level of association. All statistical analyses were performed using the XLSTAT 2024 software.

RESULTS AND DISCUSSION

Physicochemical and bacteriological assessment

The results of this study highlight significant spatiotemporal variability in water quality across the studied rivers, driven by seasonal changes and anthropogenic pressures. Key physicochemical parameters, such as electrical conductivity (EC), organic matter (BOD_5, COD), and nutrients (TKN, TP), exhibited elevated concentrations, particularly during the dry season when dilution capacity was minimal (Table 2).

For in situ measurements, the evolution of surface water temperature is characterized by lower values during the spring and higher values in the summer, oscillating between 17.3 °C and 24.1 °C at the same station of Oued Ykem (Fig. 2). The pH values were slightly alkaline with non-significant variations between the two studied periods, ranging from 7.45 and 8.05. Electrical conductivity (EC) showed a significant variation between the wet and dry periods with recorded values fluctuating between 276 µs/cm at Oued Cherrat (S2) during the autumn and 12640 µs/cm at Oued Hassar (S6) during the spring. Turbidity values vary between 185.16 NTU during spring

Table 2. Values of physicochemical and bacteriological parameters of the 6 sampling sites stations during March and September 2024

Parameters	Oued Ykkem (S1)		Oued Cherrat (S2)		Oued El Ghbar (S3)		Oued Nfifikh (S4)		Oued El Maleh (S5)		Oued Hassar (S6)	
	March	Septembre	March	Septembre	March	Septembre	March	Septembre	March	Septembre	March	Septembre
T	17.4	24.1	17.3	-	20.3	20.7	18.1	-	19.5	20.3	20.4	22.8
pH	7.8	8.05	8.05	-	7.8	7.45	8.0	-	7.65	7.67	7.45	7.77
EC	1288	1754	276	-	1636	1622	443	-	3910	5456	12640	10180
Turb	55	153	546	-	16	6.77	429	-	25	50.01	40	53.44
DO	5.62	2.4	8.4	-	5.52	4.53	8. 0	-	7.1	6.63	8.2	8.93
COD	55.6	223	23.5	-	41.4	55.4	9.87	-	22.3	40.0	24.1	58.0
BOD_5	18.1	58.04	2.32	-	8.45	4.345	1.12	-	0.92	0.82	1.83	2.45
TKN	30.2	72.8	8.44	-	35.3	24.332	10.11	-	0.95	1.04	1.12	1.33
NH_4^+	16.0	81.6	0.232	-	7.93	15.54	0.711	-	0.465	0.055	0.21	0.034
TP	2.03	8.44	0.532	-	1.386	5.34	0.455	-	0.082	0.094	0.102	0.164
TSS	56.4	101	609	-	16.4	7.11	588	-	14.66	38.1	40.4	73.2
NO_{3-}	1.38	1.22	8.04	-	2.64	75.4	16.93	-	7.63	7.11	5.93	4.93
Cl^-	234	256	32	-	276	275	75.4	-	1043	1466	4133	3804
SO_4^{2-}	90.1	74.34	21.3	-	153	114	21.4	-	166	232	255.3	202
FC	25000	2500000	21000	-	1600	115000	575000	-	125	215000	2850	670

