Spatiotemporal Interpolation of Water Quality Index and Nitrates Using ArcGIS Pro for Surface Water Quality Modeling in the Oum Er-Rabia Watershed

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ABSTRACT

This study aims to create complete surface water quality maps for the Oum Er Rabia watershed by predicting nitrate (NO_3^-) and water quality index (WQI) values at unsampled locations. Utilizing a combination of NO_3^-, IQE data, and ArcGIS Pro software. Water samples were collected from 40 stations across the basin during twelve campaigns conducted in the winter and summer of 2021 and 2022. The database contains the analysis results of 12 parameters measured in 480 samples. The method used to model water quality is interpolation with ArcGIS Pro. The distribution map of nitrate values for all samples shows concentrations ranging from 0.26 to 38.89 mg/L. These values are lower than the admissible level recommended by the Moroccan standard for drinking water (50 mg/L). The resulting map of the modeling shows higher NO_3^- concentrations in summur than in winter. The resulting map of the WQI modeling shows that water quality is excellent in most of the Oum Er-Rbia watershed, with the majority of the area falling into the "good" and "excellent" categories. The water quality deterio-rates in certain parts, especially at stations SS3, SS4, SS5, SS8, and PS9, where the water is of poor quality. In the central and eastern parts, the presence of excessively high ammonium concentrations has significantly compromised the water quality, leading to heavy pollution. Exceeding Moroccan drinking water standards, these observed levels likely stem from human activities. Accurate water quality predictions with ArcGIS Pro require considering data quality, historical trends, and spatiotemporal variations. Understanding these limitations ensures responsible and effective tool use. The study concluded that water pollution could be due to proximity to industrial and urban areas. This study's uniqueness lies in integrating the WQI, NO_3^-, and ArcGIS-Pro into maps. This approach makes informa-tion accessible to the public and useful for decision-makers to take action at all watershed points.Keywords: Water quality modeling, WQI, ArcGIS-Pro, interpolation, NO_3^- modeling, Oum Er-Rabia.

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INTRODUCTION

Water, a vital and irreplaceable element, is the cornerstone of all ecosystems and plays a crucial role in the sustainability of life on Earth [Markad et al., 2021; Islam et al., 2021; Layani et al., 2022]. Water scarcity is driving global concern about worsening water quality [Wu et al., 2018; Ouhamdouch, Bahir, and Carreira 2018]. Industry and daily life rely on clean water [Alnaimi et al.,

2020; Farhan et al., 2020]. Growing populations, expanding agriculture, and increasing urbanization are straining the world's freshwater supplies [Kubicz, Pawełczyk and Lochyński, 2018]. These activities pollute our water bodies with a mix of contaminants, including nutrients, heavy metals, pesticides, and pharmaceuticals. [Evans et al., 2019]. Morocco's water resources, essential for its economy (drinking water, agriculture, indus-try), are under threat. Activities like farming and

industry pollute rivers, leading to water quality decline [Emenike et al., 2020]. Industrial and urban development around rivers harms nearby water quality, leading to environmental degradation. [Mishra and Shah, 2018]. While some chemical elements are necessary for life, high concentrations can become toxic. [Das et al., 2021; Pervez et al., 2021]. Monitoring water quality in large basins like Oum Er-Rabia is essential, yet faces limitations. Resource constraints restrict sampling, creating knowledge gaps that impede pollution source identification and effective solutions. Additionally, the multitude of parameters analyzed complicates data management and interpretation, hindering a clear understanding of overall water quality. Focusing on individual pollutants risks misinterpretations, while a holistic approach considering their interactions is crucial for assessing their combined impact on ecosystems and human health. These limitations have significant consequences, potentially delaying pollution source identification and underestimating environmental and health risks, ultimately threatening public health and sustainable development efforts.

This synthetic indicator allows the aggregation of a multitude of physicochemical data into a single index, thus facilitating the understanding and interpretation of water quality [Boyacioglu, 2007; Gulgundi and Shetty, 2018; Zhang et al., 2017]. Water Quality Index (WQI) is gaining popularity as a method to assess and compare surface water quality over time and space [Şener and Davraz 2017]. This approach utilizes essential parameters to provide a single, informative metric for decision-making regarding water pollution levels within a watershed [Kanga, Naimi and Chikhaoui 2020]. ArcGIS Pro's interpolation tools offer a valuable solution for predicting pollution levels across a study area, making it possible to gain valuable insights from limited sampling data [Fiannacca et al., 2017]. This technique relies on mathematical algorithms to predict the spatial distribution of parameters. It does this by considering local variations and the relationships between sampling points [Canales et al., 2022].

Our study relies on the interpolation modeling of nitrates and the overall WQI to assess the status of surface water in the Oum Rabia watershed. This approach considers various physicochemical parameters to obtain a holistic view of water quality in this region. Our study aims to assess the quality and pollution status of surface water in the Oum Rabia watershed. To achieve this, we collected data from 40 stations distributed throughout the watershed during twelve field campaigns in 2021 and 2022. For the purpose of water quality assessment, This study aims to create complete surface water quality maps for the Oum Er Rabia watershed by predicting NO_3^- and WQI values at unsampled locations. Utilizing a combination of NO_3^-, IQE data, and ArcGIS Pro software, the project will provide a more comprehensive picture of water quality across the entire basin.

