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Investigation of the Water Quality in Oum Er Rbia River (Morocco): A Multifaceted Analysis of Physicochemical, Undesirable Substances, Toxic Compounds, and Bacteriological Traits

Hicham Ouhakki[1]*, *Kamal Elfallah*[2], Atman Adiba[3], Taouil Hamid[1], *Nouredine Elmejdoub*[1]

[1]*Laboratory: Organic chemistry, catalysis and environment, Department of Chemistry, Faculty of Science, University Ibn Toufail BP 133-14000, Kenitra, Morocco*
[2]*Laboratory of Natural Resources and Sustainable Development, Department of Biology, Faculty of Science, University Ibn Toufail, BP 133-14000, Kenitra, Morocco*
[3]*Regional Agricultural Research Center of Meknes, National Institute of Agricultural Research, Avenue Ennasr, P.O. Box 415, 10090, Rabat, Morocco*

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ABSTRACT

Consecutive years of droughts and increasing human pressure heighten the vulnerability of Oum Er Rbia water to pollution. This study presents a comprehensive evaluation of water quality in the Oum Er Rbia River, employing a multifaceted approach encompassing physicochemical parameters, undesirable substances, toxic compounds, and bacteriological traits. In this study, 26 physicochemical and 3 biological parameters (SF, CF, CT) were analyzed along the Oum Er Rbia River at 10 different stations during the seasons of the years 2020 to 2022. The analysis assessed the water samples against Moroccan drinking water standards and the recommended values set by the World Health Organization (WHO) to evaluate their conformity. A comprehensive analysis of the results revealed notable deviations from the stipulated standards at certain stations, indicating potential concerns regarding the suitability of drinking water. The findings revealed a significant variation in the concentrations of all traits among the analyzed stations and years. Analysis of the second-year data showed the highest concentration of physicochemical traits. Thus, the bacteriological analyses induced contamination of all experimental stations by total coliforms, faecal coliforms, and faecal streptococci. Furthermore, the data multivariate analyses highlighted three distinctive groups among the studied stations in terms of the polluting substances and found that the most contaminated station was S9, followed by S7. These findings inform environmental monitoring programs and water resources management in the Oum Er Rbia basin. The multi-faceted assessment guides interventions to preserve the river's ecological integrity and safeguard the health of dependent communities.

Keywords: Oum Er Rbia River, water quality, physicochemical traits, bacteriological analysis.

Introduction

On the surface of our planet, water encompasses more than 70% of the Earth's expanse, manifesting in the vast reservoirs of oceans, lakes, rivers, glaciers, ice caps, and concealed depths of groundwater.[1] This abundant resource, which is essential for sustaining life, has played a pivotal role in the development and flourishing of civilizations throughout history.[2] However, the escalating demand for water resources worldwide, driven by population growth, industrialization, and agricultural expansion, has raised concerns about the degradation of water quality.[3]
The confluence of anthropogenic activities and natural processes has significantly altered the pristine state of many water bodies, prompting global awareness of the intricate challenges associated with water quality management.[4,5] The repercussions of compromised water quality are far-reaching, impacting ecosystems, human health, and the overall well-being of the planet.[6]

***Corresponding author.** E mail: ouhakki_hic@yahoo.fr
Tel: +212614215548

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In the same way, the Lancet Commission on Pollution and Health has brought to light a sobering reality an estimated 1.8 million deaths worldwide are attributed to water contamination.[7] This revelation underscores the urgent need for comprehensive assessments of water quality to understand the multifaceted dimensions of the challenges posed by polluted water sources.
Among the many regions grappling with water quality issues, the Oum Er Rbia River in Morocco stands out as an essential focal point for scientific inquiry.[8–10] As an indispensable source of water for agricultural, industrial, and domestic purposes, the Oum Er Rbia River plays a crucial role in sustaining the livelihoods of the communities along its course.[11] However, the escalating pressures of anthropogenic activities and environmental changes on this vital waterway necessitate a thorough and multifaceted examination of its water quality.[12,13]
Several studies have revealed that some natural processes, such as weathering, precipitation, and soil erosion, play a pivotal role in shaping the quality of Oum Er Rbia River water.[10] Weathering of rocks contributes minerals and ions to water bodies, influencing their chemical composition.[14] Precipitation can alter the balance of nutrients and pollutants in the water, while soil erosion transports sediment and contaminants into rivers, affecting their overall quality. Understanding these natural processes is crucial for distinguishing between baseline conditions and anthropogenic impacts on water quality.[15,16]
On the other hand, the influence of human activities on the Oum Er Rbia River water cannot be understated. Anthropogenic sources, including agricultural, urban, and industrial activities, significantly contribute to the degradation of surface water quality.[17] Agricultural runoff introduces pesticides, fertilizers, and other agrochemicals into rivers, altering nutrient levels and posing threats to aquatic ecosystems.[11]

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Urban and industrial discharges release a diverse array of contaminants, including heavy metals and organic pollutants, further compromising water quality.[15,18]

The excessive use of water resources exacerbates the challenges faced by surface water bodies. Over-extraction of water for agricultural irrigation, industrial processes, and domestic consumption can lead to reduced flow, altering the dilution capacity of rivers and concentrating pollutants.[11,18] This imbalance in water availability poses a direct threat to the ecological integrity of aquatic ecosystems and underscores the importance of a comprehensive assessment to discern the multifaceted impacts on water quality.[10,19]

However, despite its significance, there is a notable knowledge gap regarding a comprehensive understanding of water quality in the Oum Er Rbia River. Previous studies have primarily focused on specific aspects of water quality, such as physicochemical parameters or bacteriological traits, leaving a fragmented understanding of the overall water quality profile. Moreover, there is limited information on the presence of undesirable substances, toxic compounds, and their potential impact on the ecosystem and public health. To address these critical gaps in knowledge, this study aimed to conduct a multifaceted analysis of the Oum Er Rbia River, encompassing physicochemical attributes, the presence of undesirable substances, the occurrence of toxic compounds, and bacteriological traits. The objective of adopting a holistic approach is to provide a comprehensive assessment of water quality, offering valuable insights for the effective management and sustainable utilization of this essential water resource.

Materials and Methods

Description of the study area

The study area, centered on the Oum Er Rbia River, encompasses a diverse range of geographic and socio-economic settings and influences water quality along its course. The Oum Er Rbia River, with a total length of 550 km, is a prominent watercourse in Morocco that supports various ecological habitats and is a vital resource for both urban and rural communities. The river traverses distinct landscapes, ranging from mountainous terrain to more arid plains, thereby exposing the watercourse to varying ecological characteristics. Notable regions along its course include Beni Mellal, Fkih Ben Salah, Khenifra, Azilal, Khouribga and Kasba Tadla, each with unique environmental attributes. Anthropogenic impacts on water quality are notable because of agricultural runoff, industrial discharge, and urban effluents. Given the vital role of rivers in supporting ecosystems and human activities, an in-depth evaluation of their water quality is imperative to comprehend the extent of environmental stressors and implement effective management strategies.

Station selection

Rriver water samples were collected from ten different stations dispersed along the Oum Er Rbia River during different seasons over a period of three years (January 2020 to December 2022) (Figure 1 and Table 1). A meticulous and multi-faceted approach was employed to select ten study stations along the Oum Er Rbia River. The primary consideration was to ensure a representative geographic distribution that covered diverse ecological characteristics, including mountainous terrain, plains, and transitional zones. The chosen stations were strategically situated to capture variations in land use practices encompassing agricultural, industrial, and urban areas, thus allowing us to assess the impact of different human activities on water quality.

Sampling procedures

Sampling from the ten designated stations along the Oum Er Rbia River was conducted with precision to ensure an accurate assessment of physicochemical and biological variables. At each station, water samples were collected approximately 30 cm below the surface using dedicated polyethylene bottles with a capacity of 1.5 liters. This specific depth was chosen to capture the representative water conditions and characteristics. The samples were promptly stored under refrigerated conditions at approximately ±4 °C within isothermal boxes to maintain their integrity during transportation to the laboratory. The temperature control was aimed at preserving the chemical and biological composition of the water samples, preventing any potential alterations that might occur at higher temperatures.

