ORIGINAL PAPER

The combined use of GIS and water quality indices for environmental assessment of Ouislane River watershed, Morocco

Abdennabi Alitane[1,2] · Ali Essahlaoui[1] · Estifanos Addisu Yimer[2] · Narjisse Essahlaoui[1] · Celray James Chawanda[2,3] · Yassine El Yousfi[4] · Ann Van Griensven[2,5]

Abstract

The Ouislane River, located in the R'Dom watershed, is significantly polluted owing to urbanization, industry, and agriculture. Given its importance to the region and its evident degradation, understanding the extent and nature of this pollution is crucial. The reasons for the assessment of water quality in the selected river are strongly related to industrial and domestic wastewater discharges and agricultural activities, which are considered to be the main causes of the deterioration in its quality. The novelty of this work is to integrate a geographical information system (GIS) technique with water quality models and to provide a good picture of the surface water adequacy. The present study aims to assess the water quality of the Ouislane River on the basis of measured water variable data for irrigation uses, utilizing a combination of GIS and water quality indices. The specific objectives of this research project are: (i) to assess its water quality status by using the water quality index (WQI), synthetic pollution index (SPI), and water quality parameters such as the sodium adsorption ratio (SAR), sodium percent (%Na), and residual sodium carbonate (RSC); and (ii) to classify and determine the suitability of the natural river waters for irrigation purposes. Fifteen samples from the river were collected to determine their suitability for irrigation use. The results showed that the WQI values range from 38 to 198, while the SPI values range from 0.99 to 5.5. This result was confirmed and validated by a satisfactory correlation between the WQI and the SPI ($R^2 = 0.99$). On the basis of the GIS interpolated map, the WQI and SPI models show that the river water was suitable for irrigation purposes. According to the SAR, % Na$^+$, and RSC values, irrigation use of the water was acceptable and permissible. The results of this research will help water managers develop strategies to mitigate the potential adverse effects of surface water pollution on environment. They will also improve water quality assessment in the region and could provide an essential reference for quality studies and valuable guidance for watershed management strategies.

Keywords Ouislane River · Water quality index · Synthetic pollution index · Water quality · GIS

Introduction

Water is a natural resource that is essential to life in all ecosystems, and its conservation should be a concern for all societies (Postel 2003), because without water there

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✉ Abdennabi Alitane
  Abdennabi.Alitane@vub.be

1 Geoengineering and Environment Laboratory, Research Group "Water Sciences and Environment Engineering," Geology Department, Faculty of Sciences, Moulay Ismail University, Presidency, Marjane 2, BP 298, Meknes, Morocco

2 Water and Climate Department, Vrije Universiteit Brussels (VUB), 1050 Brussels, Belgium

3 Texas A&M AgriLife Research, Blackland Research & Extension Center, Temple, TX 76502, USA

4 Research Team—Water and Environment Management, Laboratory of Applied Sciences (LSA), National School of Applied Sciences Al Hoceima, Abdelmalek Essaadi University, 93030 Tetouan, Morocco

5 IHE Delft Institute for Water Education, 2611 AX Delft, The Netherlands

would be no life on the planet (Abu-Zeid 1998). Rivers are the world's largest and most easily accessible freshwater resource, needed for domestic use, agriculture, industry, and irrigation. Morocco considers water resources to be one of the priorities for socioeconomic development (Ait Kadi and Ziyad 2018). Nevertheless, water resources in the country face challenges owing to the predominantly semi-arid to arid climate, episodic droughts (Yimer et al. 2022), and intensive uses or drainage (Yimer et al. 2023). Water quality is defined by physical, chemical, toxicological, and biological parameters as well as specific uses. It is worth noting that agriculture is one of the major contributors to the deterioration of river water quality. Therefore, its impacts must be integrated into the comprehensive management of water quality (Van Griensven and Bauwens 2001). On the other hand, the agricultural sector is a significant consumer of water globally, especially in arid and semi-arid regions (Heidecke 2010; López-Serrano et al. 2020). Water resources from a river basin have very diverse characteristics depending on location and the strength of pollution sources (Hem 1985). The demand for irrigation water in the Mediterranean area is increasing owing to decreased precipitation. For this reason, farmers are becoming more interested in reusing wastewater (Carr et al. 2004).

The Ouislane River is one of the rivers of the R'Dom watershed that is included in the Sebou Basin, considered to be one of the most polluted rivers in Morocco (Soumaila et al. 2021; Elhajjami et al. 2023). It flows from south to north (Alitane et al. 2022a; Ben-Daoud et al. 2022). The river is strongly dependent on the springs—the Sidi Slimane Moul El kifane, Mazila, Kannab, Bou Rahhou, and Zwawka—feeding the Ouislane River. Surface water is one of the sources of irrigation water for agriculture in the Ouislane subwatershed (Golcher Benavides 2018).

Owing to the increase in industrialization, agriculture, population, and urbanization, large quantities of untreated sewage (e.g., cities in the Sebou Basin discharge an estimated 80 million m^3 of wastewater annually, 86% of which into rivers) and industrial wastewater (70% of industrial pollution in the basin comes from sugar and milk producers, paper companies, and oil mills) discharged into the river have significantly contributed to its pollution (ABHS 2011). Pollution is a common issue in all Moroccan cities, with Meknes facing particular challenges owing to its expanding population and industrial sectors (El Addouli et al. 2011; Karrouch et al. 2017). Several industrial units have been developed in the Ouislane subwatershed, including oil mills, plastics, and tannery operations. In addition, the increase of livestock breeding and agricultural activities constitutes a significant pollution source into the river (El Addouli et al. 2011). Surface water must be protected from all sources of pollution in order to meet needs.

Several studies have been conducted around the world to assess the suitability of water for agricultural practices, using WQI and GIS technology to separate irrigation quality sites and produce thematic water quality maps (Gaagai et al. 2023; Ibrahim et al. 2023). GIS provides a flexible environment for evaluating the suitability of water for irrigation purposes, offering a clear picture of water quality (Masoud et al. 2022). A GIS environment was used to interpolate and map the spatial evolution of pollution inputs in the Ouislane subwatershed by applying the water quality index (WQI) and synthetic pollution index (SPI). The irrigation water indices were used to determine the risk to soils during irrigation by applying the sodium adsorption ratio (SAR), percent sodium (%Na), and residual sodium carbonate (RSC) (Almeida et al. 2008; Elsayed et al. 2020; Yıldız and Karakuş 2020). Irrigation water quality refers primarily to the physicochemical composition of the water and the presence of solids or organic substances in the water. The chemical and physical properties determine the suitability of water for irrigation use (Sarkar and Islam 2019). The Piper, Wilcox, and Schoeller hydrochemical classification diagrams are widely used to show the sources of ions in surface waters for a better understanding of complex water systems (Afzali et al. 2014; Ewaid 2018). Therefore, it is hypothesized that water quality indices and parameters could be used to represent the adequacy of surface water for irrigation purposes, with promising results in this study area. Both untreated wastewater and industrial wastewater are discharged directly into the river, marking them point sources of pollution (Jamal et al. 2009). Furthermore, overfertilization of agricultural fields and excessive pesticide use contaminate the river through leaching and represent a diffuse source of pollution (Ben-Daoud et al. 2012).

The present research project aims to assess the water quality status of the Ouislane River by integrating the water quality index (WQI) and synthetic pollution index (SPI) within a GIS environment. These are completed by the determination of irrigation water quality parameters including SAR, %Na, and RSC. Classification and determination of water suitability for irrigation rely heavily on the analysis of water samples.