This study sets itself apart by combining WQI, NO_3^- data, and geographic information systems (GIS) to create comprehensive water quality maps. This approach democratizes the information, making it understandable for the public and valuable for decision-makers to identify the true impact of pollution and set targeted remediation goals across the entire watershed

METHODOLOGY AND DATA USED

Study area overview

The Oum Er-Rbia watershed is located in central Atlantic Morocco, between 31° 33' and 33° 32' North latitude and between 5° 06' and 9° 34' West longitude. According to the Lambert coordinates for Morocco, the Oum Er-Rbia basin is located between 83,510 and 306,978 km in longitude, and between 127,487 and 531,050 km in latitude. It covers an area of 47,032 km². From east to west, it has a length of 660 km. The watershed investigated in this study has an irregular shape**.** It is determined from a stream network that corresponds to the flow directions calculated from the hydrologically corrected digital terrain model (DTM) using the steps implemented in the GIS software (ArcGIS Pro). Dividing the Oum Er-Rbia watershed reveals two main entities:
- The Oum Er-Rbia sub-basin (the upper basin zone): 35,000 km²;
- The Safi El Jadida Coastal sub-basin (the lower basin zone): 12,000 km².

It emerges from this decomposition that the Oum er Rebia has two very different basins, a high upper basin with a strong retention capacity, capable of greatly mitigating the variations of the Mediterranean climate. Located at a higher elevation, the upper basin contrasts with the lower basin, which has a low water retention capacity.

Database

Our study relies on physicochemical data collected from surface water in the Oum Rabia watershed. To conduct our study, we collected 480 water samples distributed across 40 stations in the Oum Rabia watershed. Data collection involved 12 bi-seasonal campaigns spread throughout 2021 and 2022, encompassing both winter and summer seasons. This large database allows us to obtain an accurate analysis of the water quality in the watershed. The physicochemical parameters studied included pH, dissolved oxygen (DO), electrical conductivity (EC), and temperature (°C), which were measured in situ in the field. Laboratory analyses were conducted to determine the concentrations of various parameters in the water samples, including sulfates, orthophosphates (PO_4^{3-}), ammonium (NH_4^+), nitrates (NO_3^-), total dissolved solids (TDS), total phosphorus (TP), suspended matter (TSS), and total Kjeldahl nitrogen (TKN). Physicochemical analyses followed established protocols outlined in the AFNOR (1997) and Rodier et al., (1996) standards. The following figure (Fig. 1) illustrates the sampling locations. Data analysis and visualization were performed using Excel 2010 for processing and ArcGIS Pro for map creation.

WQI is a tool used to assess water quality by comparing it to pre-established standards. These standards can be international, such as those defined by the World Health Organization (WHO), or national, as in the case study of Morocco. WQI was calculated using twelve key water quality parameters: pH, dissolved oxygen, electrical conductivity, temperature, sulfate (SO_4^{2-}), phosphate, ammonium (NH_4^+), total phosphate, nitrate, total Kjeldahl nitrogen, total suspended solids, and total dissolved solids. WQI is a useful tool that categorizes water quality. It assigns different grades (excellent, good, average, bad, very bad) based on how measured values compare to established national or international water quality standards [Chadli and Boufala 2021; Kanga et al., 2020].

The calculation of the index followed the weighted arithmetic index method [Kambalagere et Puttaiah 2008; Mukherjee and Paramanik 2022; Ruhela et al., 2018], where a relative weight (Wi) is assigned to each physicochemical parameter (see Table 1). The weight is calculated using the following formula:

$$Wi = Si / \Sigma Si \qquad (1)$$

where: *Wi* is the weight assigned to each parameter, *Si* is the maximum value of the Moroccan standard for each parameter in (mg/L), except for pH, temperature, and electrical conductivity, Σ is the sum of the values.

The quality of each parameter is then expressed as a quality index (*Qi*), calculated by dividing its concentration by the standard and multiplying the result by 100. The equation $Qi = (Ci/$
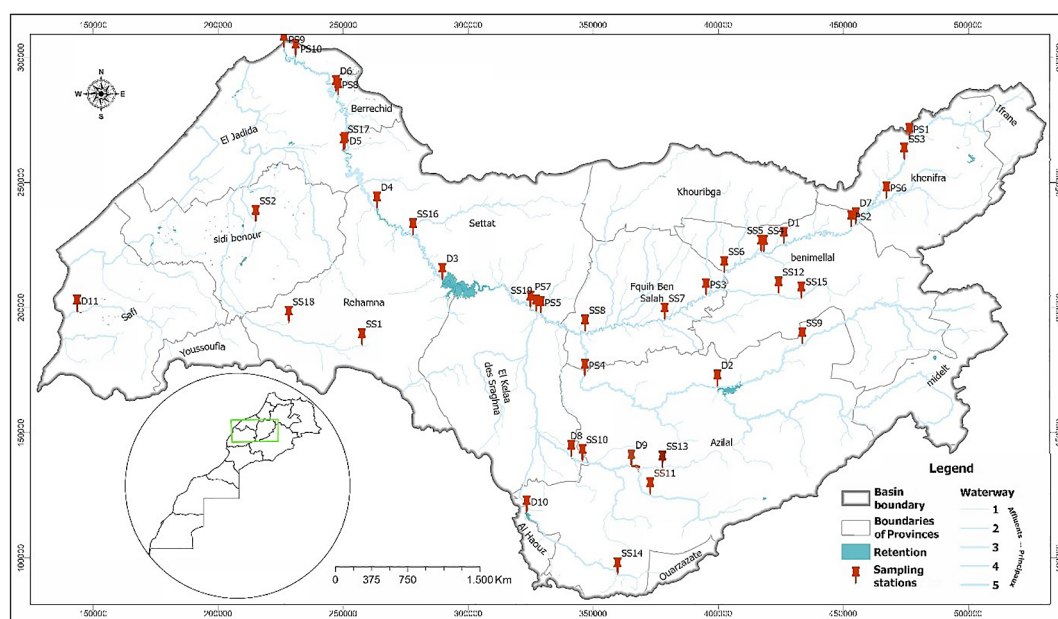