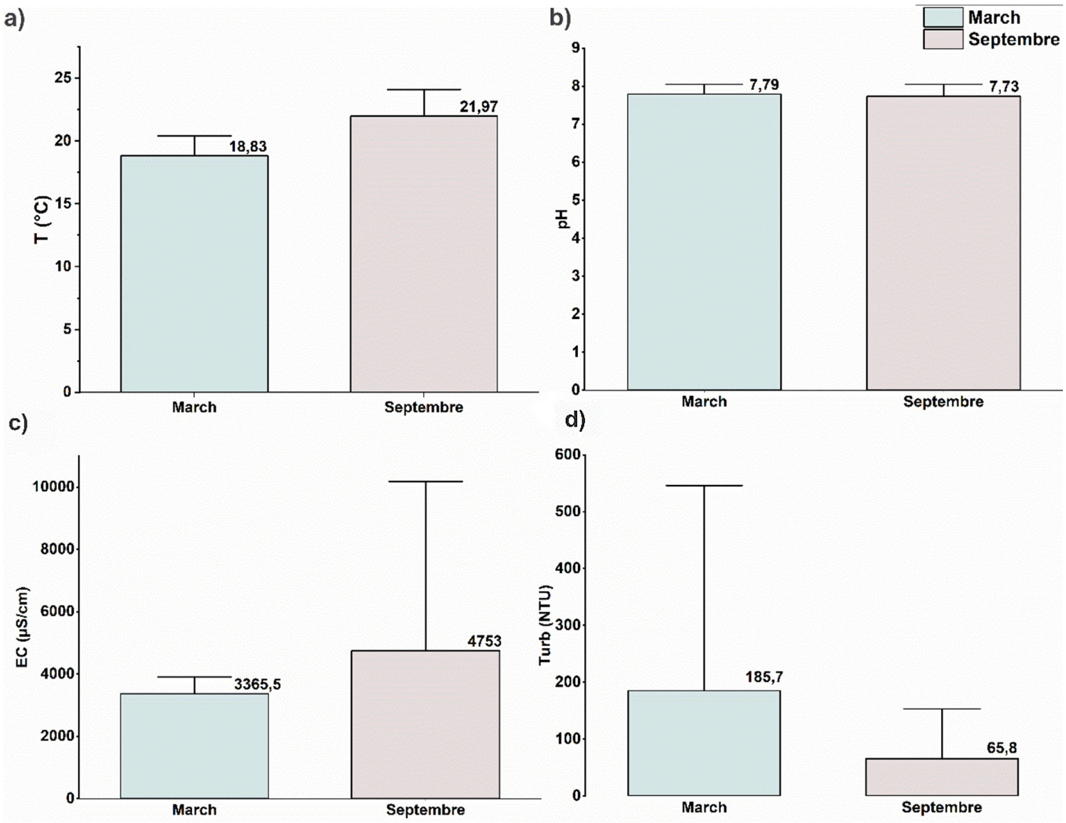

Figure 2. Spatio-seasonal variation of (a) temperature (°C), (b) pH, (c) conductivity (µS/cm), (d) turbidity (NTU)

and 65.80 during autumn, with peaks recorded at S2 and S4. The measured dissolved oxygen values showed higher concentrations and notable variations ranging from 2.40 mg/l in dry period at Oued Ykem (S1) and 8.4 mg/l at Oued Hassar (S6) throughout the wet period. The levels of BOD_5 oscillated in the water studied range from 0.82 mg/l at Oued El Maleh in spring and

58.04 mg/l at Oued Ykem in autumn. COD followed the same trend with a minimum of 9.87 mg/l recorded at Oued Nfifikh (S5) during summer and a maximum of 222.58 mg/l recorded at Oued Ykem (S1) in autumn. Spatio-seasonal trends in COD indicate that all stations exhibit levels exceeding the recommended surface water standard of 30 mg/L set as the limit value (SEEE, 2002) (Fig. 3).

The seasonal evolution of the Total Kjeldahl Nitrogen (TKN) and Total Phosphorus (TP) were relatively similar. During the dry season, TKN and TP reached their peak values of 72.80 mg/l and 8.44 mg/l, respectively at Oued Ykem (S1). Moreover, at this last station during the same period of the year, ammonium concentrations reached a maximum of 81.55 mg/l. In the other rivers, ammonium levels were observed to be slightly elevated, according to Moroccan standards (SEEE, 2002).

In all stations, the average total suspended solids levels ranged from 54.70 mg/l in autumn to 250.66 mg/l during the dry period, with a peak of 609 mg/L recorded at Oued Cherrat in March, immediately following a flood event (Fig. 4). Furthermore, the nitrate concentration in the waters of the studied rivers showed low values, oscillating between 1.22 mg/l at Oued Ykem and 75.4 mg/l at Oued El Ghbar in autumn. The majority of stations recorded values below the recommended limit of 10 mg/l, according to Moroccan standards (SEEE 2002).

Spatio-seasonal chloride and sulfate loads were relatively similar. Chloride levels were notably elevated, especially in Oued Hassar and Oued El Maleh, with concentrations of 4133 mg/l and 1043 mg/l, respectively, during the dry period. Furthermore, the majority of the stations recorded chloride levels exceeding the standard of 100 mg/l set by Moroccan regulations (SEEE, 2002). These same stations (S5, S6) also recorded maximum sulfate concentrations of 255.3 mg/l and 166 mg/l, respectively. Additionally, most stations showed chloride and sulfate levels surpassing the thresholds of 200 mg/l and 100 mg/l respectively, as defined by Moroccan standards (SEEE, 2002).

The results obtained during the study period showed that the faecal coliforms (FC) showed higher level in autumn, compared to spring, especially at Oued Ykem (S1), being the highest value with 2500000 FS/100 ml in autumn and 25000 FC/100 ml in spring (Fig. 5).