Determination of physicochemical traits

The study of the physicochemical properties of the Oum Er Rbia River was based on the investigation of a multitude of traits, including: temperature (T: Recorded in situ at the time of sample collection using a calibrated thermometer, pH (measured using INOLAB pH7110 meter), electrical conductivity (EC: determined using a conductivity meter), chlorides content (Cl^-: assessed by titration with silver nitrate), sulphates concentration (SO_4^{2-}: quantified using the Nephelometric method), turbidity (NTU: measured using a HACH 2100N turbidimeter), dissolved oxygen (DO: Measured using iodometric method), biological oxygen demand (BOD_5: BOD meter), chemical oxygen demand (COD: COD meter).

Determination of the undesirable substances

The undesirable substances such as nitrate (NO_3^-: quantified using the sulphanilamide method), Kjeldahl nitrogen (NTK: determined by mineralization with the sulfuric acid), ammonia (NH_4^+: measured using the ndophenol blue method), phosphate (PO_4^{3-}: determined using the APHA 4500-P C method), and the total phosphorus content (PT) in water samples was determined using the molybdenum blue method.[20]

The determination of calcium (Ca^{2+}) and magnesium (Mg^{2+}) concentration in all samplings was quantified through the volumetric titrimetry method.[21] However, the water sodium (Na^+) and potassium (K^+) content was measured using BWB flame photometer. On the other hand, the Nitrite (NO_2^-) was estimated using the spectrophotometry method and chloride (Cl^-) was analyzed using the titration by silver nitrate. In the assessment of physicochemical traits, we conducted measurements with six repetitions to ensure robust and reliable data for accurate analysis.

Determination of hydrotimetric titre, complete alkalimetric titre and alkalimetric titre

The following method is used to determine the hydrotimetric titre (HT), complete alkalimetric titre (TAC), and alkalimetric titre (TA):

TH: The hydrotimetric titre corresponds to 10 ppm of limestone representing 10^{-4} mol/L of calcium, or 4 mg/L of Ca^{2+}, or 2.4 mg of magnesium per liter of water:

$$TH = 10 ([Ca^{2+}] + [Mg^{2+}]).$$

TA: The alkalimetric title analysis was carried out in the presence of phenolphthalein, which turned from colorless to pink-fuchsia at a pH of 8.2.

1 °f = 3.4 mg/l of hydroxide ion OH^- = 6.0 mg/l of carbonate ion CO_3^{2-}.

TAC: The total alkalimetric titre is the quantity used to measure the level of hydroxide ions, carbonates and bicarbonates in water.

$$TAC = [OH^-] + [CO_3^{2-}] + [HCO_3^{2-}]$$

Each analysis was done in triplicate and the mean value was taken.

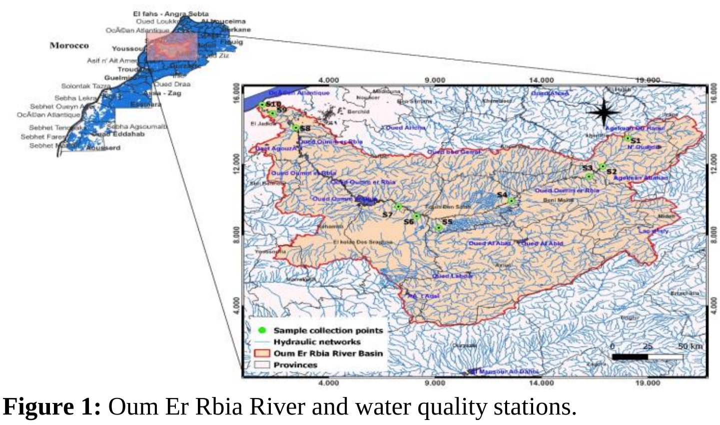

Figure 1: Oum Er Rbia River and water quality stations.

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Table 1: Geographic and environmental characteristics of sampled locations

Code	Station	Temperature (°C)	Latitude	Longitude
S1	Taghat	16.55	47°62'20"	26°69'40"
S2	Aval El hanssali	18.78	45°27'50"	80°30'47"
S3	Mechraa Ed Dahk	18.86	39°49'62"	20°47'44"
S4	Ouaouirinth	19.65	34°61'54"	17°26'18"
S5	Ouled Sidi Driss	19.86	32°88'15"	19°79'58"
S6	Av Cft Tassaout	20.76	32°71'50"	19°82'70"
S7	Am Confooer	20.04	46°75'20"	24°33'49"
S8	Amt Bge Maachou	22.3	24°79'19"	28°45'65"
S9	Aval rejet Azemmour	20.1	56°13'44"	36°84'48"
S10	Sidi Daoui	24.32	56°60'71"	36°80'94"

Bacteriological quality

The faecal coliforms (FC), total coliforms (TC) and faecal streptococci (FS) were enumerated using the Most Probable Number (MPN) method, with the double tube technique.[22] A three-tube MPN series with five dilutions per tube was prepared for each sample. Indeed, a presumptive test was conducted by inoculating tubes with a predetermined volume of water sample and incubating at 37 °C for 24 hours. Thus, a confirmed test was performed on tubes showing gas production in the presumptive phase. Furthermore, a completed test involved additional confirmation through biochemical testing and enumeration using standard MPN tables.

Statistical analysis

Using SPSS v22, an Analysis of Variance (ANOVA) was performed to investigate significant differences between the experimental stations. This statistical method allowed for a comprehensive examination of the variations in physicochemical traits, undesirable substances, toxic compounds, and bacteriological traits across different monitoring stations. A Student-Newman and Keuls test (SNK) was conducted to compare trait means among all the analyzed traits.

Results and discussion

Physicochemical traits

The variation in the physicochemical traits for different sampling points (S1 to S9) along the Oum Er Rbia River in Morocco during the 2020-2022 seasons is presented in Table 2. The results showed a significant variation between the analyzed traits at the nine tested stations. Indeed, the results indicate that the water temperature ranges from 16.55 °C at the S1 station to 26.03 °C at the S10 station across different sampling points and years, with higher temperatures observed in the later year (2022) compared to 2020. For the pH, the results revealed the values range from 8.11 to 8.65 (2020) and 7.86 to 8.74 (2022). The highest pH value was detected in S7, whereas the lowest was observed in S9. For electrical conductivity, which is a measure of the ability of water to conduct an electric current and is often related to the presence of dissolved ions, the results reported that the values during the 2022 season were higher than those revealed during the 2020 season. Furthermore, the lowest value of this parameter was observed at S4 with an average value of 1076.7 µs.cm^{-1} during both seasons. As reported in Table 2, a significant variation between sampling points and years was observed for chloride concentration. The highest Cl^- concentration during the first experimental year was observed at S7 station (1864.7 mg/L), whereas the highest Cl^- concentration during the second experimental season was detected at S9 station (13943.83 mg/L). The water sulfate (SO_4^{2-}) content ranged from 901.3 to 5548.6 mg/L across different sampling points and years. Thus, the data analyzed revealed that the S9 experimental station has the highest sulfate concentration with a value of 2280.5 mg/L during the 2020 season and 1809.16 mg/L in 2022. The lowest SO_4^{2-} concentration was observed at S1 station with an average of 65.97 mg/L during both experimental seasons. Turbidity (NTU) is a representation of the cloudiness or haziness of the fluid caused by individual particles. The results showed that the turbidity values range from 3.7 NTU (S2 station) to 258.8 NTU (S5 station) during 2020 and from 4.8 NTU (S2 station) to 192.8 NTU (S6 station) during the 2022 season. The findings also revealed that the dissolved oxygen (DO) concentration ranged from 7.8 to 24.6 mg/L (2020) and from 4.9 to 12.2 mg/L (2022). Similarly, the highest DO values were observed at S6 and S7 in 2020 and 2022, respectively. On the other hand, the results indicated that S9 station was characterized by the highest DBO_5 value during 2020 (47.1) and 2022 (28.17), while the lowest value was observed at S8 station during the 2020 season, with an average of 0.87, and in S1 station during the 2022 season, with an average of 0.7. For the DCO, statistical analyses revealed a significant variation between all analyzed stations and the values varied between 12.5 and 275.8. The S4 station was characterized by the lowest value of DCO, with an average of 12.7, at both experimental stations. The obtained results regarding the physico-chemical quality of the water at the stations studied corroborate those found by Moustaine *et al.*[23] in the Meknes region. who revealed an increase in the physico-chemical quality of the water at the stations observed, temperature (T) varies from 16.2 to 18.1 °C, pH varies from 6.8 to 7.21, 507 to 13840 µs/cm (EC), 3.43 to 187.26 mg/L (SO_4^{2-}), 10 to 40 mg/L (COD). In the same way, Methal *et al.*[24] revealed poor groundwater quality based on physico-chemical analyses in certain wells located near the Nador canal and the Esbou River. It should be noted that the majority of parameter values exceed the limits recommended by the World Health Organization (WHO) for safe consumption. The results of Karim *et al.*[25] on water in the Gharb plain showed that the physico-chemical characterization of water in rice fields varies according to the station and weather conditions. However, the physico-chemical parameter values recorded did not exceed the Moroccan normative values for irrigation water. The deterioration in water quality from upstream to downstream of the stations is thought to be mainly linked to discharges of urban and industrial wastewater and/or the impact of agricultural activities and a significant anthropogenic mineral and organic load from neighboring urban municipalities.[26,27]