Figure 1. Map of the sampling site locations

Table 1. Water quality classification based on WQI values

WQI value	0–25	25–50	50–75	75–100	< 100
Water quality	Excellent	Good	Bad	Very poor	Non-potable
Usefulness	P; Ir; Ind	P ;Ir ;Ind	Ir ;Ind	Ir	Pré-T

$Si) \times 100$ is used to calculate WQI for a specific parameter. The overall water quality index is calculated using the following formula:

$$WQI = \Sigma\ (Qi \times Wi)\ /\ \Sigma\ Wi \qquad (2)$$

WQI values allow for the classification of water quality into five distinct classes (refer to Table 1 for details).

Interpolation modeling in ArcGIS Pro

The method used is water quality modeling using interpolation. This method adopts a simplified perspective, inherently assuming the data possesses spatial continuity. The accuracy of interpolation results hinges on several factors: the precision, quantity, and spatial distribution of the known data points used in the calculation, along with the chosen mathematical function's ability to predict the unknown value. GIS-based IDW interpolation provides a richer spatial representation of surface water quality compared to traditional methods. To bridge data gaps in areas inaccessible for sampling, researchers employed GIS techniques for spatial analysis of water quality [Aminu et al., 2015]. This allows for the estimation of attribute values at any point located within the data boundaries. Interpolation is a technique that employs estimated values in place of measured data. It is applicable when analyzing data that gradually changes across a geographic region. The computational technique utilizes control points with known values and mathematical equations to approximate the values located between them [Bashir et al., 2020; Kaliraj et al., 2024]. Leveraging ArcGIS Pro, we initiated our water quality modeling by gathering and formatting ge

oreferenced water quality data for the watershed. We then explored the spatial distribution of the data using GIS tools (ArcGIS Pro) and treated outliers if necessary. We employed an interpolation method, such as IDW, Kriging, or Spline, that was most appropriate for our data. Optimized the interpolation parameters to ensure accurate representation of the data. Running the interpolation tool to create a raster surface representing water quality throughout the watershed. Validation

of results by comparing them with independent validation data. Thematic maps are a powerful tool for visualizing spatial data and understanding the geographic distribution of a phenomenon. By analyzing the data, we can pinpoint specific areas with different water quality levels. Subsequently, the findings and recommendations, communicated via reports, maps, and visual media, contribute to informed water quality management. By combining WQI and NO_3^- with geographic information systems, water quality data in the Oum Er-Rabia watershed becomes more accessible and understandable, even for those without scientific expertise [Supardi et al., 2023]. This project aims to leverage WQI and NO_3^- with GIS to develop detailed maps that effectively communicate surface water quality throughout the watershed.

RESULTS AND DISCUSSION

Water quality index

Table 2 offers a comprehensive overview of the organic pollution parameters, as measured at 40 strategically dispersed sampling points within the Oum Rbia watershed. In general, physicochemical parameters are essential for studying surface water quality. They enable us to monitor the health of aquatic ecosystems, detect pollutants, and ensure the safety of drinking water. However, interpreting each parameter independently is insufficient for decision-making. Hence, the need to combine all parameters into a single index, which in our study is WQI. Using the Moroccan standard for surface water (Moroccan Water Quality Standard, 2002) of the studied physicochemical parameters, the relative weight (Wi) is calculated for each physicochemical parameter with the following formula: $Wi = k/Si$, the proportionality constant (k) is also determined (Table 3).