The novelty of this work lies in its integrated approach that combines geographic information system (GIS) techniques with water quality models to comprehensively assess the water quality of the Ouislane River. This integrated methodology allows for a more thorough understanding of surface water adequacy, particularly in the context of pollution resulting from urbanization, industry, and agriculture. In addition, the findings of this research project will be useful to politicians and decision-makers, providing a valuable guide for researchers on how to utilize water quality models to assess the water status effectively, thereby enhancing the management of water resources in the region.

Materials and methods

Study area description

The Ouislane subwatershed is located in the northwest part of Morocco (Fig. 1), 60 km west of Fez City, in the Meknes and El Hajeb regions (Aboulkacem et al. 2007). It is a part of the R'Dom watershed with an area of approximately 315.4 km², a perimeter of 150.6 km, and a maximum altitude of 1434 m in the southern part and a minimum altitude of 276 m in the northern part. It is located between latitudes 33.95° and 33.54° and longitudes −5.57° and −5.29° and occupies a strategic geographical position because it is bounded by the Prerif to the north and the Middle Atlas Mountains to the south. It is characterized by agricultural and industrial activity that contributes significantly to the regional economy. From the climatic point of view, the study area is characterized by a Mediterranean climate with an average annual rainfall of 660 mm (Jamal et al. 2009), of which more than 70% of total rainfall returns to the atmosphere in the form of evapotranspiration (Alitane et al. 2022b). According to the hydrological system, the Ouislane River flows from south to north over a total length of 98 km. In terms of its hydrogeology, the study area is composed of two principal aquifers: the shallow Plio-Quaternary aquifer and the deep Lias aquifer (Essahlaoui and Ouali 2003; Alitane et al. 2022a).

From a geological perspective (Fig. 2), the study area covers a variety of geological formations from the Paleozoic to the Quaternary (Alitane et al. 2022a), with a predominance of Jurassic dolomites, Trias shales, Paleozoic conglomerates, and volcanic formations arranged in a basaltic flow in the southern part of the study area. The central and northern parts are marked by Tertiary lacustrine limestones and Quaternary silt and fluvial deposits (alluvium). This geological diversity determines the environmental context of the basin, offering a range of substrates that contribute to understanding the quality and composition of the Oued Ouislane.

Methodology

Quality assurance/quality control (QA/QC)

Quality assurance (QA) and quality control (QC) have become paramount in research laboratories, ensuring that
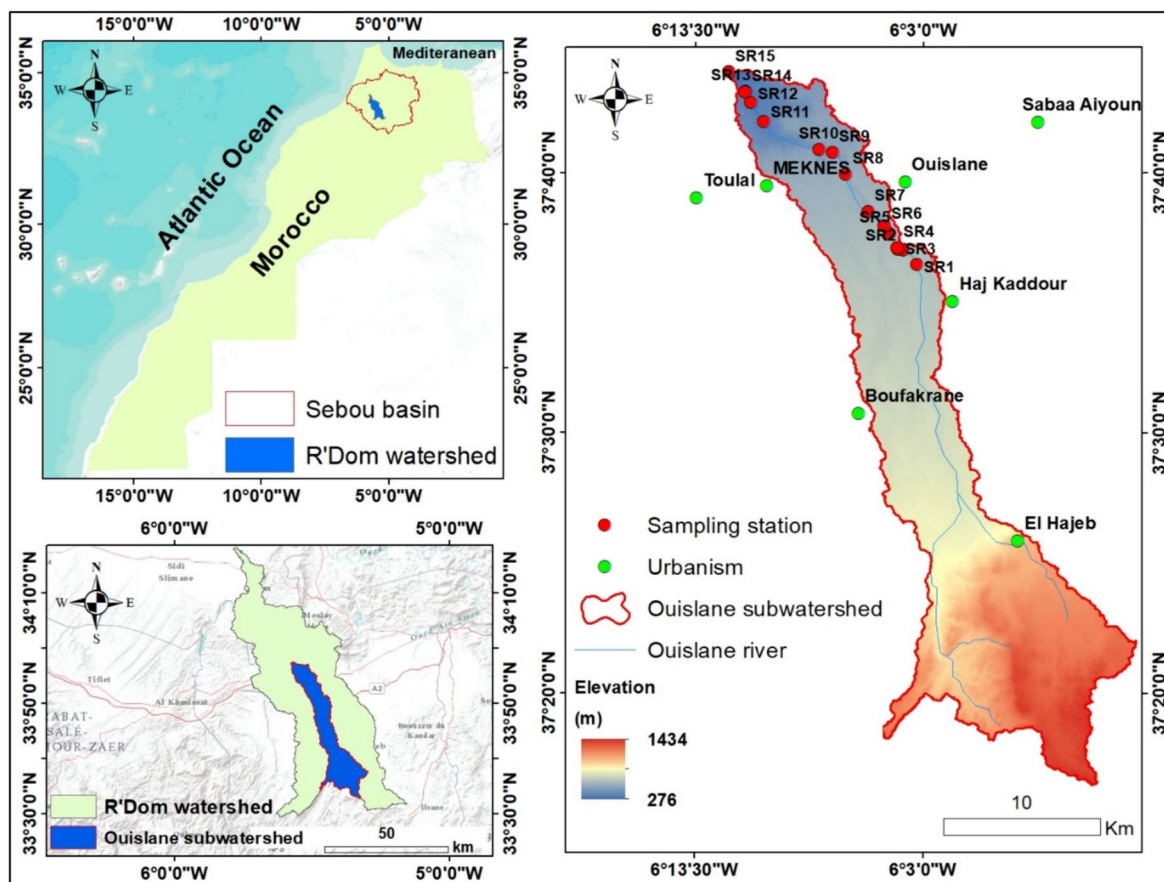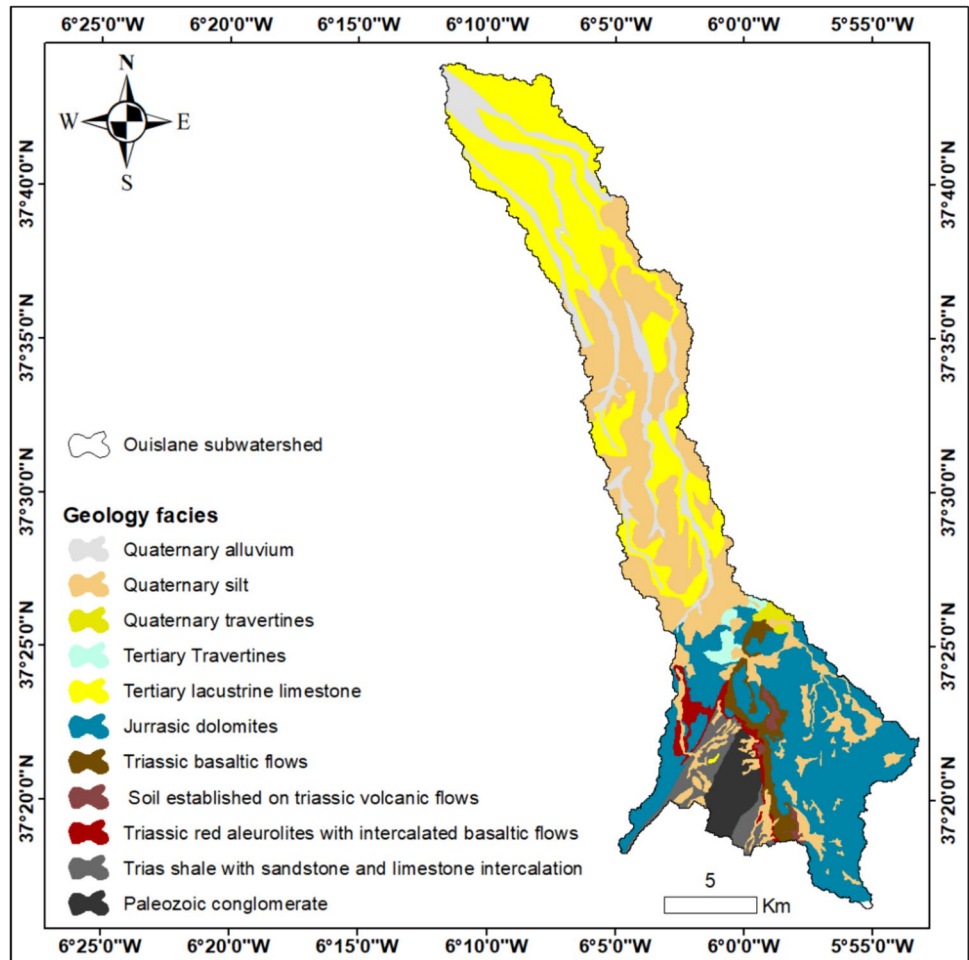