Undesirable substances

The variation of the concentration of the various undesirable substances in the different sampling points (S1 to S10) along the Oum Er Rbia River in Morocco is presented in Table 3. The traits include concentrations of nitrate (NO^{3-}), total nitrogen (NTK), ammonium (NH_4^+), phosphate (PO_4^{3-}), and total phosphorus (Pt) for the years 2020 and 2022. The concentrations of all analyzed parameters vary across the experimental stations. The finding induced that the S5 station is characterized by the highest value of nitrate with an average of 5.56 mg/L (2020) and 7.05 mg/L (2022), however, the lowest value of this trait is reported in the S10 station with an average of 0.44 mg/L. Thus, the total nitrogen levels (NTK) also vary across the experimental sites and years. The experimental stations S2, S4, S5, S6, S7, and S9 show a significant increase in total nitrogen concentration from 2020 to 2022.

Table 2: Physicochemical traits of Oum Er Rbia River during 2020-2022 seasons

Parameter	**T**		**pH**		**EC**		**Cl^-**		**SO_4^{2-}**		**NTU**		**DO**		**DBO_5**		**DCO**	
Season	2020	2022	2020	2022	2020	2022	2020	2022	2020	2022	2020	2022	2020	2022	2020	2022	2020	2022
S1	16.5^{a}	16.8^{a}	8.3^{d}	8.4^{d}	2554^{b}	3016.6^{b}	757.1^{ab}	832.1^{b}	67.6^{a}	64.3^{a}	14.1^{ab}	12.7^{ab}	8.8^{a}	9.0^{ab}	0.79^{a}	0.7^{a}	14.5^{ab}	18.0^{a}
S2	18.8^{ab}	20.8^{ab}	8.26^{bc}	8.62^{bcd}	2616.6^{b}	3406.6^{b}	750.3^{ab}	994.5^{b}	85.6^{ab}	88.4^{a}	3.7^{a}	4.8^{a}	8.7^{a}	11.3^{b}	1.06^{ab}	1^{a}	15.8^{ab}	21.7^{ab}
S3	18.8^{ab}	23.5^{ab}	8.24^{ab}	8.74^{e}	2275.5^{b}	3546.6^{b}	666.5^{ab}	1137.6^{bc}	83.8^{ab}	88.2^{a}	67.3^{bc}	96.5cd	8.6^{a}	9.7^{ab}	1.67^{ab}	3.8^{b}	18.35^{b}	33.6^{b}
S4	19.5^{ab}	20.8^{ab}	8.29^{a}	8.23^{bc}	901.3^{a}	1252.1^{a}	165.5^{a}	227.5^{a}	81.3^{ab}	100.8^{ab}	129.6^{c}	102.2cd	8.5^{a}	8.1^{ab}	0.83^{a}	0.94^{a}	12.5^{a}	12.9^{a}
S5	19.8^{ab}	21.4^{ab}	8.3^{d}	8.2^{abc}	1828.6^{ab}	2573.6^{ab}	500.8^{ab}	582.1^{ab}	86.6^{ab}	93.8^{a}	258.8^{cd}	188.1^{d}	8.2^{a}	7.9^{ab}	2.38^{bc}	1.53^{ab}	18.7^{b}	19.4^{a}
S6	20.7^{b}	20.6^{ab}	8.3^{d}	8.28^{bcd}	1776.8^{ab}	2370.6^{ab}	481^{ab}	607.3^{ab}	85.0^{ab}	101.3^{ab}	158.1^{c}	192.8^{d}	24.6^{ab}	8.2^{ab}	3.08^{bc}	1.74^{ab}	20.9^{bc}	17.5^{a}
S7	20.0^{b}	21.5^{ab}	8.56^{f}	8.56^{de}	5548.6^{c}	9836.6^{bc}	1864.7^{b}	3276.8^{c}	205.8^{bc}	263.5^{b}	28.8^{b}	97.5c^{d}	9.8^{a}	12.2^{b}	1.55^{ab}	7.18^{bc}	25.5^{bc}	88.7^{bc}
S8	22.3^{bc}	20.7^{ab}	8.23^{ab}	8.15^{ab}	1866.3^{ab}	2526.6^{ab}	515.1^{ab}	674.3^{ab}	111.8^{b}	125.5^{ab}	16.1^{ab}	16.7^{ab}	8.2^{a}	8.1^{ab}	0.78^{a}	0.77^{a}	15.8^{ab}	19.4^{a}
S9	20.1^{b}	22.3^{ab}	8.11^{a}	7.86^{a}	3685^{bc}	35333.3^{c}	142.3^{a}	13943.8^{cd}	2280.5^{c}	1809.1^{c}	73.8^{bc}	55.8c	7.8^{a}	4.9^{a}	47.1^{c}	28.17^{c}	14.8^{c}	274.8^{c}
S10	26.0^{c}	22.9^{ab}	8.4^{e}	8.32^{bcd}	2401.6^{b}	2576.6^{ab}	667.6^{ab}	730.6^{ab}	155.6^{b}	146.5^{ab}	21.6^{b}	23.5^{bc}	7.8^{a}	8.6^{ab}	1.21^{ab}	1.03^{a}	18.0^{b}	16.0^{a}

Means indicated by different letters are significantly different ($P \leq 0.05$), according to SNK test.
T: Temperature; EC: Electrical conductivity; Cl^-: Chlorides; SO_4^{2-}: Sulfates; NTU: Turbidity; DO: Dissolved Oxygen; BOD_5: 5 day biochemical oxygen demand; COD: Chemical oxygen demand.

Table 3: Undesirable substances concentration of Oum Er Rbia River during 2020-2022 seasons