Table 4 shows the results of calculating WQI across the 40 samples collected throughout the study area. Figure 2 presents a classification of water quality according to WQI index into five quality classes (excellent quality, good quality, bad quality, very bad quality and non-potable

Table 2. Descriptive statistics of physicochemical parameters for the twelve sampling campaigns in 2021 and 2022

Campaign		pH	T (°C)	Cond µS/cm	TSD mg/l	TSS mg/l	DO mg/l	NH_4^+ mg/l	NTK mg/l	NO_3^- mg/l	SO_4^{2-} mg/l	PT mg/l	PO_4^{3-} mg/l
Winter	Min	7.4	3.15	567	362.88	3.27	0.1	0.02	0.13	0.53	49.35	0.05	0.02
	Average	8.23	13.90	2285.72	1462.86	57.49	8.74	7.23	7.33	4.54	148.22	0.78	0.58
	Max	8.75	20.85	19915	12745.6	239.5	11.1	152.5	142.5	13.29	1429.5	15.03	11.7
	Stand	0.68	8.92	10708.96	6853.73	123.74	5.79	86.03	80.20	6.53	769.88	8.45	6.59
Summer	Min	7.6	17.88	327.5	209.6	4.55	0	0.02	0.22	0.2605	34.3	0.04	0.02
	Average	8.16	25.42	2873.33	1838.93	296.01	8.01	6.55	7.88	3.69	193.06	0.84	0.57
	Max	8.95	29.15	39250	25120	4742.7	55.83	126.36	144.5	38.89	2050	17.29	12.8
	Stand	0.68	5.74	21774.24	13935.51	2655.44	30.19	71.13	81.18	21.38	1120.75	9.74	7.23

Table 3. Relative weight (Wi) of physicochemical parameters

Parameters	Moroccan standard	Si (maximum standard value, Morocco)	1/Si	Wi	K
pH	6.5–9.2	9.2	0.10869565	0.0248823	
T (°C)	20–30	30	0.03333333	0.0076306	
Cond (µs/cm)	750–2700	2700	0.00037037	0.0000848	
DO (mg/l)	3–5	5	0.2	0.0457834	
NH_4^+ (mg/l)	0.1–0.5	0.5	2	0.4578336	
NO_3^- (mg/l)	< 50	50	0.02	0.0045783	
SO_{42}^- (mg/l)	100–250	250	0.004	0.0009157	$1/\sum(1/Si)=$ 0.2289168
TDS	1000	1000	0.001	0.0002289	
PO_{43}^- (mg/l)	0.2–1	1	1	0.2289168	
PT	< 2	2	0.5	0.1144584	
TSS	1000	1000	0.001	0.0002289	
NTK (mg/l)	< 2	2	0.5	0.1144584	

water) are well identified. Table 5 presents a simple ranking of the studied stations according to WQI values measured in winter and summer of 2021 and 2022. Figure 3 presents a pie chart illustrating the distribution of studied stations across different remediation categories, based on their water quality index scores.

WQI results indicate that approximately 82% of the water in our basin is suitable for agricultural use. Nearly four out of five samples (77%) are fit for industrial applications, 5% of the water is drinkable, while 35% of the water requires pretreatment to become drinkable. Water quality is excellent in most of the Oum Er-Rbia watershed. However, it deteriorates in 35% of the watershed, particularly in certain areas such as stations SS11-SS15 (very poor water quality) and stations SS1-SS13-SS2-SS3-SS5-SS8 and PS9. This water is unsuitable for drinking, agriculture, or industrial applications without prior treatment.

The main culprits behind the worsening water quality in the watershed are the discharge of wastewater from urban and industrial areas, as well as agricultural practices. The central and eastern areas experience critical water contamination due to excessively high concentrations of ammonium. These levels exceed Moroccan drinking water standards and are likely of anthropogenic origin. Possible sources include agricultural activities, such as the leaching of soils heavily laden with fertilizers, and the discharge of urban and industrial wastewater.

Summer sees a decline in water quality at 55% of the stations compared to winter. Generally, these stations receive the majority of pollutants from non-compliant discharges from local industries, untreated or partially treated urban wastewater discharges, and direct discharges from septic tanks and latrines. Several factors contribute to the decrease in WQI observed during winter. Lower temperatures, higher flow

Table 4. Calculated WQI values for different analysed elements

Stations	WQI values		Stations	WQI values	
	Winter	Summer		Winter	Summer
D1	26.58726301	77.85193108	PS10	24.22227728	23.53479869
D2	57.3642712	80.27236152	SS1	15951.78933	12646.28555
D3	23.93164073	44.47199046	SS2	11950.27497	13057.90813
D4	22.11226926	41.59221603	SS3	470.949738	213.6014038
D5	19.42609329	22.58278751	SS4	86.26710327	45.27776323
D6	22.22562275	22.77272055	SS5	275.5850147	123.2119464
D7	21.55819614	21.95983374	SS6	62.1691265	23.43652374
D8	18.26920975	51.80030503	SS7	56.04333895	20.91372189
D9	27.52397513	65.99281619	SS8	721.0395007	140.3298894
D10	16.62634475	21.10808838	SS9	24.45703611	17.30875611
D11	19.12693852	17.06962374	SS10	18.15251962	37.48842649
PS1	34.57240948	17.09626713	SS11	18.80935499	164.1736963
PS2	17.47676786	42.6035088	SS12	17.10367367	16.68075069
PS3	31.66209386	20.70302538	SS13	16.81843036	861.274328
PS4	22.84514658	43.44414464	SS14	20.18508352	14.92329893
PS5	58.07261275	24.97608212	SS15	32.13664328	131.1702499
PS6	42.18269421	91.16252541	SS16	22.41240309	28.18808334
PS7	49.19594067	68.88026529	SS17	23.16154081	21.32418171
PS8	18.50232702	18.84302199	SS18	24.12514147	33.56606535
PS9	592.4712326	303.762388	SS19	23.29262446	28.97284864