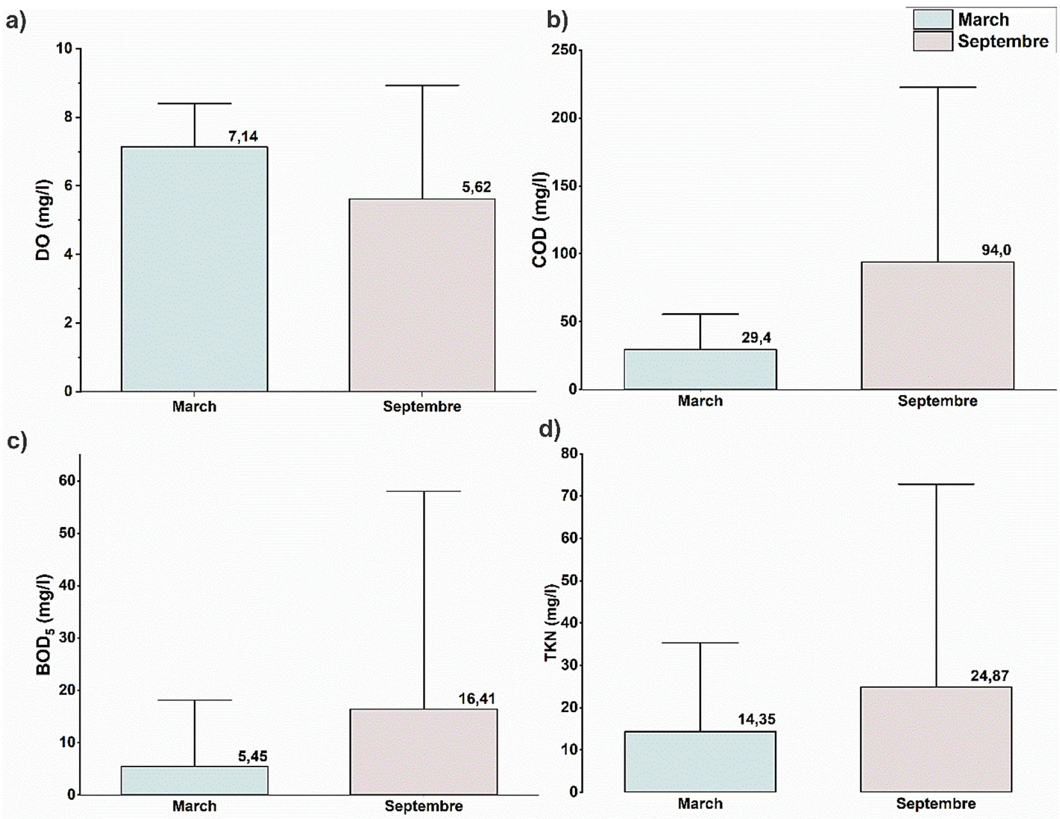

Figure 3. Spatio-seasonal variation of (a) dissolved oxygen (mg/L), (b) COD (mg/l), (c) BOD_5 (mg/l), (d) TKN (mg/l)