Parameter	**NO^{3-}**		**NTK**		**NH_4^+**		**PO^{3-}**		**Pt**	
Season	2020	2022	2020	2022	2020	2022	2020	2022	2020	2022
S1	1.34 ± 0.035^{ab}	3.93 ± 0.856^{c}	0.35 ± 0.031^{a}	0.34 ± 0.026^{a}	0.20 ± 0.011^{ab}	0.06 ± 0.023^{bc}	0.02 ± 0.012^{a}	0.02 ± 0.003^{a}	0.07 ± 0.004^{a}	0.9 ± 0.011^{ab}
S2	4.94 ± 0.823^{bc}	5.02 ± 0.726^{cd}	0.26 ± 0.042^{a}	0.25 ± 0.003^{a}	0.05 ± 0.004^{a}	0.12 ± 0.008^{ab}	0.02 ± 0.005^{a}	0.02 ± 0.005^{a}	0.05 ± 0.006^{a}	0.05 ± 0.003^{a}
S3	1.21 ± 0.029^{ab}	2.31 ± 0.434^{b}	0.39 ± 0.065^{a}	0.37 ± 0.005^{a}	0.24 ± 0.002^{ab}	0.07 ± 0.006^{a}	0.02 ± 0.006^{a}	0.01 ± 0.004^{a}	0.05 ± 0.006^{a}	0.06 ± 0.004^{a}
S4	5.56 ± 0.045^{c}	7.07 ± 1.704^{e}	0.28 ± 0.012^{a}	0.41 ± 0.010^{a}	0.24 ± 0.002^{ab}	0.08 ± 0.007^{a}	0.02 ± 0.005^{a}	0.02 ± 0.006^{a}	0.09 ± 0.006^{a}	0.08 ± 0.004^{a}
S5	5.32 ± 0.857^{c}	5.3 ± 1.145^{cd}	0.54 ± 0.108^{a}	0.64 ± 0.031^{ab}	0.07 ± 0.000^{a}	0.06 ± 0.006^{a}	0.03 ± 0.007^{ab}	0.02 ± 0.007^{a}	0.22 ± 0.005^{b}	0.13 ± 0.002^{ab}
S6	5.21 ± 0.736^{c}	4.44 ± 0.983^{c}	1.27 ± 0.316^{ab}	0.57 ± 0.004^{ab}	0.09 ± 0.001^{a}	0.05 ± 0.004^{a}	0.02 ± 0.004^{a}	0.02 ± 0.006^{a}	0.24 ± 0.005^{b}	2.94 ± 0.012^{c}
S7	1.3 ± 0.048^{ab}	0.67 ± 0.064^{a}	0.56 ± 0.058^{a}	1.18 ± 0.056^{b}	0.18 ± 0.008^{ab}	0.57 ± 0.013^{bc}	0.02 ± 0.005^{a}	0.09 ± 0.010^{ab}	0.13 ± 0.008^{ab}	0.21 ± 0.000^{b}
S8	1.65 ± 0.072^{ab}	0.83 ± 0.086^{a}	0.36 ± 0.034^{a}	0.33 ± 0.032^{a}	0.03 ± 0.005^{a}	0.03 ± 0.005^{a}	0.02 ± 0.004^{a}	0.02 ± 0.003^{a}	0.08 ± 0.004^{a}	0.05 ± 0.001^{a}
S9	0.56 ± 0.045^{a}	4.16 ± 0.232^{c}	10.5 ± 2.231^{b}	13.22 ± 2.324^{c}	4.36 ± 0.156^{c}	5.37 ± 0.745^{d}	0.54 ± 0.008^{b}	0.57 ± 0.030^{c}	1.2 ± 0.005^{c}	1.42 ± 0.021^{bc}
S10	0.31 ± 0.047^{a}	0.57 ± 0.032^{a}	0.5 ± 0.049^{a}	0.45 ± 0.036^{a}	0.03 ± 0.000^{a}	0.04 ± 0.03^{a}	0.02 ± 0.005^{a}	0.02 ± 0.005^{a}	0.05 ± 0.002^{a}	0.05 ± 0.003^{a}

Means indicated by different letters are significantly different ($P \leq 0.05$), according to SNK test.

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Similar to nitrate and total nitrogen levels, the concentrations of ammonium (NH_4^+) vary across the experimental sites. Indeed, the S9 station has the highest concentration, while S8 and S10 have the lowest. The results revealed also that the S9 station had the highest phosphorus concentration during both experimental stations, while the S2 and S3 have relatively lower concentrations. On the other hand, platinum concentrations exhibit significant variation, with extremely high values observed in S6 and S9. Other sites generally have lower platinum concentrations. The results concerning the presence of undesirable substances in the water at the stations studied align with findings reported by Moustaine *et al.*[23] in the Meknes region. Who revealed fairly high levels of undesirable substances in the water at the stations observed, ranging from 1.13 to 37.49 mg/L (NO_3^-), 0.024 to 1.90 mg/L (NH_4^+) and 0.002 to 0.32 mg/L (PO_4^{3-}). The stations are highly polluted due to very high concentrations of nitrates and ammonium, which exceed Moroccan drinking water standards and may be mainly of anthropogenic origin, with agricultural activities leaching fertilizer-rich soil and discharges of urban and industrial wastewater.[28] This environmental degradation of water quality in urban areas is due to the relatively high concentrations of ammonium, nitrates and BOD_5, which exceed the Moroccan drinking water standards of 0.5 for ammonium, 50 mg/l for nitrates and 5 mg/l for BOD_5. The deterioration in water quality at the stations is thought to be due to agricultural activities and discharges of urban wastewater from municipalities located along the river. Similar causes of pollution have been observed along the lower Sebou valley in Morocco[26] and along the lower Oueme valley in Benin.[29]

Mineral molecules

Significant differences in minerals were observed between the stations studied (Table 4). The concentration of sodium ion (Na^+) at the stations varied from 99.2 to 760.06 mL/L during the two years of the study. The lowest sodium ion concentration was recorded by station S4, with mean values of 99.2 mL/L (2020) and 134 mL/L (2022) respectively. The highest values were obtained by stations S7 and S9 with mean values of 1138 mL/L (2020) and 760.06 mL/L (2022), respectively. Potassium ion (K^+) values at the stations ranged from 2.51 mL/L to 315 mL/L. The highest concentration was recorded by station S9 with mean values of 315 mL/L and 26.21 mL/L, respectively, during the two years of the study. However, station S4 recorded the lowest concentration, with mean values ranging from 2.51 mL/L (2020) and 3.06 mL/L (2021). In terms of calcium ion concentration (Ca^{2+}), mean values ranged from 59.58 mL/L to 302.66 mL/L. Station S9 has the highest concentrations, with mean values of 157.02 mL/L and 302.66 mL/L in 2020 and 2021 respectively. Stations S3 and S10 recorded the highest concentrations, with average values of low 59.58 mL/L (2020) and 62.43 mL/L (2022), respectively. Regarding Mg^{2+} concentration, the highest value was recorded by station S9 where the average was 101.6 mL/L and 91.11 mL/L, in 2020 and 2022 respectively, while stations S1 and S4 recorded the lowest values with averages of 34.08 mL/L (2020) and 35.26 mL/L (2022). The concentration of chloride ion (Cl^-) varied between 165.5 mL/L and 1394.38 mL/L. The highest concentrations were recorded at station S9, with mean values of 1427.3 (2020) and 1394.38 mL/L (2022), respectively. The lowest values were observed at station S4, where the overall averages were 165.5 mL/L (2020) and 227.5 mL/L (2022), respectively. Nitrite ion (NO_2^-) ranged from a concentration of 0.01 mL/L at station S9 in both 2020 and 2021 to 0.94 mL/L (2020) and 2.23 mL/L (2022) at stations S2 and S3, respectively. The results regarding the mineral concentration of water at the studied stations align with findings in the Meknes region, which revealed a fairly high mineralization of the water at the analyzed stations: 335 mg/L (Ca^{2+}), 187.5 mg/L (Mg^{2+}), 4082.5 mg/L (Cl^-) and 0.523 (NO_2^-).[24] These stations are generally hard and saline, and the water at stations close to a source of local pollution is often of mediocre quality.

Bicarbonate, carbonate and sulphate ions

Significant differences in bicarbonate and sulphate ion concentrations were observed between the studied stations (Table 5). The highest value of bicarbonate ions (HCO_3^-) was recorded by station S9 where the average was 131.5 mL/L and 161.45 mL/L, respectively during 2020 and 2022, while stations S1 and S10 recorded the highest values with averages of 274 mL/L (2020) and 288 mL/L (2022). Stations S4 and S6 recorded the lowest values for the concentration of carbonate ions (CO_3^{2-}), with overall averages of 2.2 mL/L (2022) and 2 mL/L (2020), respectively, while the highest values were observed at stations S9 and S2 with mean values of 18 mL/L (2020) and 18.6 mL/L (2022). Stations S1 and S10 recorded the lowest values of sulfate ions (SO_4^{2-}), averaging from 64.35 mL/L to 67.6 mL/L (2020) (2022). The highest values were observed at station S9 with mean values of 2280.5 mL/L (2020) and 1809.16 mL/L (2022), respectively. The results regarding the presence of bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), and sulfate (SO_4^{2-}) ions in water are in agreement with those reported by EL Moustaine *et al.*[23] who observed that the concentrations of these ions are quite common and can be used in water quality investigations. These ions are natural components of water and originate from various geological, biological and anthropogenic sources. Bicarbonates can influence the pH of water. They are generally responsible for the temporary hardness of water, while carbonate ions, present in calcium and magnesium, can form solid precipitates, contributing to the scaling of pipes and household appliances.[30] Knowledge of the ionic composition of water is important for assessing its quality and suitability for different uses, such as drinking water supply, irrigation or industrial use. High concentrations of certain ions may require water treatment to meet quality standards and prevent problems such as scaling of equipment or deterioration in drinking water quality.