Table 5. Surface water quality based on the WQI

WQI values	Water type	Station count	Stations	Rate (%)
0–25	Excellent quality	11	D5-D6-D7-D10-D11-PS8-PS10-SS9-SS12-SS14-SS17	27.5
> 25–50	Good quality	15	D3-D4-D8-D9-PS1-PS2-PS3-PS4-PS5-SS6-SS7-SS10-SS16-SS18-SS19	37.5
> 50–75	Bad quality	5	D1-D2-PS6-PS7-SS4	12.5
> 75–100	Very poor quality	2	SS11-SS15	5
> 100	Non-potable water	7	PS9-SS1-SS13-SS2-SS3-SS5-SS8	17.5

rates, and increased precipitation all play a role. Lower winter temperatures can lead to reduced biological activity in water bodies. While this may initially decrease oxygen consumption, it can also allow pollutants to persist for longer periods, potentially affecting WQI negatively. Conversely, higher flow rates result from increased snowmelt and rainfall, which dilutes existing pollutants and generally improve WQI. However, it is important to note that high flow rates can also lead to increased erosion and sedimentation, introducing new pollutants and potentially outweighing the benefits of dilution. Finally, as highlighted in the cited studies, increased winter precipitation directly dilutes existing pollutants,

contributing positively to WQI improvement [Qiu et al., 2021]. Nearly half (45%) of the stations experience a more significant drop in water quality during winter months compared to summer. Generally, these stations receive the majority of pollutants from agricultural activities.

Figures 4 and 5 presents WQI distribution-modeling map prepared using the geographic information system with the ArcGIS Pro tool.WQI modeling indicates that the southern and southwestern parts of the basin (Sidi Benour, Rehamna, Kelaat Seraghna, and El Jadida regions) and a part of the Azilal region have very poor water quality. The remaining areas of the basin have well to excellent water quality, except for areas near urban
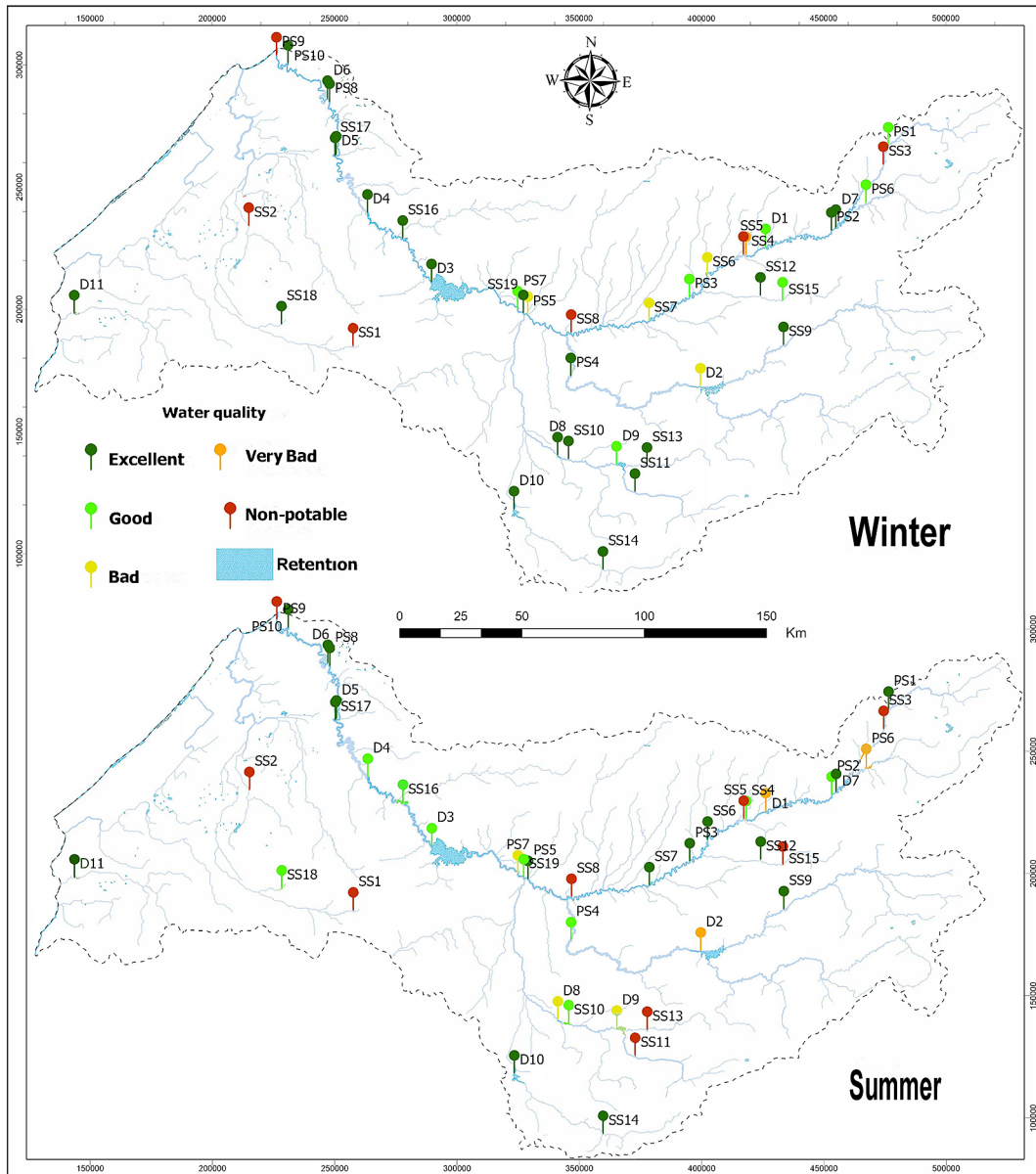
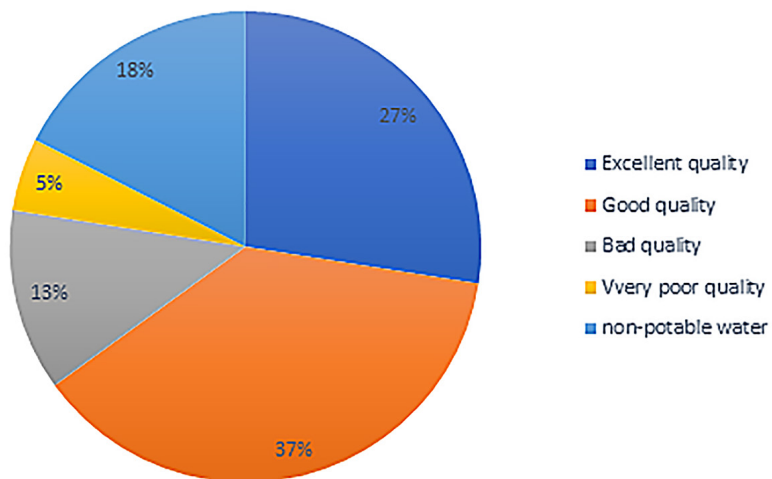**Figure 2.** Water quality distribution in the study area for the 40 stations