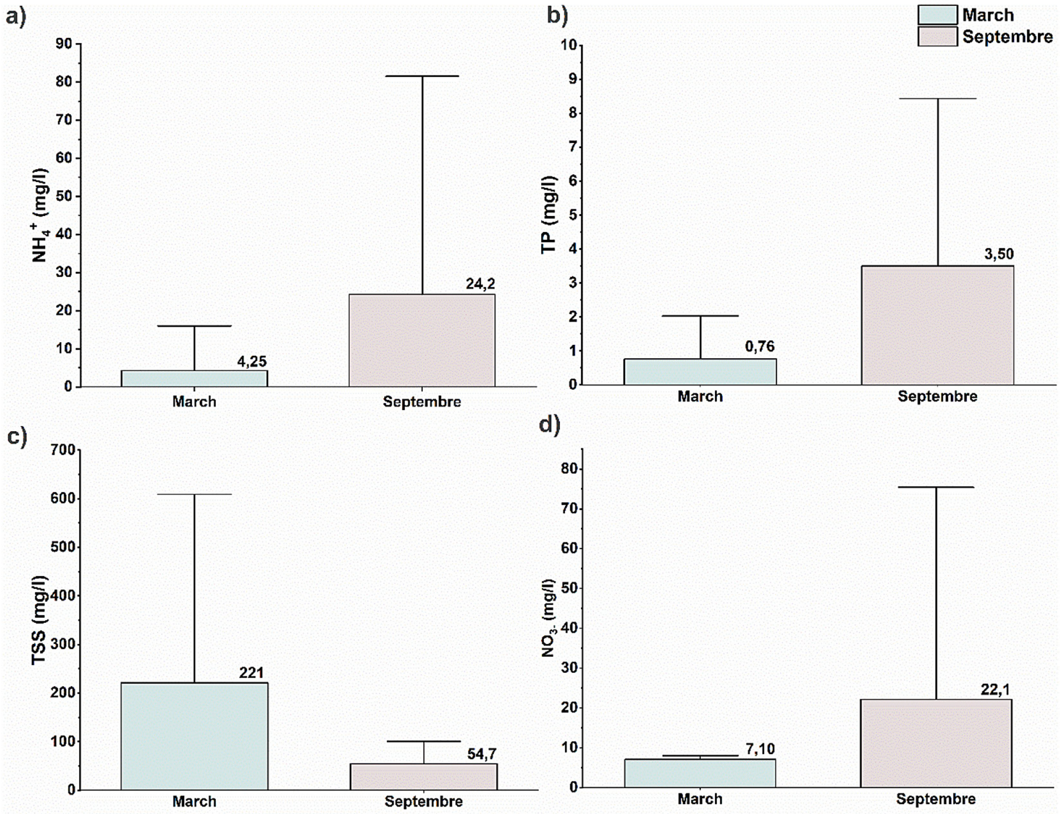

Figure 4. Spatio-seasonal variation of (a) NH_4^+ (mg/l), (b) TP (mg/l), (c) TSS (mg/l), (d) NO_{3-} (mg/l)

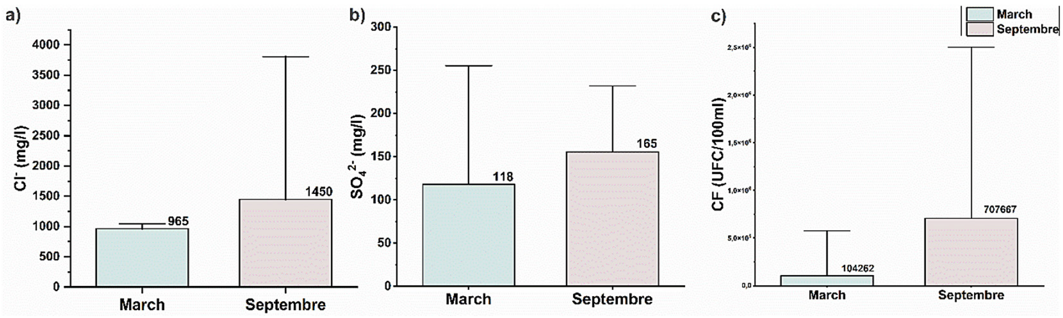

Figure 5. Spatio-seasonal variation of (a) Cl^- (mg/l), (b) $S0_4^{2-}$ (mg/l), (c) FC (UFC/100 ml)

Spatial and temporal variation in river water quality

The analysis of physicochemical and bacteriological parameter intercorrelations among the surveyed stations, as detailed in Spearman's correlation (Table 3), reveals several notable patterns. A strong positive correlation was observed between indicators of organic pollution, including TP and TKN ($r = 0.934$, $p = 0.01$), TKN and BOD_5 ($r = 0.867$, $p = 0.01$), TP and $NH4^+$ ($r = 0.823$, $p = 0.01$), TKN and $NH4^+$ ($r = 0.796$, $p = 0.01$), BOD_5 and COD ($r = 0.782$, $p = 0.01$), and TP and BOD_5 ($r = 0.772$, $p = 0.01$). Similarly, significant positive correlations were identified among indicators of mineral pollution, such as Cl^- and EC ($r = 0.964$, $p = 0.01$), SO_4^{2-} and Cl^- ($r = 0.939$, $p = 0.01$), and SO_4^{2-} and EC ($r = 0.867$, $p = 0.01$).

During the wet season, positive correlations were also noted between pH and indicators of sediment runoff. Specifically, TSS and turbidity were strongly correlated ($r = 0.976$, $p = 0.01$), while turbidity and pH ($r = 0.859$, $p = 0.01$), as well as TSS and pH ($r = 0.816$, $p = 0.01$), also showed significant associations. The principal component analysis (PCA) was applied to examine the relationships among physicochemical and bacteriological characteristics, enabling the

Table 3. Spearman's correlation matrix for the fifteen physicochemical and bacteriological parameters analyzed in the study area