Table 4: Concentration of minerals of Oum Er Rbia River during 2020-2022 seasons

Parameter	**Na^+**		**K^+**		**Ca^{2+}**		**Mg^{2+}**		**Cl^-**		**NO_2^-**	
Season	2020	2022	2020	2022	2020	2022	2020	2022	2020	2022	2020	2022
S1	466.33^{bc}	529.33^{bc}	2.86^{a}	3.42^{a}	72.65^{ab}	80.86^{a}	35.31^{a}	35.26^{a}	757.16^{ab}	832.16^{b}	0.02^{a}	0.02^{a}
S2	461^{bc}	617.16^{bc}	3.69^{ab}	4.52^{a}	68.41^{ab}	73.81^{a}	38.01^{a}	40.7^{ab}	750.33^{ab}	994.5^{b}	0.94^{b}	0.15^{ab}
S3	391.83^{b}	605^{bc}	3.83^{ab}	5.73^{a}	59.58^{a}	72.13^{a}	45.16^{ab}	47.4^{ab}	666.5^{ab}	1137.66^{bc}	0.11^{ab}	2.23^{bc}
S4	99.2^{a}	134^{a}	2.51^{a}	3.06^{a}	63.28^{ab}	81.53^{a}	34.08^{a}	37.06^{a}	165.5^{a}	227.5^{a}	0.03^{a}	0.05^{a}
S5	294.16^{ab}	352.71^{ab}	3.56^{ab}	4.39^{a}	66.75^{ab}	77.01^{a}	41.85^{ab}	40.98^{ab}	500.83^{ab}	582.16^{ab}	0.05^{a}	0.07^{a}
S6	283.83^{ab}	367.38^{ab}	3.53^{ab}	4.15^{a}	67.78^{ab}	75.41^{a}	42.01^{ab}	39.03^{a}	481^{ab}	607.33^{ab}	0.04^{a}	0.04^{a}
S7	1138^{c}	1883^{c}	8.25^{b}	14.85^{b}	98.9^{b}	164.16^{ab}	71.76^{b}	211.9^{c}	1864.7^{b}	3276.83^{c}	0.1^{ab}	0.24^{b}
S8	286^{ab}	401.66^{ab}	4.03^{ab}	5.19^{ab}	65.46^{ab}	68.76^{a}	49.71^{ab}	54.76^{ab}	515.16^{ab}	674.33^{ab}	0.02^{a}	0.02^{a}
S9	814.1^{cd}	760.06^{cd}	315^{bc}	26.21^{c}	157.01^{c}	302.66^{c}	101.6^{c}	91.11^{d}	1427.3^{c}	1394.38^{cd}	0.07^{a}	0.16^{ab}
S10	395.33^{b}	434^{ab}	5.17^{b}	5.505^{ab}	62.9^{ab}	62.43^{a}	62.01^{b}	65.78^{b}	667.66^{ab}	730.66^{ab}	0.01^{a}	0.01^{a}

Means indicated by different letters are significantly different ($P \leq 0.05$), according to SNK test.

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Table 5: Concentration of bicarbonate, carbonate and sulphate ions of Oum Er Rbia River during 2020-2022 seasons

Parameter	**HCO^{3-}**		**CO_3^{2-}**		**SO_4^{2-}**	
Season	**2020**	**2022**	**2020**	**2022**	**2020**	**2022**
S1	274^{bc}	288.66^{ab}	3.8^{a}	2.2^{a}	67.6^{a}	64.35^{a}
S2	238.3^{ab}	185.26^{a}	0	18.6^{b}	85.63^{ab}	88.4^{a}
S3	223.8^{ab}	200.75^{ab}	4^{a}	9.4^{ab}	83.85^{ab}	88.28^{a}
S4	230.2^{ab}	255^{ab}	4^{a}	2.2^{a}	81.31^{ab}	100.8^{ab}
S5	232^{ab}	228.83^{ab}	3.4^{a}	3.2^{a}	86.68^{ab}	93.86^{a}
S6	234.3^{ab}	217.16^{ab}	2^{a}	4.8^{a}	85.06^{ab}	101.36^{ab}
S7	210.7^{ab}	211.66^{ab}	8^{b}	10.4^{ab}	205.83^{bc}	263.55^{b}
S8	215.2^{ab}	209.5^{ab}	0	3.2^{a}	111.83^{b}	125.5^{ab}
S9	131.5^{a}	161.45^{a}	18^{bc}	4.8^{a}	2280.5^{c}	1809.16^{c}
S9	174.5^{a}	175^{a}	4^{a}	8.5^{ab}	155.66^{b}	146.5^{ab}
S10	274^{bc}	288.66^{ab}	3.8^{a}	2.2^{a}	67.6^{a}	64.35^{a}

Means indicated by different letters are significantly different ($P \leq 0.05$), according to SNK test.

Hydrotimetric titre (TH), total alkalinity (TA) and total alkalimetric titre (TAC)

Significant differences in the hydrotimetric titre (TH), total alkalinity (TA) and total alkalimetric titre (TAC) of the water were observed between the stations studied (Table 6). Stations S1 and S10 recorded the lowest values for hydrotimetric titre (TH) with overall averages of 32.65 and 34.66 mg/L, respectively, while the highest values were observed at station S9 with overall averages of 499.5 and 450.33 mg/L, respectively. Regarding total alkalinity (TA), the highest values were recorded at the two stations S2 and S9 with overall averages of 1.55 mg/L (2022) and 1.5 mg/L (2020) respectively, while in 2020 station S6 recorded the lowest value with an average of 0.16 and 0.18 at stations S1, S4 and S10. Total alkalinity titre (TAC) recorded the lowest values at stations S9 and S10 with overall averages of 14.01 mg/L (2022) and 16.36 mg/L (2020), while the highest values were observed at stations S4 and S9 with average values of 21.26 mg/L (2022) and 22492 mg/L (2020), respectively. The obtained results about TH, TA and TAC of the water from the studied stations corroborate those found by EL Moustaine *et al.*[23] in the Meknes region who revealed an increase in these parameters of the water from the stations observed 7.5 to 52.25 mg/L (TH), 13 to 28.75 mg/L (TAC).

Bacteriological quality

Significant differences in the number of germs/100ml in the water were observed between the stations studied (Table 7). The number of germs at the stations varied from 276.33 to 638833.3 for total coliforms (CT), from 65 to 9574.33 for faecal coliforms (FC) and from 21.66 to 18563.33 for faecal streptococci (SF). The two stations S10 and S3 recorded the lowest germ counts for total coliforms (CT), with overall averages of 218.33 (2020) and 276.33 (2022), respectively, however the highest number of germs was observed at stations S8 and S9, with mean values of 638833 (2020) and 157650 (2022) respectively. Similarly for faecal coliforms (CF), the highest number of germs was observed at stations S7 and S8 with mean values of 9574.33 (2022) and 54850 (2020), while the lowest number of germs was recorded at stations S3 and S10 with values of 86 (2022) and 65 (2020). Station S9 showed the highest number of faecal streptococci (SF) with overall averages of 2500 (2020) and 18563.33 (2022), respectively. However, the lowest germ counts were observed at stations S3 and S10 with mean values of 44.66 (2022) and 21.66 (2020), respectively. The obtained results regarding bacteriological quality are in agreement with those found in the Meknes region.[23] and in the Marrakech region[31] revealed that the CT, FC and FS varied from 5 to 3840, 0 to 1320 and 15 to 8660 germs/100 m. In the stations studied and mentioned that the bacteriological quality of the water in the stations surveyed highlights contamination by neighbouring pollution (public rubbish dump, sewage spreading, cattle rearing, existence of septic tanks). In addition, the water in the study area is highly polluted in terms of faecal contamination. From a bacteriological point of view, the stations surveyed also enabled us to conclude that bacteriological contamination of the water studied is almost general. This contamination may be the result of the presence of livestock and domestic animals that have free access to the watercourse, as well as the use of animal feces as fertilizer in the cultivated areas along the river and the contribution of streptococci from the upper zones.[30]