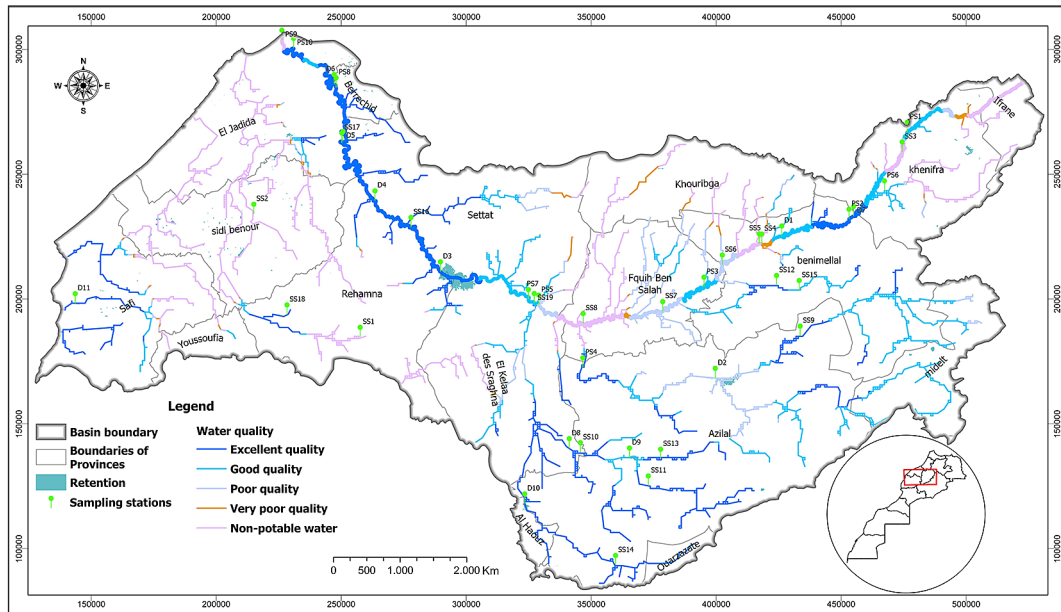**Figure 3.** Pie chart of the distribution of WQI classes in the Oum Er Rabia watershed
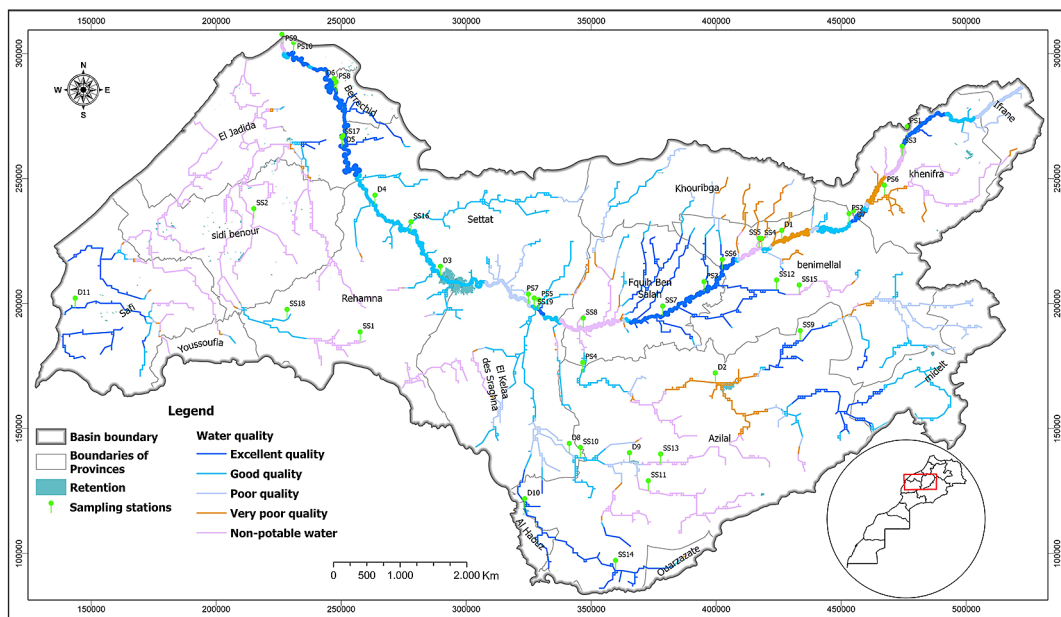
Figure 4. Winter surface WQI map