Fig. 1 The location of the study area and sampling stations in the Ouislane subwatershed

Fig. 2 Digitalized geological map of the study area

analytical parameters meet or exceed predetermined standards. QA focuses on systematic processes used to prevent errors, defects, or deviations from established standards. Meanwhile, QC involves testing and monitoring of analyses and processes to identify and rectify any deviations from specified requirements (Bell and Moore 1998). QA/QC is either directly related to or included in the laboratory workbook, and the goodness of analytical data is judged on the basis of accuracy and precision including in the reference materials ("Instruments and Experimental Conditions") (Konieczka 2007), since the instrument had been calibrated before any analysis parameters.

Water sampling and data collection

The applied methodology is grouped into five major steps corresponding to: (1) in situ measurements of water quality variables in the field, (2) sampling, (3) laboratory analysis, (4) data analysis, and (5) interpretation of the results. The assessment of water quality in the study area was conducted during the campaign of March/May 2022 for 15 stations (Table 1). Figure 3 shows the spatial distribution of

Table 1 Location of river sampling stations (longitude: Long. and latitude: Lat.) in the Ouislane subwatershed

Sampling station	Station code	Long. °	Lat. °	Elevation m
Station 1	SR1	− 5.449	33.848	596
Station 2	SR2	− 5.459	33.856	577
Station 3	SR3	− 5.462	33.856	577
Station 4	SR4	− 5.463	33.857	593
Station 5	SR5	− 5.468	33.865	560
Station 6	SR6	− 5.472	33.870	553
Station 7	SR7	− 5.483	33.878	580
Station 8	SR8	− 5.498	33.899	492
Station 9	SR9	− 5.507	33.912	459
Station 10	SR10	− 5.517	33.914	428
Station 11	SR11	− 5.555	33.930	350
Station 12	SR12	− 5.564	33.941	301
Station 13	SR13	− 5.568	33.947	287
Station 14	SR14	− 5.568	33.947	320
Station 15	SR15	− 5.579	33.959	358

Fig. 3 Location map of the Ouislane River: **A** the distribution of sampling stations on the river, **B**–**D** field photos
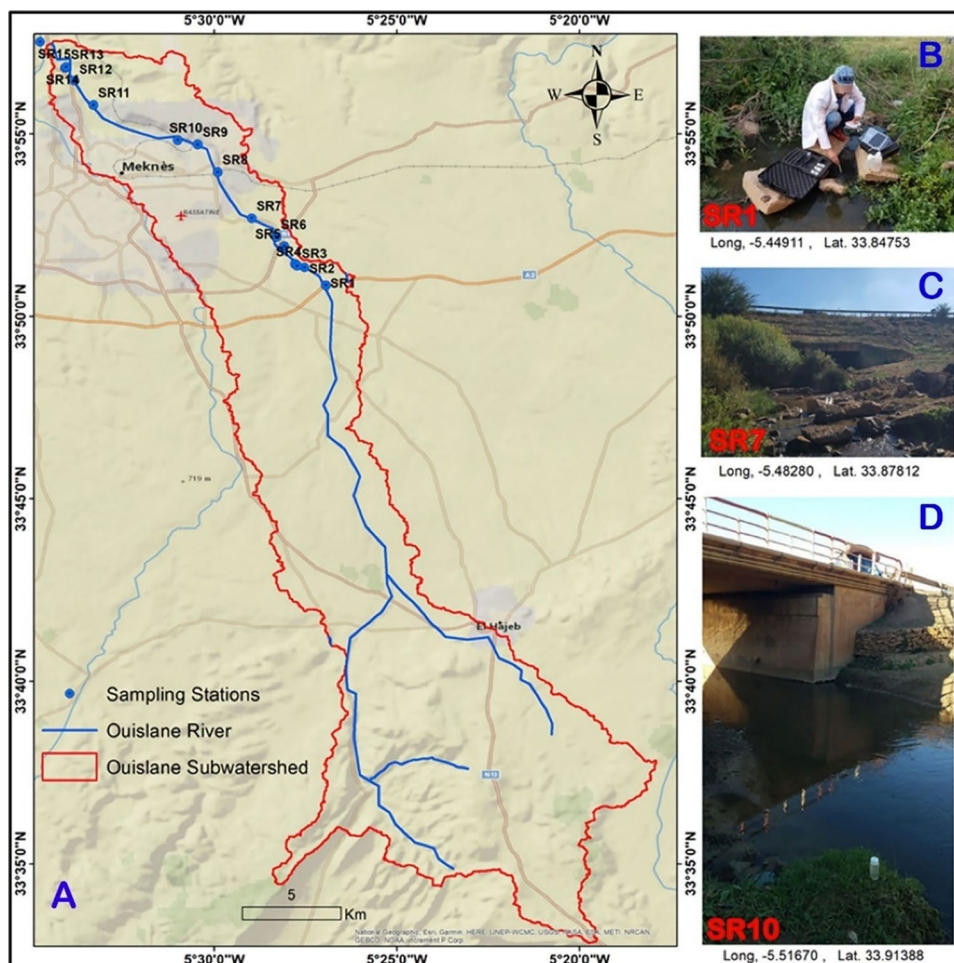
the investigated sites in the river in the Ouislane subwatershed. The sampling sites were selected on specific stations receiving water from natural springs, domestic and industrial wastewater, in order to determine their impact on water quality changes in the Ouislane River. Generally, this study focuses on pollution and contaminants; selecting locations near potential pollution sources (proximity to pollution sources) can provide valuable information on the impact of human activities.