Correlation analysis

To better understand the relationship between all the measured traits of the stations studied, the mean values of all the variables studied were involved in a bivariate correlation using Pearson's coefficient. Potential and significant correlations at the 0.05 or 0.01 levels are summarized in Table 8 electrical conductivity is positively correlated with BOD_5, COD, NTK, K^+ and TH with highly significant correlation coefficients 0.991, 0.998, 0.990, 0.990 and 0.995, respectively. Similarly, NTU is positively correlated with TSS, with a highly significant correlation coefficient of 0.882. BOD_5 is positively correlated with Mg_2^+ and SO_4^{2-} with highly significant correlation coefficients of 0.996 and 0.991, respectively. This correlation could be because certain microbial activities, including the decomposition of organic matter, may release sulfate ions into the water, influencing both BOD_5 and sulfate concentrations positively.[31] DCO is positively correlated with Na^+, Ca^{2+} and TAC with highly significant correlation coefficients 0.998, 0.997 and 0.989, respectively. NTK is also positively correlated with Cl^- and PO_{43} with highly significant correlation coefficients 0.992 and 0.999, respectively. TH is positively correlated with SO_4^{2-} and PO_4^{3-} with highly significant correlation coefficients 0.997 and 0, 998, respectively. TAC is positively correlated with SO_4^{2-} and PO_4^{3-} with highly significant correlation coefficients 0.992 and 0.997, respectively. DO is positively correlated with PT with a highly significant correlation coefficient of 0.805. TA is positively correlated with CO_3^{2-} with a highly significant correlation coefficient of 0.998. SF is positively correlated with FC with a highly significant correlation coefficient of 0.901. TC and FC are not correlated with nitrates, which is normally contradictory with the case found by Bou Saab *et al.*[31] who reported a strong positive correlation between nitrates and total germs ($P < 0.05$) and between nitrates and faecal coliforms ($P < 0.05$). Faecal coliforms have an exclusively faecal habitat and nitrate ions can also come from faecal matter by oxidation of ammonium ions.[32] Nitrate ions and faecal coliforms therefore have a common origin.[30] Correlation coefficients can provide information on the discrimination of measured parameters that are potentially important in assessing the degree of pollution at the stations studied.

Multivariate analyses

In this study, principal component analysis (PCA) was used to define the most discriminating measured parameters between the stations studied, based on the mean values of the parameters observed (Table 9). Only a principal component load greater than 0.7 was considered significant for each variable. The total variance was explained by six components. The first component explains 55.33% of the total variance. It is positively correlated with electrical conductivity (r=0.997), BOD_5 (r=0.993), COD (r=0.998), NTK (r=0.992), NH^{4+} (r=0.714), Na^+ (r=0.996), K^+ (r=0.990), Ca^{2+} (r=0.995), Mg^{2+} (r=0,996), Cl^- (r=0.997), CO_3^{2-} (r=0.709), SO_4^{2-} (r=0.993), PO_4^{3-} (r=0.989), TH (r=0.995), TA (r=0.714), TAC (r=0.986) and negatively correlated with HCO_3^- (r=0.700). The second component represents 15.2% of the total inertia and is mainly positively correlated with NTU (r=0.759), DO (r=0.804), FC (r=0.865), FS (r=0.930), MES (r=0.688) and PT (r=0.644). The third component represents 12.51% of the total inertia and is mainly positively correlated with T (r=0.681), CO_3^{2-} (r=0.608), pH (r=0.700) and negatively correlated with NO_3^- (r=-0.761). The fourth component represents 6.08% of the total inertia and is mainly positively correlated with T (r=6.088). However, it is important to note that when we consider a major component load greater than 0.7, the most discriminating parameters for station classification are: EC, BOD_5, COD, NTK, NH_4^+, Na^+, K^+, $Ca^{2+,}$ Mg^{2+} , Cl^-, CO_3^{2-}, SO_4^2, PO_4^{3-}, TH, TA, TAC, NTU, DO, FC, FS, NO_3^-. Moreover, the clustering analysis based on physicochemical parameters, undesirable substances, toxic compounds, and bacteriological traits of the 10 monitoring stations along the Oum Er Rbia River in Morocco based using the unweighted pair group (UPGMA) method has revealed distinct patterns in water quality (Figure 2). The results induced the presence of two mean clusters corresponding to two homogenous station groups. The first cluster is presented by the S7 station which emerges as a distinctive outlier, forming the first group, indicating that this location has a unique water quality profile that differentiates it from the other stations. The finding revealed that this station is characterized by the highest water temperature, pH, electrical conductivity, dissolved oxygen, chemical oxygen demand and the highest concentration of sodium. Biological analysis revealed that the highest number of faecal coliforms characterized this station. This station faces challenges arising from a combination of urbanization, land use practices, and occasional industrial discharges. The observed variations in water quality parameters at this site can be attributed to a dynamic interplay of these factors, highlighting the complex nature of anthropogenic influences on river ecosystems. Understanding these specifics is crucial for formulating effective strategies to mitigate pollution and ensure the sustainable management of water resources in the region. The second group is presented by the other nine experimental stations and subdivided into two homogeneous and distinctive subgroups. The first subgroup is presented by the S9 station, which suggests that this station has a distinct environmental context compared to the others in the vicinity.

Table 6: TH, TA and TAC of Oum Er Rbia River during 2020-2022 seasons

Parameter	**TH**		**TA**		**TAC**	
Season	**2020**	**2022**	**2020**	**2022**	**2020**	**2022**
S1	32.65^a	34.66^a	0.31^{ab}	0.18^a	23.11^{ab}	24.1^b
S2	32.75^a	35.16^a	0	1.55^{bc}	19.51^a	18.3^{ab}
S3	33.45^a	37.5^a	0.33^{ab}	0.78^{ab}	19.01^a	17.95^{ab}
S4	29.81^a	35.58^a	0.33^{ab}	0.18^a	19.53^a	21.26^b
S5	33.95^a	36.08^a	0.28^{ab}	0.26^{ab}	19.56^a	19.28^{ab}
S6	34.21^a	34.88^a	0.16^a	0.4^{ab}	19.55^a	18.6^{ab}
S7	54.21^{ab}	84.6^b	0.66^b	0.86^b	18.58^a	19.06^{ab}
S8	36.41^a	39.7^a	0	0.26^{ab}	17.61^a	17.71^a
S9	499.5^b	450.33^c	1.5^{bc}	0.4^{ab}	22492^c	14.01^a
S9	41^{ab}	41.41^{ab}	0.2^{ab}	0.7^{ab}	16.36^a	15.93^a
S10	32.65^a	34.66^a	0.31^{ab}	0.18^a	23.11^{ab}	24.1^b

Means indicated by different letters are significantly different ($P \leq 0.05$), according to SNK test.