Figure 5. Summer surface WQI map

agglomerations (Benimelal and Khenifra cities). The two obtained maps clearly show a seasonal variation of WQI between winter and summer. The average WQI level is higher in summer than in winter in most of the basin, especially in the areas north of the Oum Rbia River (Khouribga, Settat, Berrechid and Fquih Ben Salah) and those upstream (Beni Mellal, Khenifra and Midelt and part of Ifrane). This is particularly true in parts of the basin where agricultural activities are dominant, with the exception of areas with urban agglomerations. Water quality index is higher in winter than in summer in the western part of the basin (El Jadida, Safi, Sidi Benour and part of Youssoufia) and in the south (Rehamna, Youssoufia and part of Al Haouz). This increase is mainly due to urban and industrial discharges, especially the chemical industry linked to the production of fertilizers, pesticides and various chemicals. In addition, there are discharges from intensive agricultural activities (pesticides and chemical fertilizers).

Nitrate modeling

This study found that nitrate levels in all samples ranged between 0.26 and 38.89 mg/L (Fig. 6 and 7). The permissible limit for nitrate in drinking water is 50 mg/L. Therefore, the nitrate levels in all samples were below the permissible level recommended by the Moroccan standard for drinking water during both winter and summer of the two study years. Overall, modeling shows that nitrate concentrations are higher in summer than in winter. Hydrologic modeling aligns with previous scientific observations, indicating a consistent pattern of elevated nitrate concentrations during summer months within the Oum Rbia basin's surface water [Strohmeier et al., 2020]. Several potential explanations exist for these variations, including seasonal shifts in precipitation patterns, water flow regimes, and agricultural activity levels within the watershed.

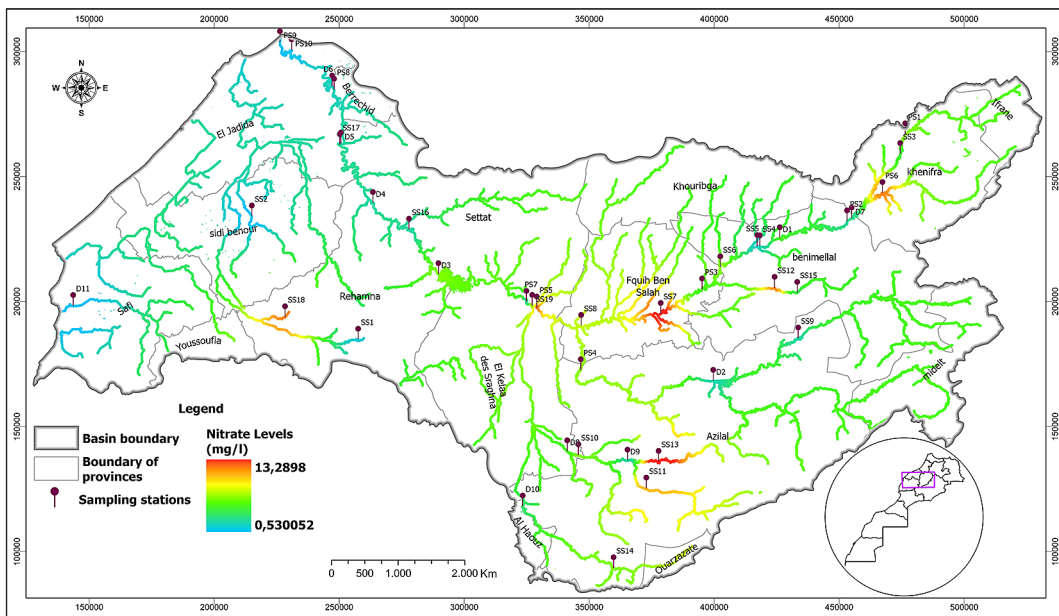Several scientific studies [Eimers, Buttle and Watmough 2007; Park et al., 2003; Zheng et al.,