The goodness of analytical data is judged on the basis of the accuracy and precision of instruments. Water samples were collected in the field using glass bottles, previously rinsed with distilled water. These samples were then transported to the laboratory in isothermal iceboxes set at 4 °C, following the recommendations outlined in the Rodier standard. The analysis methods were those recommended by the standards of Rodier et al. (1984, 2016). The analyses cover 15 parameters: pH, T, total dissolved solids (TDS), electrical conductivity (EC), DO, Cl^-, HCO_3^-, NO_3^-, SO_4^{2-}, Na^+, Mg^{2+}, K^+, Ca^{2+}, BOD_5, and carbonate oxygen disolved (COD). Temperature, pH, TDS, and EC were measured in the field using a 900P portable multiparameter water quality meter/

analyzer, which has an accuracy of ± 0.002 pH for pH and 1% for EC and TDS. Dissolved oxygen measurements were performed in the field using an 821P portable dissolved oxygen meter, which has an accuracy of ± 0.2 mg/l. Cation measurements (Na^+, Mg^{2+}, K^+, and Ca^{2+}) of the sampled waters (filtered ($\varphi = 0.45$ μm) into 60-ml glass bottles) were made using ICP-MS (ICPE-9000). The measurements of anions Cl^-, SO_4^{2-} and NO_3^-, were analyzed using a visible spectrophotometer, which has an accuracy of ± 0.05 nm. The bicarbonate values were obtained using a titration procedure with 0.01 N HCl. The biochemical demand was measured using a BOD meter, which has an accuracy of $\pm 8\%$ for BOD_5, and the chemical oxygen demand was determined by adopting the Rodier standard method (T90–101) using an AL 200 photometer, which has a wavelength accuracy of ± 1 nm. The analysis were realized at the 2E2C laboratory and the research center of Moulay Ismail University of Meknes. The quality of water parameters was verified and validated using the charge balance error (CBE) and Moroccan standards (MN). According to Eq. 1, the confirmation of the analytical error in the analyzed ion concentration was crosschecked using the CBE within a limit of 5% (Al-Mashreki

et al. 2023); this was confirmed for the stations investigated in this study and shows the accuracy of the chemical analysis in relation to Moroccan surface water guidelines.

$$\text{CBE} = \frac{\sum \text{Cations} - \sum \text{Anions}}{\sum \text{Cations} + \sum \text{Anions}} \times 100 \qquad (1)$$

The hardness refers to the amount of calcium and magnesium in water and derives from the dissolution of soils and rocks containing Ca and Mg. However, when the water hardness is too high, precipitation of calcium and magnesium carbonates occurs in the irrigation system, whereas too low a hardness can cause corrosion of the irrigation system (Landreau and Monition 1977).

Data analysis

The statistical study was based on principal component analysis (PCA). The intermediate correlation matrices, the (Pearson) correlation coefficient between the variables, and the two axes (component 1) and (component 2) as well as the projection of the variables in the space of component 1 and component 2 were obtained using SPSS software. The correlation matrix groups together all the correlations that exist between the variables (Karroum et al. 2019b). The GIS environment was used to locate the stations studied and represent the spatial evolution of pollution along the river water on thematic maps based on the results of the water quality index (WQI) and the synthetic pollution index (SPI). The irrigation water indices were used to determine the risk to soils in case of water use during irrigation via the sodium adsorption ratio (SAR), percent sodium (%Na), and residual sodium carbonate (RSC) indices (Almeida et al. 2008; Elsayed et al. 2020; Yıldız and Karakuş 2020).

Water quality indices

The water quality index (WQI) and synthetic pollution index (SPI) provide a single value for the quality of water from a river by translating numerous measured parameters. These provide an indicator of the quality of the water with respect to its use in agricultural irrigation (Bora and Goswami 2017; Ali et al. 2021). These indices were calculated by using the following models:

Water quality index model The water quality index (WQI) is defined as a rating reflecting the composite influence of different water quality parameters on global water quality. The WQI was determined by adopting the weighted arithmetic index method (Table 2) by considering many water quality parameters as T°, pH, EC, TDS, DO, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, NO_3^-, COD and BOD_5 to evaluate the suitability of river water for irrigation, as presented

Table 2 Unit weights (W_i) and standard values of different parameters used to calculate thee WQI and SPI (Ali et al. 2021; Krishan et al. 2022)

Parameter	Standard value (V_s)	Unit weight (W_i)
T°	40	0.034435
pH	6.5–8.5	0.183655
EC	300	0.004591
TDS	500	0.002755
Ca^{2+}	75	0.018365
Mg^{2+}	30	0.045914
Cl^-	250	0.005510
DO	5	0.275482
DBO_5	5	0.275482
DCO	10	0.137741
NO_3^-	50	0.00540
SO_4^{2-}	250	0.00108

in Table 3 (Krishan et al. 2022). The WQI is given by the following equation:

$$\text{WQI} = \sum_{i=1}^{n} \frac{W_i Q_i}{\sum_{i=1}^{n}, W_i} \qquad (2)$$

where QWI is the water quality index; W_i is the ith parameter's unit weight; Q_i is the ith parameter's subindex; Q_i is calculated by using the following equation:

$$Q_i = \frac{V_0 - V_i}{V_s - V_i} \qquad (3)$$

where V_0, V_s, and V_i are the observed value, the ideal value, and the standard value, respectively. The optimum values for pH and DO were set to 7 and 14.6 mg/l, respectively, while V_i was set to zero for all other parameters.

Synthetic pollution index model The synthetic pollution index (SPI) is calculated by using the following formula based on the selection of parameters and the unit weight for each parameter (Ali et al. 2021; Krishan et al. 2022); these parameters are the analytical value of the water quality parameters (V_0) and the standard value of the water quality parameters (V_s) recommended by the World Health Organization (WHO) as presented in Table 2.

$$\text{SPI} = \sum_{i=1}^{n} \frac{V_0}{V_s} W_i, \qquad (4)$$

where V_0 represents the analytical value of the water quality parameters; V_s represents the standard value of the water quality parameters; W_i is the ith parameter's unit weight.

Table 3 WQI and SPI ranges for estimation of water quality classification (Ali et al. 2021; Krishan et al. 2022)

WQI range	SPI range	Water classification	Probable usage
1–25	< 0.2	Suitable for drinking	Drinking, irrigation, and industrial purposes
26–50	0.2–0.5	Slightly polluted	Drinking, irrigation, and industrial purposes
50–75	0.5–1.0	Moderately polluted	Irrigation and industrial purposes
75–100	1.0–3.0	Severally polluted	For irrigation purposes
> 100	> 3.0	Unsuitable for human consumption	Proper treatment required for any kind of usage

Irrigation water quality parameter description

The salinity of irrigation water modifies the physical properties of soils and limits the ability of roots to absorb water (Merouche et al. 2020). The quality of surface water intended for irrigation can be determined using several water quality indices such as the irrigation water quality index (IWQ), sodium percentage (Na%), sodium adsorption ratio (SAR), permeability index (PI), Kelley index (KI), and residual sodium carbonate (RSC) (Elsayed et al. 2020; Eid et al. 2023). SAR, %Na^+, and RSC were used to evaluate the water quality appropriate for irrigation.

The SAR is a useful parameter for determining the suitability of water for irrigation on the basis of the comparative concentrations of sodium, calcium, and magnesium (Bauder et al. 2011; Arshad and Shakoor 2017). It is calculated by using the following equation:

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}.$$ (5)

The %Na^+ value is used to assess the suitability of water for irrigation use (Wilcox 1955). A sodium concentration of more than 60% (mg/l) in water leads to an accumulation of Na and, thus, a deterioration of the physical properties of the soil. The sodium concentration should be less than 60% (Mtoni et al. 2013; El Yousfi et al. 2023). It is determined by using the following equation:

$$\%Na^+ = Na^+/(Ca^{2+} + Mg^{2+} + Na^+ + K^+) \times 100.$$ (6)

The RSC is a concept used to evaluate waters with high carbonate concentrations and is calculated by using the formula below (Joshi et al. 2009). It allows for predicting the additional sodium risk related to $CaCO_3$ precipitation involving the calculation of residual sodium carbonate (Arshad and Shakoor 2017). The RSC calculates the danger of using water with a high concentration of bicarbonate that reacts with calcium and magnesium and forms a solid that tends to precipitate, increasing the relative proportion of sodium ions in the water (Yassine and Deliège 2021). It is estimate by using the following equation:

$$RSC \, (mq/l) = (CO_3^- + HCO_3^-) - (Ca^{2+} + Mg^{2+}).$$ (7)

Results

Surface water quality assessment of the Ouislane subwatershed was performed on the basis of 15 physicochemical parameters measured in the surface water at 15 river stations. This work contributes to enrich the databases collected on the R'Dom watershed and provides a clearer picture of the water quality in the rivers of the region. It could be deduced that different types of pollution resulting from anthropic origin occur (agricultural, industrial, and urban).