Parameters	T	pH	EC	Turb	DO	COD	BOD_5	TKN	NH_4^+	TP	TSS	NO_{3-}	Cl^-	SO_4^{2-}	FC
T															
pH	-0.163														
EC	.648*	-.671*													
Turb	-0.309	**.816****	-0.455												
DO	-0.261	0.031	0.152	0.358											
COD	0.539	-0.050	0.297	-0.127	-0.515										
BOD_5	0.261	0.245	-0.176	0.018	-0.564	**.782****									
TKN	0.030	0.452	-0.515	0.200	-0.624	0.515	**.867****								
NH_4^+	0.000	0.060	-0.383	-0.116	-.845**	0.383	0.602	**.796****							
TP	0.122	0.437	-0.547	0.103	-.717*	0.511	**.772****	**.924****	**.823****						
TSS	-0.200	**.859****	-0.418	**.976****	0.394	-0.115	0.067	0.224	-0.182	0.109					
NO_{3-}	-0.200	-0.075	-0.236	-0.103	0.273	-.673*	-.648*	-0.442	-0.249	-0.219	-0.127				
Cl^-	0.564	-.778**	**.964****	-0.612	0.188	0.200	-0.236	-0.576	-0.438	-0.596	-0.564	-0.103			
SO_4^{2-}	0.406	**-.740***	**.867****	-.636*	0.139	0.164	-0.188	-0.515	-0.438	-0.608	-0.576	-0.200	.939**		
FC	0.164	0.508	-0.309	0.418	-0.479	0.212	0.248	0.491	0.450	0.523	0.394	0.030	-0.430	-0.430	

* The correlation is significant at level 0.05 (bilatéral)

** The correlation is significant at level 0.01 (bilatéral)

Table 4. Summary statistics of squared cosines for variables in the PCA

Parameters	F1	F2	F3
T	0.219	**0.507**	0.064
pH	0.236	**0.463**	0.238
EC	0.244	**0.499**	0.186
Turb	0.002	**0.790**	0.096
DO	**0.758**	0.057	0.144
COD	**0.847**	0.087	0.045
BOD_5	**0.901**	0.023	0.047
TKN	**0.915**	0.003	0.004
NH_4^+	**0.942**	0.033	0.012
TP	**0.851**	0.032	0.058
TSS	0.003	**0.815**	0.074
NO_3^-	0.000	0.001	**0.664**
Cl^-	0.265	**0.424**	0.218
SO_4^{2-}	0.222	**0.705**	0.014
FC	**0.816**	0.003	0.088

identification of spatio-seasonal differences between sampling sites within the study area during March and September 2024 (Fig. 6).

The first two PCA axes accounted for 77.74% of the total variation, with F1 and F2 explaining 48.13% and 29.61%, respectively. The analysis revealed that Temperature, COD, NH_4^+, BOD_5, TP, TKN, and FC, primarily expressed through the first axis, were positively associated in the lower-right quadrant of the plot and negatively correlated with DO. Conversely, EC, Cl^-, and SO_4^{2-} were positioned in the upper-left part of the plot. The second axis showed a positive correlation with pH, Turbidity, and TSS, which were located in the upper right quadrant of the plot (Table 4).

According to the PCA analysis, the stations were clustered based on the sampling period and the different types of pollutants. In the dry season, S1 A and S4 A showed a positive association with organic loads and bacterial contamination, while S6 and S7 were strongly correlated with nutrient and mineral indicators. During the wet period, S2 and S5 were grouped with alkaline waters characterized by high sediment loads and significant runoff.

The Hierarchical Cluster Analysis exposed four clusters based on the physicochemical and bacteriological variables as shown in Figure 7.

- Cluster 1: corresponds to the lowland section of Oued Ykem (S1), which is covered by agricultural, industrial, and urban areas, and is subject to high levels of human activity, which contribute to the discharge of organic pollutants and bacterial contamination from domestic wastewater and industrial effluents of Skhirat, and Tamesna cities, leading to a significant deterioration in water quality.