Figure 6. Map of nitrate values in the study area (winter campaign)
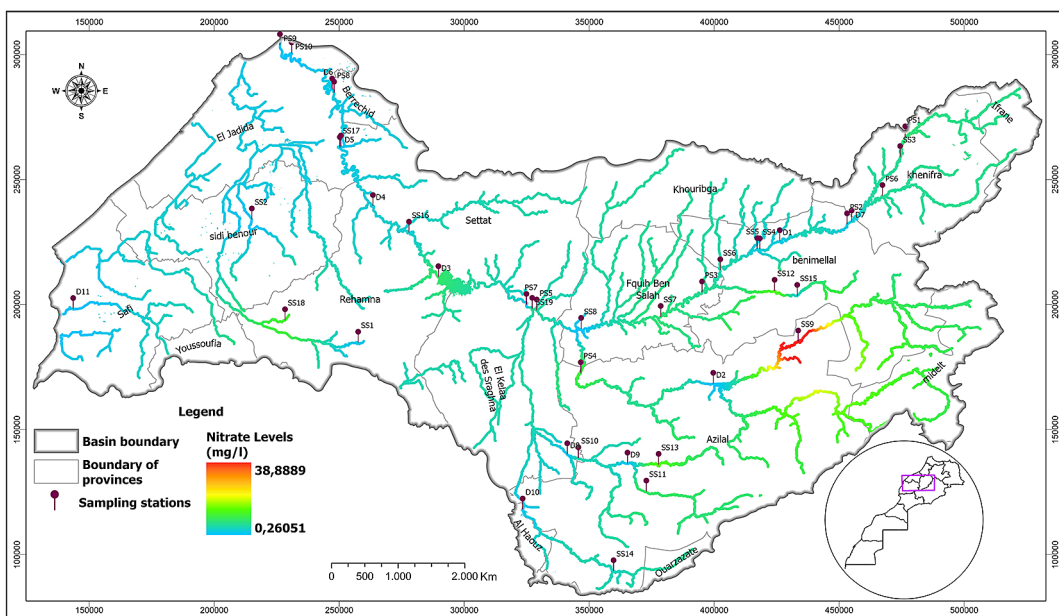

Figure 7. Map of nitrate values in the study area (summer campaign)

2020] confirm an increase in nitrate concentration in water during winter, especially in temperate regions with higher winter precipitation [Casson et al., 2012]. Understanding the seasonal variability of nitrate concentration in water bodies requires considering a multitude of interacting factors. Increased rainfall during winter enhances nitrate leaching from agricultural soils, particularly those fertilized with nitrogenous fertilizers. This coincides with reduced plant uptake due to lower vegetation density in winter, leading to higher nitrate concentration in soils and water. Furthermore, consecutive years of drought, as experienced in Morocco recently, can exacerbate the issue, as nitrate concentration in arid areas tends to be higher in summer than in winter. Nitrate levels in surface water can increase during summer for several reasons. Firstly, reduced river flow during droughts concentrates pollutants, including nitrates. Secondly, increased evaporation in summer intensifies nitrate concentration in surface water. Furthermore, higher summer temperatures promote the oxidation of ammonium into nitrates. Finally, the use of nitrogen fertilizers in agriculture, particularly during the growth period of summer crops, also contributes to the increase in nitrate concentrations.

Nitrate levels remained below the standard during the winter seasons of both 2021 and 2022. These four regions – Safi, Sidi Bennour, El Jadida, and Berrechid – had the lowest readings compared to the others, while the highest values were detected in Khenifra, south of Azilal, and downstream of Fquih Ben Salah. Nitrate levels are generally lower in the summer across the majority of the watershed, except for the region between Benimalal and Azilal where concentrations remain relatively high.

CONCLUSIONS

A significant decline in the quality of surface water, including rivers and dams, has been observed, severely affecting the actual water potential and leading to major health and ecological consequences. The main sources of water degradation in this region are urban wastewater and agricultural and industrial chemicals. The frequent discharge of these substances without proper treatment into the natural environment is a critical factor in the contamination of surface water.

Excessive use of agricultural chemicals, including nitrogen and phosphate fertilizers, pesticides, and herbicides, is a major source of water pollution. These substances contaminate soil and surface water through runoff and infiltration, contributing to the degradation of water resources. Monitoring and modeling of the water quality index and nitrate concentration in the Oum Rabia basin during this study showed that surface water in the basin is of good and excellent quality in 65% of the area, and 82% is suitable for irrigation.

Seasonal variation is only apparent upon close examination of the WQI and reveals a slight tendency for water quality to deteriorate in winter in areas receiving mainly agricultural pollutants, which are located mainly in the south and west of the basin. However, urban stations show an increasing deterioration of water quality as a function of population pressure, especially in summer. Significant signs of human-induced (anthropogenic) pollution are evident downstream from the urban centers of Khénifra, Kasbat Tadla, Benimelal, Sidi Benour, and Benguerir. The contamination is evident in significantly elevated levels of specific physicochemical parameters, including TKN, ammonium, and conductivity, all surpassing established standards by a considerable margin. The interpolation of NO_3^- concentrations in surface water shows excellent quality with higher concentrations in winter than in summer.

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