Physicochemical parameter description

The values of the water quality parameters measured and analyzed for each investigated station are shown in Fig. 4. This analysis was done to assess the suitability of the water for irrigation uses; the classification was based on Moroccan surface water guidelines (2002) (Barakat et al. 2016). The pH did not vary significantly, and the water was generally alkaline, with pH ranging from 7.42 to 8.22, resulting from alteration of the limestone and marl soils that characterize the area. The electrical conductivity varied from 629 to 2000 µS/cm, indicating that all the evaluated water samples were suitable for irrigation according to the Moroccan irrigation standard (< 2700 µS/cm) (Hamdaoui 2018). The total dissolved solids of the water samples ranged from 411 to 842 mg/l, confirming that all the sampled water is suitable for irrigation according to the Moroccan irrigation water classification (< 2000 mg/l) (Table 4). The nitrate values ranged between 2 and 56 mg/l, possibly originating from agricultural activity involving fertilizers, wastewater, and natural processes. The highest concentration was observed at station SR4, situated in the central part of the subwatershed with intense agricultural activity. Concentrations were lower at the other stations, reaching a minimum of 2 mg/l at station SR15 in the northern area. The sulfate concentration ranged from 1.3 to 32.5 mg/l, indicating that the water from all the
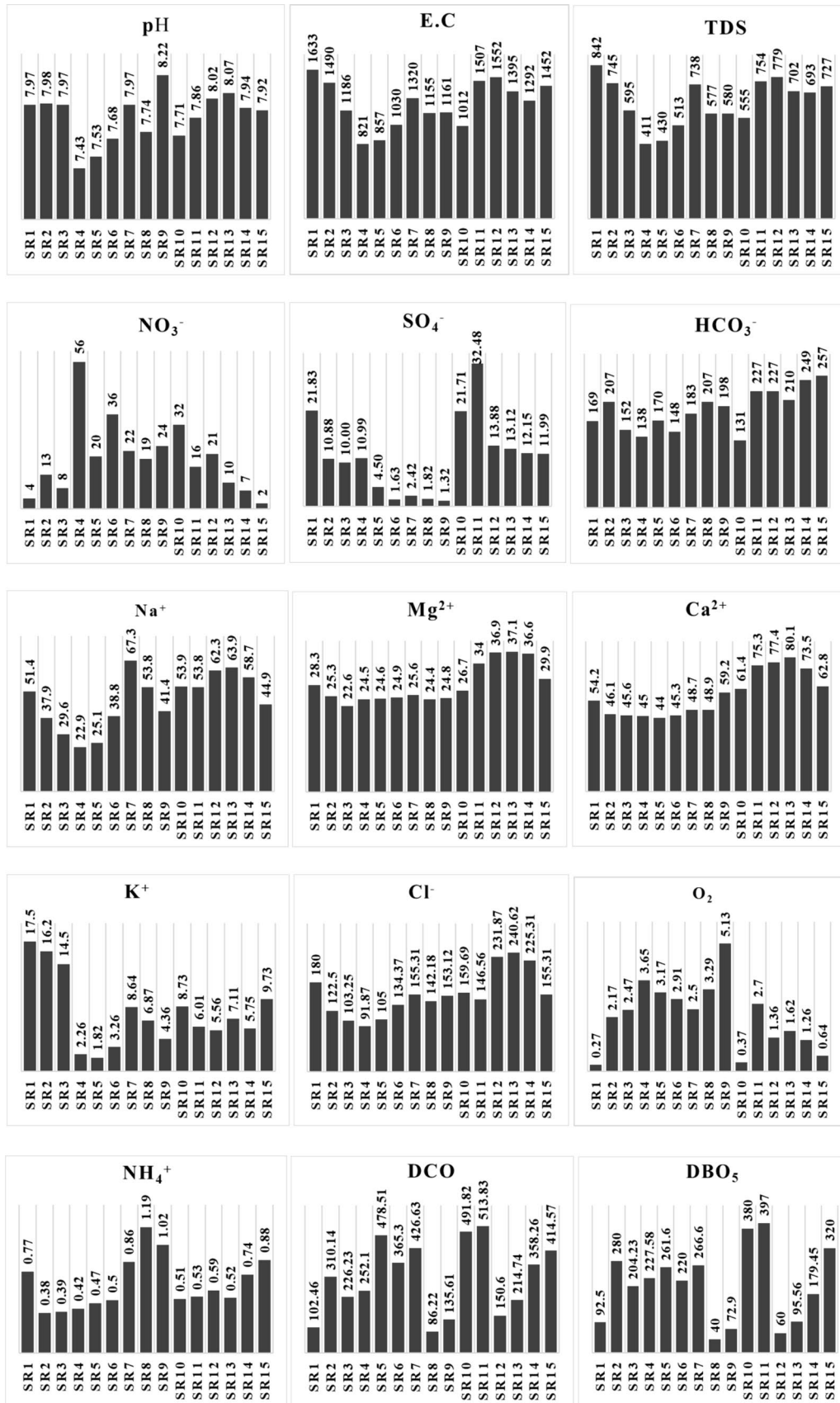
Fig. 4 Spatial evolution of physicochemical parameters along the Ouislane subwatershed

Table 4 Water classification of Ouislane River according to the electrical conductivity, nitrate, and sulfate

	Range	Water class	Total samples	Percentage
Electrical conductivity (μS/cm)	100–250	Low-salinity water	–	–
	250–750	Medium-salinity water	–	–
	750–2250	High-salinity water	15	100
	> 2250	Very high-salinity water	–	–
Nitrate (mg/l)	< 10	Excellent	4	27
	10–25	Good	8	53
	25–50	Moderately polluted	2	13
	> 50	Polluted	1	7
Sulfate (mg/l)	< 192	Excellent	15	100
	192–336	Good	–	–
	336–575	Permissible	–	–
	> 575	Precaution but usable	–	–

Table 5 Chloride levels of irrigation waters and their effects on crops (Zaman et al. 2018)

Cl^- concentration		Total samples	Percentage	Effect on crops
meq l^{-1}	ppm			
< 2	< 70	–	–	Generally safe for all plants
2–4	70–140	5	33	Sensitive plants usually show slight to moderate injury
4–10	141–350	10	67	Moderately tolerant plants usually show slight to substantial injury
> 10	> 350	–	–	Can cause severe problems

sampled stations was excellent for irrigation according to the water classification established for sulfate (Table 4).

The chloride concentration (Cl^-) ranged between 92 and 240 mg/L, with an average of 157 mg/l. Among all the samples, 33% posed a moderate risk to sensitive plants, while 67% presented a slight to substantial risk to moderately tolerant plants (Table 5). The dissolved oxygen values for the investigated stations ranged from 0.25 to 5.13 mg/l. The bicarbonate (HCO_3^-) ranged between 131 and 257 mg/l; this can derive from interaction with soils containing carbonates, dissolving carbon dioxide (CO_2) through naturally circulating water. Calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) will tend to precipitate from water rich in carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) when the soil solution is concentrated by evapotranspiration. The sodium concentration ranged between 22.9 and 67.9 mg/l; this element contributes directly to the total salinity of the water and can be toxic to sensitive crops, being considered as one of the most undesirable elements in irrigation, which can come from rock, soil alteration, treated water, or irrigation systems. The calcium concentration ranged from 44 to 80.1 mg/l, while magnesium ranged from 22.6 to 37.1 mg/l. The calcium was generally higher than magnesium in all the investigated waters; this can derive from the alteration of limestone and dolomite lithology (Fig. 2). The biological oxygen demand (BOD_5) varied between 40 and 397 mg/l, indicating that the evaluated waters were highly polluted according to the Moroccan surface water guidelines (Barakat et al. 2016). The carbonate (COD) varied from 86 to 513.3 mg/l, and according to the Moroccan surface water guidelines (Barakat et al. 2016), all evaluated waters were organically polluted (COD > 40).