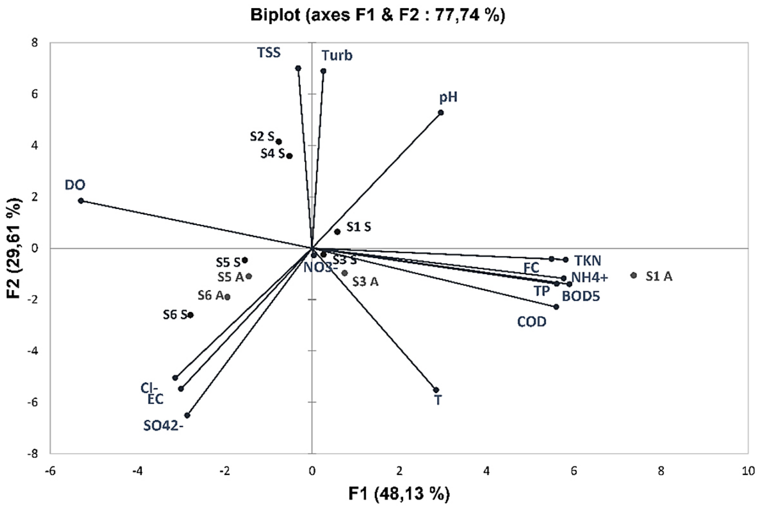

Figure 6. Bioplot representation showing the projection of the six studied sites and the physicochemical and bacteriological variables measured during spring (S) and autumn (A) on the factorial plane (F1×F2) of PCA

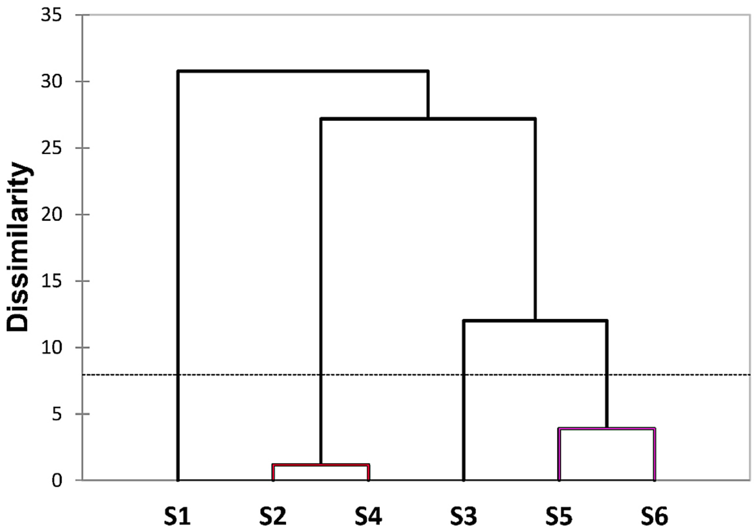

Figure 7. Hierarchical cluster analysis (HCA) of the six sampling sites based on physicochemical and bacteriological indicators observed during the study period

- Cluster 2: includes stations of Oued Cherrat (S2) and Oued Nfifikh (S4) linked to intermittent rivers. This cluster is mainly marked by high turbidity and elevated levels of suspended matter, due to the sudden reflow experienced by the streams during the wet period following a prolonged dry phase.
- Cluster 3: associated with Oued El Ghbar (S3), which is distinguished by high levels of organic pollutants mainly coming from the city of Benslimane, along with nutrient-rich waters from the surrounding agricultural lands.
- Cluster 4: comprises Oued El Maleh (S5) and Oued Hassar (S6), areas predominantly covered by agricultural/rural lands and is subjected to intensive agricultural practices, resulting in higher concentrations of mineral and nutrient pollutants, associated with fertilizers and/or pesticide runoff.

Rewetting periods and increased flow during rainy seasons significantly alter sediment load and streambed structure in intermittent rivers, leading to elevated turbidity and reduced water quality (Cid et al., 2017; Magand et al., 2020). In this study, PCA analysis and Spearman's correlation revealed that alkalinity trends at S2 and S5 were strongly linked to TSS and turbidity, driven by the transport of solutes accumulated in terrestrial soils and streambed sediments during the dry phase. These findings are consistent with studies on other Moroccan streams (Benamar et al., 2012; Barakat et al., 2016). Furthermore, the elevated electrical conductivity observed at S6 and S7 reflects the concentration of dissolved ions, including SO_4^{2-} and Cl^-, likely originating from industrial discharges and agricultural runoff (Hameed et al., 1999; Boroon and Coo, 2015; Papadaki et al., 2023), geochemistry of the region, particularly those enriched with evaporitic minerals and calcite, may also contribute to the increased levels of these ions (Fakri et al., 2012). Similarly, organic pollutants (BOD_5, COD, TP, NH_4^+, and TN) and fecal coliforms reached their highest concentrations at S1 and, to a lesser extent, S4. These peaks are attributed to untreated domestic wastewater and industrial effluents, particularly during the dry period when dilution capacity is minimal (Juahir et al., 2011; Halder et al., 2014).