Table 7: Bacteriological analysis of water of Oum Er Rbia River during 2020-2022 seasons

Parameter	**TC**		**FC**		**FS**	
Season	2020	2022	2020	2022	2020	2022
S1	265^{ab}	433^{ab}	234^{ab}	532^{ab}	76^{ab}	434.54^{ab}
S2	2170^{ab}	7715^{bc}	372.5^b	3097.66^c	215.83^b	589.16^b
S3	7117.33^b	276.33^a	199.66^{ab}	86^a	99.66^{ab}	44.66^a
S4	51225^c	8066.66^{bc}	4335^b	551^{ab}	1759.83^c	346.33^{ab}
S5	43355^c	36083.33^c	3903.33^b	6678.33^{cd}	633.33^{bc}	1348.33^{abc}
S6	46008.33^c	88718.33^{cd}	3170.83^b	1568.33^{bc}	704.16^{bc}	196.66^{ab}
S7	25016.66^d	34898.33^c	44521.7^c	9574.33^d	514.16^{bc}	125266^c
S8	638833.3^e	150590^d	54850^c	5993.66^{cd}	516.66^{bc}	152266^c
S9	2703.66^{ab}	3776.16^b	143.66^{ab}	944^b	184.33^b	616.33^b
S9	127000^{de}	157650^d	20350^{bc}	18130^{de}	2500^c	18563.33^c
S10	218.33^a	2075.33^{ab}	65^a	275.16^{ab}	21.66^a	73.5^a

Means indicated by different letters are significantly different ($P \leq 0.05$), according to SNK test.

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Table 8: Matrix of coefficients correlations between the analyzed traits involved in the study

	T°air	T°eau	PH	EC	NTU	DBO_5	DCO	MES	DO	NTK	PT	NH_4^+	Na^+	K^+	Ca_2^+
T	1														
pH	0.572	-0.099	1												
EC	-0.418	0.213	-0.431	1											
NTU	0.046	0.044	0.049	-0.035	1										
DBO5	-0.407	0.235	-0.495	.991**	0.017	1									
DCO	-0.404	0.233	-0.454	.998**	0.012	0.470	1								
MES	-0.148	0.120	-0.195	0.398	.882**	0.452	0.443	1							
DO	0.262	-0.125	0.419	-0.345	0.399	-0.344	-0.336	0.258	1						
NTK	-0.418	0.236	-0.518	.990**	-0.004	0.012	0.470	0.437	-0.349	1					
PT	0.027	0.084	-0.136	-0.008	0.426	0.046	0.022	0.470	.805**	0.052	1				
NH_4^+	-0.333	0.129	-0.558	.678	0.114	.702	.693	0.478	-0.411	.714	-0.078	1			
Na^+	-0.425	0.202	-0.438	0.400	-0.034	0.418	.998**	0.400	-0.345	.682	-0.005	.682	1		
K^+	-0.432	0.228	-0.531	.990**	-0.052	0.052	0.532	0.392	-0.386	0.211	0.017	.715	-.679	1	
Ca^{2+}	-0.443	0.203	-0.500	-0.531	-0.023	0.240	.997**	0.418	-0.364	-0.041	0.012	.721	-0.063	0.169	1
Mg^{2+}	-0.419	0.242	-0.496	0.228	-0.039	.996**	0.040	0.401	-0.372	-.671	0.006	.708	0.005	0.288	.685
Cl^-	-0.423	0.207	-0.444	-0.496	-0.034	0.325	-0.063	0.401	-0.348	.992**	-0.004	.685	0.024	-0.364	0.418
NO_2^-	0.512	0.014	0.519	-0.046	-0.133	-0.034	-0.037	-0.121	0.040	-0.058	-0.177	-0.142	-0.043	-0.063	-0.067
NO_3^-	-0.232	-0.434	-0.245	-0.311	0.519	-0.225	-0.271	0.432	0.110	-0.222	0.231	0.240	-0.300	-0.237	-0.240
HCO_3^-	-0.288	-.748	0.129	-.679	0.218	-.671	-.677	-0.063	0.235	-.670	0.005	-0.300	-.671	-.671	-.653
$C\ O_3^{2-}$	0.102	0.211	0.270	.711	-0.113	.652	.688	0.169	-0.081	.63	-0.151	0.366	.706	.634	.660
SO_4^{2-}	-0.397	0.288	-0.502	-0.081	-0.066	.991**	-0.081	0.375	-0.390	-.671	0.001	.703	.708	0.578	-.673
PO_4^{3-}	-0.439	0.217	-0.541	0.401	-0.037	0.532	0.547	0.406	-0.387	.999**	0.019	.726	-0.214	0.369	0.377
TH	-0.426	0.234	-0.505	.995**	-0.041	0.012	0.401	0.401	-0.375	-.671	0.009	.712	0.366	-0.218	0.401
TA	0.081	0.176	0.260	.716	-0.093	.660	.695	0.190	-0.072	.646	-0.143	0.378	.712	.640	.667
TAC	-0.441	0.215	-0.546	0.078	-0.053	-0.037	.989**	0.392	-0.389	-0.078	0.022	.720	0.578	0.129	-.683
TC	-0.040	0.078	0.325	0.423	0.447	0.354	0.414	0.513	0.129	0.330	-0.078	0.231	0.416	0.305	0.365
FC	-0.108	0.103	0.084	0.452	0.592	0.429	0.461	.740*	0.547	0.417	0.556	0.267	0.448	0.377	0.422
FS	-0.014	-0.063	0.351	0.081	0.532	0.037	0.079	0.515	.766**	0.024	0.578	-0.101	0.077	-0.014	0.037

** Correlation is significant at the 0.01 level (two-tailed).
* Correlation is significant at the 0.05 level (two-tailed).

Table 8: (continued): Matrix of coefficients correlations between the analyzed traits involved in the study

	Mg^{2+}	**Cl^-**	**NO_2^-**	**NO_3^-**	**HCO_3^-**	**CO_3^{2-}**	**SO_4^{2-}**	**PO_4^{3-}**	**TH**	**TA**	**TAC**	**TC**	**FC**	**FS**
Mg^{2+}	1													
Cl^-	.685	1												
NO_2^-	-0.067	-0.041	1											
NO_3^-	-0.274	-0.296	-0.100	1										
HCO_3^-	-.683	-.673	-0.148	.674	1									
$C O_3^{2-}$	.665	.702	0.359	-0.560	-.701	1								
SO_4^{2-}	-0.297	-0.560	-0.090	-0.297	-.712	.657	1							
PO_4^{3-}	-.653	0.129	-0.066	-0.214	-.658	0.625	-0.017	1						
TH	-0.101	-0.217	-0.069	-0.263	-.677	.658	.997**	.998**	1					
TA	.670	.708	0.369	-0.533	-.679	.998**	.658	0.631	.663	1				
TAC	0.401	-0.148	-0.063	-0.217	-.660	0.620	.992**	.997**	.997**	0.626	1			
TC	0.363	0.410	0.003	-0.303	-0.218	0.625	0.337	0.302	0.351	.633	0.283	1		
FC	0.415	0.444	-0.137	-0.091	-0.215	0.464	0.390	0.377	0.408	0.478	0.364	.771	1	
FS	0.030	0.071	-0.138	-0.103	0.061	0.256	0.006	-0.017	0.022	0.266	-0.029	.689	.901**	1

** Correlation is significant at the 0.01 level (two-tailed).
* Correlation is significant at the 0.05 level (two-tailed).

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This divergence in characteristics is attributed to the fact that this station is characterized by the highest values of the undesirable substances specifically the total nitrogen (NTK), ammonium (NH_4^+), phosphate (PO^{3-}), the mineral substances (calcium (Ca^{2+}), chloride (Cl^-) and potassium (K^+), carbonate (CO_3^{2-}) and sulphate (SO_4^{2-}). The results revealed also that the number of faecal streptococci (FS) and faecal coliforms (FC) characterizes the water of this station. The station 9, positioned along the Oum Er Rbia River in the downstream of Azemmour, displayed unique characteristics that exerted a substantial impact on water quality. The key factors contributing to variations in water quality at this station encompass a combination of anthropogenic activities, industrial discharges, and agricultural runoff. The surrounding area is characterized by intensive agricultural practices, with the extensive use of fertilizers and pesticides contributing to elevated nutrient levels and the introduction of harmful substances into the water. Additionally, nearby industrial zones release effluents containing pollutants such as heavy metals and chemicals, further influencing the water quality profile. The insights gained from our detailed analysis at stations 9 and 7 have significant implications for water resource management along the Oum Er Rbia River. By identifying and understanding the specific factors influencing water quality at these critical points, stakeholders can develop targeted strategies to mitigate pollution, implement effective regulations, and safeguard the overall health of the river ecosystem. The second subgroup within the second group comprises the remaining eight stations. The similarity in their water quality profiles implies a shared set of characteristics distinct from those exhibited by Station 9. This could indicate a broader regional pattern or commonality in factors influencing water quality among these eight stations. Overall, this interpretation underscores the complexity and heterogeneity of water quality along the Oum Er Rbia River. Similar results were reported in both Moroccan surface water[33] and groundwater.[34]