Irrigation water quality

Irrigation surface water suitability was calculated on the basis of the referenced water quality indices, including SAR, %Na, and RSC values (Table 6). According to the SAR values, all the river water samples were excellent (SAR < 10) for irrigation. The Na% ranged from 18.7% to 38.5% with an average value of 27.1%, indicating good to permissible irrigation quality. The RSC values ranged from –3.6 to –0.9, with an average of –2.1, indicating a good water category, which is suitable for irrigation use (RSC < 1.25).

Hydrochemistry facies

The hydrochemical evolution of water may be understood on the basis of Piper (1944), Wilcox (1955), and Schoeller (Güler et al. 2002) diagrams. The results are represented as diagrams using Diagrammes software version 6.77. The Piper diagram (Fig. 5) represents the percentage concentration values of the main anions (Cl^-, SO_4^{2-}, HCO_3^- and NO_3^-) and cations (Ca^{2+}, Na^+, K^+, and Mg^{2+}) plotted in triangles to determine the dominant chemical composition of water

Table 6 Irrigation water quality parameters (Eaton 1950; Wilcox et al. 1954; Mtoni et al. 2013)

Irrigation water quality parameters										
SAR			%Na				RSC			
Range	Sodicity class	Sodicity hazard	Range	Water class	Investigated water classification		Range	Water class	Investigated water classification	
					Total	%			Total	%
<10	S1	Low	<20	Excellent	No stations		>2.5	Not suitable	No stations	
10–18	S2	Medium	20–40	Good	13	87	1.25–2.5	Marginal	No stations	
18–26	S3	High	40–60	Permissible	2	13	<1.25	Safe	15	100
>26	S4	Very high	60–80	Doubtful	No stations		Remark:		No station	
Remark: All stations are suitable			>80	Unsuitable	No stations		All stations are safe		No stations	

(Piper 1944; Ewaid 2018; El Yousfi et al. 2022). The Wilcox classification (Fig. 6) is the most common method for classifying water for agriculture; EC and SAR (or % Na) are the two factors used in this classification. They are divided into four parts, resulting in 16 water quality categories (Afzali et al. 2014). The Schoeller diagram (Fig. 7) is employed to study and plot the chemical composition and ion concentrations (meq/l) (Güler et al. 2002; El Yousfi et al. 2023).

A projection of the data on the Piper diagram (Fig. 5) showed a facies chloride type (Cl^-) and mixed type (Cl^-, SO_4^{2-}, NO_3^-, Ca^{2+}, and Mg^{2+}), which were the dominant ions, while Ca^{2+}, Mg^{2+}, Na^+, and K^+ (codominant ions) were the major elements in the composition of the river water. According to this diagram, the waters of this river had one hydrochemical facies rich in calcium, magnesium, chloride, sodium, potassium, and bicarbonate.
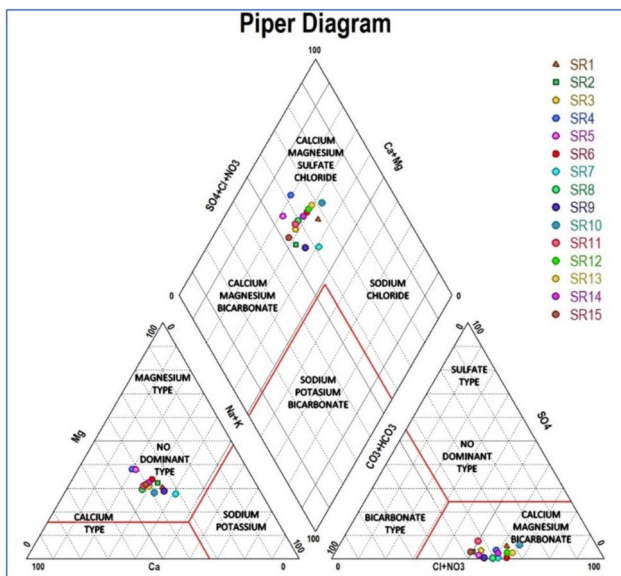

Fig. 5 Classification of the major hydrochemical facies of Ouislane River (Piper trilinear diagram)

Figure 7 shows the Wilcox classification of river water for irrigation suitability; the high values of conductivity and sodium in the river water show high proportions of salinity in the water, which reduce its suitability for irrigation and cause problems when used. A plotting technique based on the percentage of sodium and electrical conductivity is applied to better understand the water suitability categories for irrigation activity (Wilcox 1955). Na^+ is an essential cation but, in excess, deteriorates soil structure and reduces crop yields (Ayers and Westcot 1985). The results for water plotted on the diagram (Fig. 6) showed two categories for irrigation activity: excellent to good, and good to permissible classes. A percentage of sodium above 60% in irrigation water had an adverse effect on soil (Wilcox 1955). According to Wilcox diagrams (Fig. 6), all the investigated waters belonged to the high saline with low sodium (C_3S_1) category, which indicates water suitable for irrigation of salt-tolerant crops on well-drained soils, although the evolution of salinity must be monitored.

According to the results of the Schoeller diagram (Fig. 7), the similar slope lines connecting the concentrations of different parameters indicate that the water comes from a similar source. Most waters with high sodium content also have high chloride concentrations (Schoeller 1965). This diagram on a logarithmic scale allows one to identify one chemical facies and to confirm the results found by the Piper diagram, i.e., dominant Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^- and HCO_3^- species.

Correlation between hydrochemical parameters

For a preliminary assessment of the hydrochemical source of the facies and to provide insights into possible geochemical processes influencing water chemistry, a bivariate correlation technique was initially applied to establish the significant hydrochemical sources on the basis of the total dissolved solids (TDS) and electrical conductivity (EC). We assume that a correlation factor $R^2 > 0.5$ implies a statistically significant degree of correlation.