The inverse relationship between dissolved oxygen (DO) and organic/mineral indicators, especially during the dry phase, aligns with findings from Kumari et al. (2013) and Aknaf et al. (2017). Warmer water temperatures, combined with high pollutant loads, enhance nutrient release from sediments and microbial decomposition of organic matter, thereby reducing DO levels. This phenomenon is well-documented in Mediterranean and Atlantic River systems, including northern Moroccan rivers (Errochdi et al., 2012; Guellaf et al., 2021; Azhari et al., 2023; Barakat et al., 2016; Benamar et al., 2019; Chadli and Boulafa, 2021). Similar patterns have also been reported in previous studies within the study area (Merbouh et al., 2022; El Morabet et al., 2024).

Water quality and pollution index

Water quality indices (WQIs) is a widely utilized method for evaluating the quality of water, providing several benefits such as easy interpretation of water quality monitoring data, provision of public information, and support for scientific research, etc. (Mogane et al., 2023). According to the CCME-WQI and WGQI trends, the water quality at all sampling sites showed deficient quality state, with a significant and notable increase in quality during the wet period compared to the dry phase (Fig. 8).

The seasonal variation of the CCME-WQI index showed significant fluctuations among the studied rivers. This index recorded its highest values in spring, with the maximum score (33.84) observed at Oued El Maleh (S5). Due to the rigorous classification method of this index, all the studied stations were categorized as belonging to the poor-quality class during both seasons, with a slight improvement observed in the wet season.

Regarding the values of the Weighted Global Quality Index (WGQI), this index reached its peak values in the wet season, with the maximum score (19.96) observed at Oued Cherrat (S2). Based on the WGQI index, all sampling stations fell within the very poor-quality range. Likewise, the results revealed that WGQI scores during autumn were relatively low compared to those in spring. Notably, the severe drought in autumn 2024 led to the drying up of most intermittent streams, including Oued Cherrat (S2) and Oued Nfifikh (S4).

To assess the validity of the selected indices under the hydro-climatic conditions of the study area, a comparison between the CCME-WQI and WGQI revealed significant differences in quality classifications, despite all stations being highly degraded. The CCME-WQI yielded an average score of 21.55, indicating "poor quality," while the WGQI showed an average of 14.34, reflecting "very poor quality." These discrepancies highlight the sensitivity of water quality indices to their underlying methodologies and classification

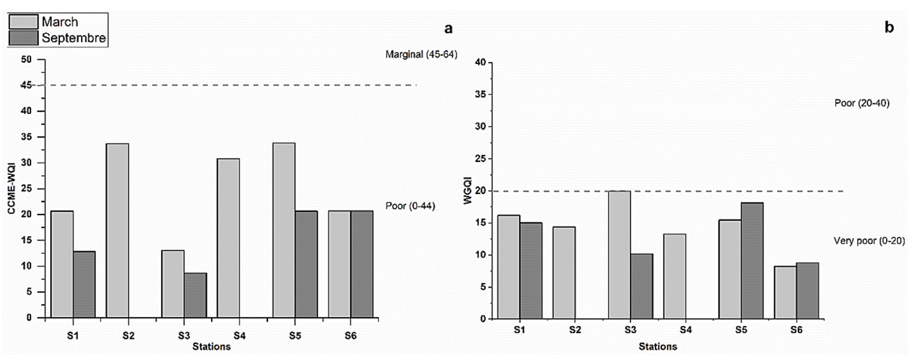

Figure 8. Scores of (a) CCME-WQI and (b) WGQI at the studied sites during autumn and spring

Table 5. WQIs comparisons of various rivers in Morocco and the Mediterranean Basin

River/basin name	Country	WQI	Rank	Causes	References
Morocco					
Moulouya basin	Morocco	WGQI	Poor	Urban wastewater, agricultural discharges, and geological substratum	El Hmaidi et al., 2021
Bouregreg basin	Morocco	WGQI	Poor	Urban, industrial, and agricultural pollution	Mourhir., 2014
Martil basin	Morocco	WGQI	Very poor	Urban, industrial, and agricultural pollution	Guellaf et al., 2021
		CCME-WQI	Poor		
Oued Fez	Morocco	WGQI	Very Poor	Industrial and municipal wastewater, hydrological conditions	Perrin et al., 2018
		CCME-WQI	Poor		
Mediterranean basin					
Acısu Creek Basin	Turkey	WGQI	Poor	Mineral pollution from agriculture and point/diffuse sources	Uslu et al., 2024
		CCME-WQI	Fair/Poor		
Sapanca Lake Basin	Turkey	CCME-WQI	Fair	Urban, industrial, and agricultural pollution	Akkoyunlu et al., 2012
Laspias basin	Greece	CCME-WQI	Poor	Mineral and salinity pollution from agricultural activities	Papaevangelou et al., 2023 Gikas et al., 2023
Lissos basin	Greece	CCME-WQI	Fair/Marginal	Municipal wastewater, and agricultural runoff	Papaevangelou et al., 2023 Gikas et al., 2023
Kosynthos basin	Greece	CCME-WQI	Fair	Untreated wastewater from settlements, urban and agricultural runoff	Gikas et al., 2023
Tafna basin	Algeria	CCME-WQI	Marginal/Poor	Domestic and industrial waste discharges	Hamlat et al., 2017
Vène basin	France	CCME-WQI	Moderate	Intermittency and wastewater treatment plant effluents	Perrin et al., 2018
		WGQI	Good		