Table 9: Eigenvectors of principal components from PCA analysis based on all analyzed traits

Parameter	**Components**					
	1	**2**	**3**	**4**	**5**	**6**
T	-0.375	0.145	0.681	0.490	0.343	0.040
T° Water	0.262	-0.009	0.391	0.805	0.133	-0.311
pH	-0.445	0.372	0.700	-0.323	0.121	0.052
EC	0.997	-0.016	0.003	-0.051	-0.043	0.015
NTU	-0.001	0.759	-0.358	0.115	0.432	-0.181
DBO_5	0.993	-0.022	-0.065	0.024	0.015	0.068
DCO	0.998	0.002	-0.025	-0.013	-0.003	0.027
MES	0.432	0.688	-0.393	0.125	0.392	-0.050
DO	-0.341	0.804	0.048	0.129	-0.302	0.341
NTK	0.992	-0.040	-0.081	0.037	-0.003	0.069
PT	0.009	0.644	-0.295	0.467	-0.325	0.415
NH_4^+	0.714	-0.076	-0.329	-0.009	0.371	-0.060
Na^+	0.996	-0.019	-0.007	-0.055	-0.040	0.026
K^+	0.990	-0.090	-0.077	0.024	-0.018	0.064
Ca^{2+}	0.995	-0.044	-0.070	-0.021	-0.016	0.040
Mg^{2+}	0.996	-0.055	-0.043	0.007	-0.026	0.024
Cl^-	0.997	-0.023	-0.010	-0.048	-0.036	0.028
NO_2^-	-0.050	-0.026	0.584	-0.129	0.471	0.575
NO_3^-	-0.290	0.136	-0.761	-0.058	0.485	0.240
HCO_3^-	-0.700	0.107	-0.528	-0.453	0.051	0.039
CO_3^{2-}	0.709	0.174	0.608	-0.230	0.062	0.070
SO_4^{2-}	0.993	-0.083	-0.028	0.050	-0.041	0.002
PO_4^{3-}	0.989	-0.086	-0.096	0.021	-0.003	0.067
TH	0.995	-0.062	-0.054	0.007	-0.025	0.032
TA	0.714	0.188	0.585	-0.254	0.074	0.090
TAC	0.986	-0.100	-0.096	0.026	-0.013	0.081
TC	0.426	0.616	0.284	-0.368	0.109	-0.443
FC	0.464	0.865	-0.007	-0.029	-0.122	-0.081
FS	0.080	0.930	0.068	-0.129	-0.287	-0.085
% of Variance	55.331	15.208	12.512	6.088	4.867	3.696
Cumulative %	55.331	70.538	83.050	89.138	94.005	97.701

Eigenvectors greater than |0.7| are marked in bold.

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The identification of distinct groups and subgroups provides valuable information for targeted environmental management strategies. Addressing the unique challenges posed by station 7 and understanding the factors contributing to the variations within the second group can guide efforts to implement more effective and location-specific measures for water quality preservation and improvement.

The water quality data for various experimental stations along the Oum Er Rbia River during the 2020-2022 seasons are presented in the Table 10. The results reported the water quality of the ten stations based on the most discriminant parameters: including the 5-day biological oxygen demand (DBO_5), chemical oxygen demand (DCO), ammonium nitrogen (NH_4^+), phosphate (Pt), and faecal coliforms (FC). Indeed, the finding revealed that all stations showed excellent (S1-S6, S8) or good quality (S7 and S9), these results revealed that all stations characterized by the low biochemical oxygen demand, indicating a high level of organic matter decomposition and excellent water quality in terms of organic pollution. For the DCO, the data induced that the stations S1 to S3 exhibit very low chemical oxygen demand, indicating minimal contamination by organic and inorganic substances, well the stations S7 to S10 show a significant increase in chemical oxygen demand, indicating poor water quality with potential environmental concerns. However, for the ammonium concentration, the results induced an excellent water quality in the stations S1 and S2 which have extremely low ammonium concentrations, a good water quality in the stations S3 to S6 which show a slightly higher but still acceptable level of ammonium and an average water quality in the stations S7 to S10 which have moderate ammonium concentrations. For the phosphate content, the results induced that stations S1 to S6 exhibit a moderate level of phosphate concentration, suggesting good water quality, well the stations S7 to S10 show an increase in phosphate levels, indicating poor to very poor water quality and potential eutrophication concerns. Conversely, the biological traits (faecal coliforms) revealed that the stations S1 to S6 have low faecal coliform counts, indicating excellent to good water quality in terms of bacterial contamination. On the other hand, the stations S7 to S10 show variable faecal coliform counts, suggesting a range of water quality from good to very poor, with potential health hazards. Bedoui *et al.*[34] revealed that more than 65% of the groundwater samples in Sidi Slimane were in the excellent category, which is dominant in the large western areas. 35% of the water samples were in the good category in the center of the study area and 5% of the water samples were in the poor category in the east of the study region. In summary, while some stations consistently maintain excellent water quality, others exhibit variations and may require targeted interventions, particularly in addressing chemical oxygen demand, nutrient concentrations, and bacterial contamination to ensure sustainable and healthy water ecosystems.

Conclusion

A study of the Oum Er Rbia River revealed a concerning deterioration in water quality during drought years. This decline exhibited significant spatial and temporal variations. The second year of the study documented particularly high levels of physicochemical parameters, exceeding established Moroccan water quality standards. Bacterial contamination was ubiquitous across all monitoring stations. Statistical analyses identified distinct clusters of pollution, with Station S9 in the estuary exhibiting the highest level of contamination, followed by Station S7. These observations strongly suggest a confluence of pollutant sources, potentially including wastewater discharge, agricultural fertilizers, and industrial runoff.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

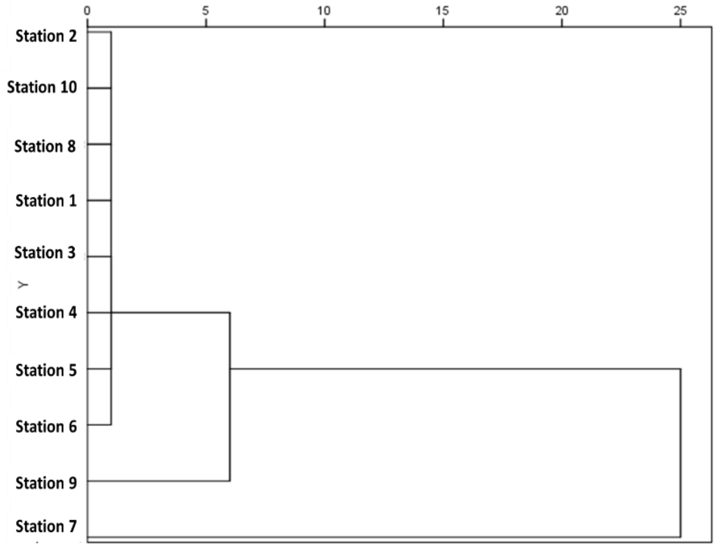

Figure 2: Cluster analysis of the tested stations of the Oum Er Rbia River in Morocco based on the measured traits using Euclidean dis

Table 10: Water quality of the experimental stations of the Oum Er Rbia River during 2020-2022 seasons

Station	DBO_5	DCO	NH_4^+	Pt	FC
S1	90%	90%	90%	50%	70%
S2	90%	70%	90%	50%	70%
S3	90%	70%	70%	30%	70%
S4	90%	70%	70%	10%	50%
S5	90%	90%	90%	10%	50%
S6	90%	70%	90%	10%	50%
S7	70%	30%	70%	10%	50%
S8	90%	90%	90%	30%	50%
S9	50%	90%	30%	10%	70%
S10	90%	90%	90%	50%	50%

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