Fig. 6 Classification water for irrigation suitability of Ouislane River (Wilcox diagrams)
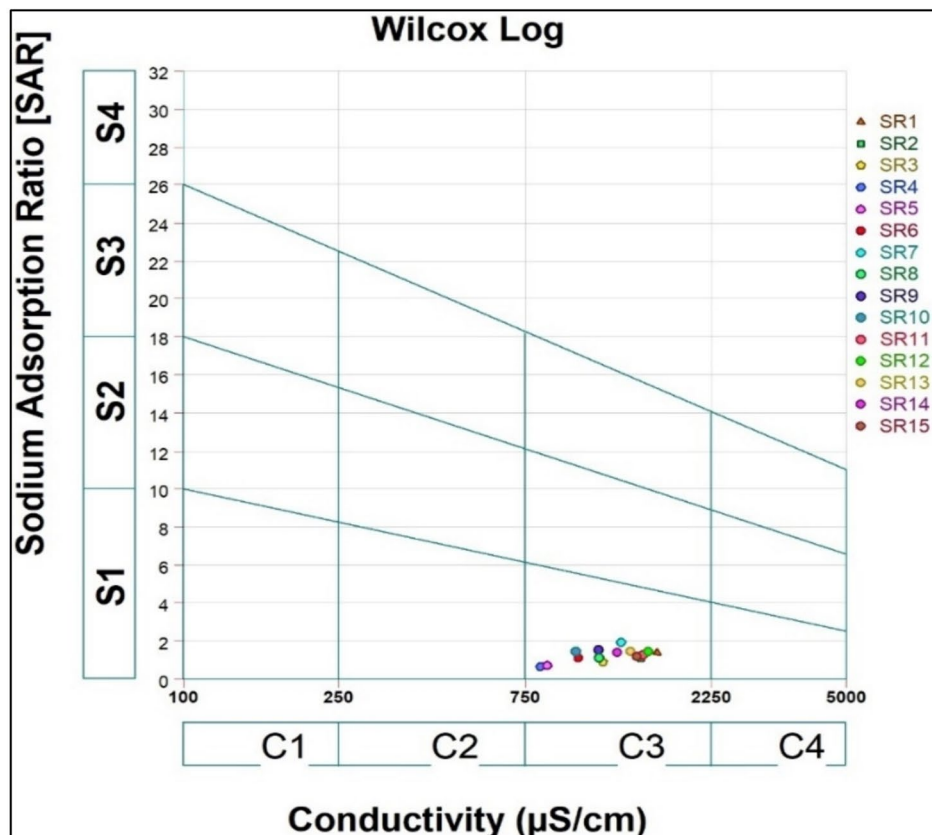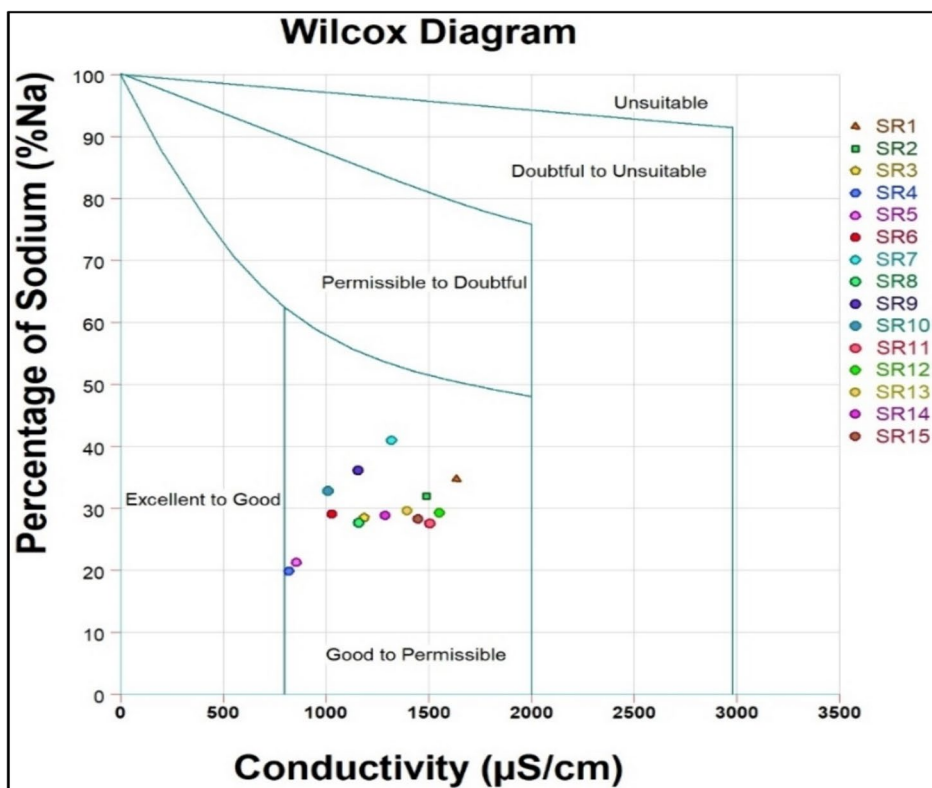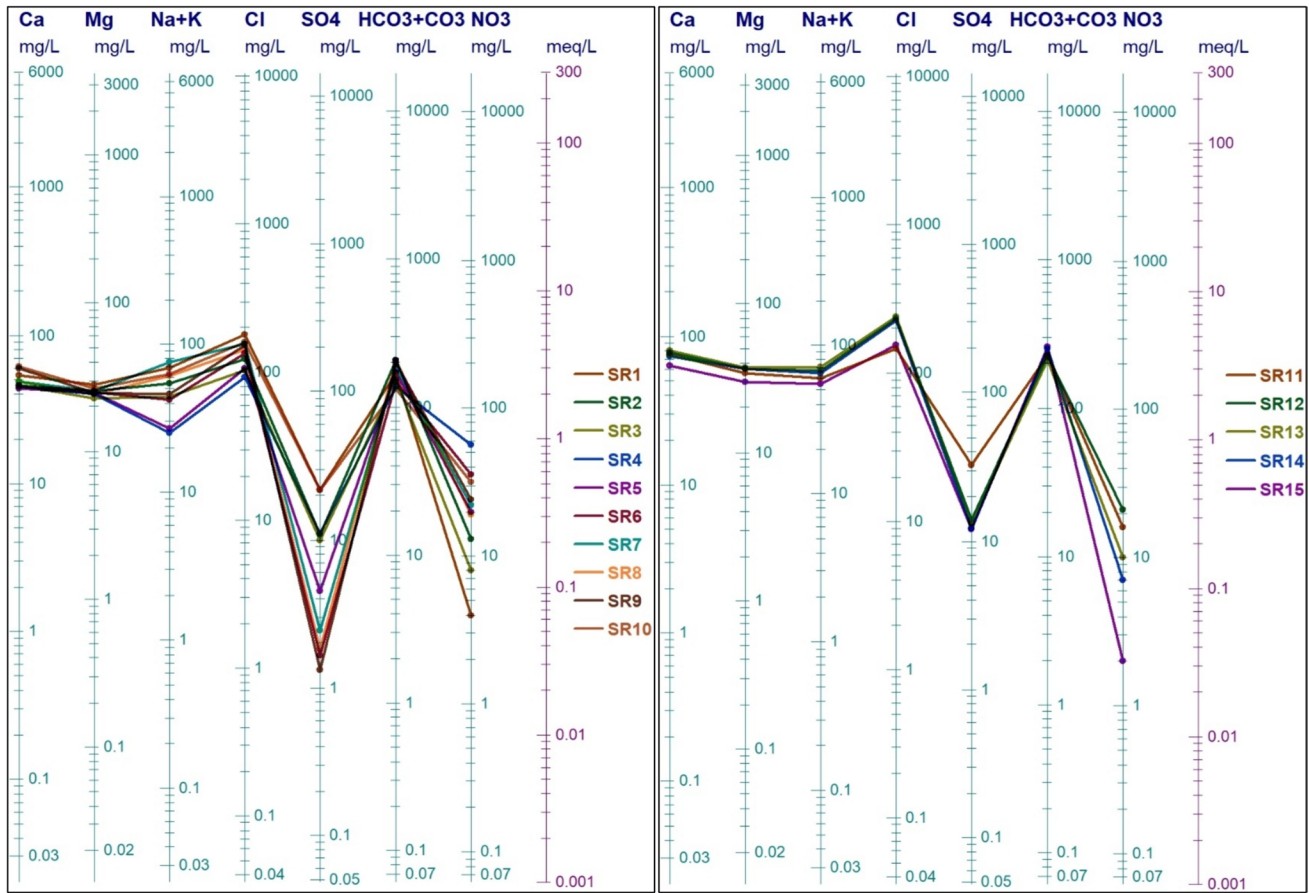
Fig. 7 Position of the water samples of Ouislane River on the Schoeller plot (Schoeller diagram)

The results, presented in Table 7, indicate a strong correlation between EC and TDS with HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, and K^+, suggesting that these elements are the principal sources of mineralization. There was also a good and positive correlation between Ca^{2+} and Mg^{2+} ($R^2 = 0.94$) and HCO_3^-, showing that these species could have originated from carbonate alteration or dolomites ($CaMgCO_3$).