criteria. While WQIs simplify the interpretation of monitoring data, they have notable limitations. The WGQI is prone to the eclipsing effect, where a single parameter exceeding permissible limits disproportionately influences the overall score, masking the compliance of other parameters (Mladenovic-Ranisavljevic and Zerajic, 2017; Uslu et al., 2024). Additionally, data aggregation in the WGQI calculation can result in the loss of critical information. On the other hand, the CCME-WQI requires a comprehensive set of parameters for accurate application, which is often not feasible in monitoring programs using the simplified Moroccan surface water quality grid (SEEE, 2002). Furthermore, the CCME-WQI's rigid classification scale, where scores below 44 are classified as "poor quality", limits its ability to differentiate between varying degrees of degradation. Despite these limitations, the CCME-WQI tends to be more efficient when a high number of parameters are available, as it incorporates all measured parameters in its calculation (CCME, 2001).

Several studies have already employed water quality indices (WQIs) to assess Moroccan rivers (Mourhir et al., 2014; Chadli and Boulafa, 2021; El Hmaidi et al., 2021; Guellaf et al., 2021). Furthermore, our study contributes to this growing body of research by providing a comparative analysis of WQIs, offering valuable insights into the spatio-seasonal variations in surface water quality within one of Morocco's most significantly impacted hydrosystems.

Although no WQI has been specifically developed for Mediterranean rivers, the CCME-WQI has gained widespread use due to its adaptability and effectiveness across diverse environmental settings (Papaevangelou et al., 2024) (Table 5). Comparative studies of European Mediterranean watercourses, such as those by Akkoyunlu et al. (2012), Perrin et al. (2018), and Gikas et al. (2023) Uslu et al. (2024), have revealed notable differences in water quality classifications. These studies consistently show that northern Mediterranean rivers tend to achieve higher water quality classifications compared to their southern counterparts (Guellaf et al., 2021; Hamlat et al.,

2017) when applying the CCME-WQI. This underscores the importance of adapting WQIs to account for hydrological changes and geographical variations specific to each region.

However, fewer studies have been performed comparing CCME-WQI and weighted indexes (NSFWQI, SEQ-Eau or WGQI) to assess their comparative performance. Recent research, including Guellaf et al., 2021, Perrin et al. 2018 in Morocco, Hamlat et al., 2017 in Algeria, and Uslu et al., 2024 in Turkey, confirmed the CCME-WQI demonstrated flexibility and efficiency in assessing spatiotemporal variations of Mediterranean rivers unlike WGQI due to eclipsing and rigidity issues.

Despite their limitations, WQIs remain widely used as they provide a convenient and standardized method for reporting water quality status. They serve as effective tools for assessing the overall state of water resources and identifying trends over time. The choice of index should be guided by the specific objectives of the study, as highlighted by Mladenovic-Ranisavljevic and Zerajic (2017) and Guellaf et al. (2021). Consequently, adapting the CCME-WQI methodology to the Mediterranean context and establishing its legal framework is now a critical step. Such efforts would support water quality assessment programs, enhance monitoring and protection initiatives, and facilitate the implementation of effective water resource management strategies

CONCLUSIONS

According to this study, the results of the water quality assessment indicate the following:

- the evaluation of physicochemical indicators and fecal coliform levels revealed significant seasonal and spatial variations among the rivers within the study area;
- among the models applied, the CCME-WQI proved to be the most stringent, categorizing the water quality of the studied rivers as poor quality;
- the six downstream stations of rivers located between Casablanca and Rabat exhibited the highest concentrations of mineral, bacterial, and organic pollutants, particularly during the dry season.

By examining the fluctuations in water quality in the lower sections of these impacted rivers, this research, supplemented by additional water monitoring data, provides valuable insights into the dominant pollution pressures. It also aims to identify effective solutions for improving water quality, particularly as this region has long been shaped by the development of industrial, urban, and agricultural activities. Furthermore, it is crucial to consider the preservation and restoration of fluvial habitats in the planning and implementation of future projects.

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