Table 7 Pearson correlation matrix for Ouislane River parameters

	T°	pH	E.C	O2	TDS	HCO3-	Cl-	NO3-	Na+	K+	Mg2+	Ca2+	DBO5	DCO	SO4-
T°	1.00														
pH	-0.63	1.00													
E.C	-0.38	0.72	1.00												
O2	0.06	-0.11	-0.51	1.00											
TDS	-0.45	0.71	0.98	-0.56	1.00										
HCO3-	-0.29	0.51	0.63	-0.18	0.60	1.00									
Cl-	-0.61	0.56	0.57	-0.50	0.61	0.54	1.00								
NO3-	0.21	-0.63	-0.71	0.47	-0.70	-0.62	-0.41	1.00							
Na+	-0.65	0.52	0.60	-0.44	0.68	0.47	0.82	-0.36	1.00						
K+	-0.07	0.44	0.60	-0.51	0.61	0.01	0.01	-0.59	0.11	1.00					
Mg2+	-0.24	0.37	0.57	-0.47	0.56	0.66	0.87	-0.37	0.65	-0.12	1.00				
Ca2+	-0.27	0.48	0.53	-0.38	0.53	0.63	0.84	-0.35	0.67	-0.13	0.94	1.00			
DBO5	0.54	-0.36	-0.14	-0.20	-0.10	-0.13	-0.41	0.12	-0.19	0.02	-0.13	-0.10	1.00		
DCO	0.39	-0.36	-0.22	-0.17	-0.15	-0.03	-0.22	0.09	-0.05	-0.23	0.03	0.02	0.91	1.00	
SO4-	0.32	0.04	0.46	-0.55	0.45	0.12	0.23	-0.21	0.24	0.29	0.49	0.53	0.42	0.27	1.00

The Pearson correlations of the physical and chemical data for the Ouislane River are presented in Table 7.

The values in Table 8 show the correlation between the variables and factors of principal component analysis. A correlation coefficient of zero means that there is no linear relationship between variables and principal component factors, while correlation coefficient values of –1 or +1 indicate a perfect linear relationship. The strength of the relationship can be between –1 and +1, and the values ranging from 0.5 to 1.0 indicate a strong positive correlation for the Ouislane River, and vice versa on the negative side. The first component (F1) was defined by the parameters nitrate (–0.720) and dissolved oxygen (–0.672) on the negative side, pH (0.647) with EC (0.868), TDS (0.894), HCO_3^- (0.717), Cl (0.799), Mg (0.810), Ca (0.788), and Na (0.775) on the positive side. The second component (F2) was defined by the organic pollution parameters of BOD_5 (0.942), COD (0.896), and SO_4^- (0.628). Sulfates had a strong correlation with both components: 0.552 for axis F1 and 0.628 for F2.

Principal component analysis (PCA)

PCA is a multivariate analysis method. It aims to group a large number of variables into a limited number of factors to facilitate the analysis of these factors and to detect any independent relationships between the different variables (El Yousfi et al. 2023; Alitane et al. 2024). PCA can be used for quantitative, ordinal qualitative, or nominal variables. In this work, PCA was used for quantitative variables of water quality. The analysis of the results showed that the first two factorial axes (F1 × F2) explained most of the information (64.35%); the first factor represented 45.61% of the total variable information, while the second factor represented 18.74%. The variables K^+, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, TDS, EC, Cl^-, and pH had a positive correlation with component 1, while NO_3^- and DO had a negative correlation with the same component. On the other hand, the variables COD and BOD_5 had a positive correlation with component 2 (Fig. 8a).

The typological structure revealed by the plot of components 1 and 1 (F1XF2) showed the individualization of three different groupings according to their hydrochemical quality (Fig. 8b): group I, formed by the first three stations characterized by low mineralization and a very high organic load; group II, formed by the stations (SR4, SR5, SR6, SR8, SR9, and SR10) where a very high decrease in the initial organic pollution was observed; group III, formed by the stations located downstream of the studied river, which are connected to several water sources, including springs that

Table 8 Correlation coefficients between the variables and the main axes

Variable		TDS	EC	Mg^{2+}	Cl^-	Ca^{2+}	Na^+	NO_3^-	HCO_3^-	DO	pH	K^+	DBO_5	DCO	T	SO_4^{2-}
Component	F1	**0.894**	**0.868**	**0.810**	**0.799**	**0.788**	**0.775**	–0.720	**0.717**	–0.672	**0.647**	0.376	–	–	–0.392	0.552
	F2	–0.154	–0.183	–	–0.347	–	–0.226	–	–0.113	–0.320	–0.516	–	**0.942**	**0.896**	**0.687**	**0.628**

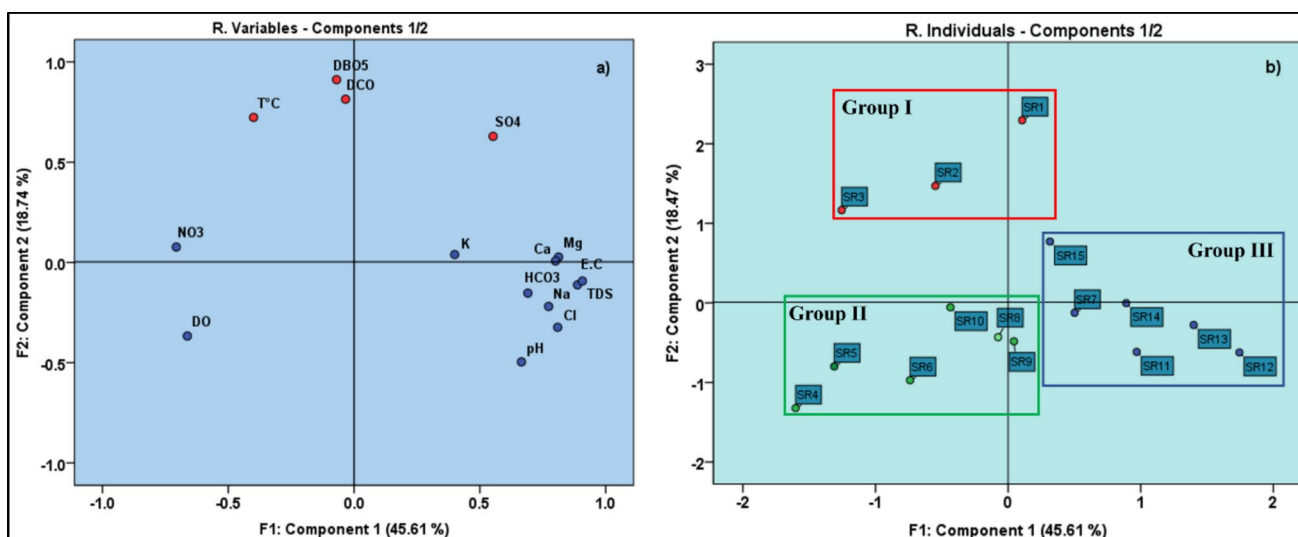Bold indicates a strong positive correlation between the water parameters and the PCA factors

Fig. 8 Graphical presentation of the PCA of physicochemical parameters in water according to the study (*F*1 × *F*2). **a** Factorial map of variables; **b** Factor map of sampling stations

Table 9 WQI categorization for water quality assessment

Range	Water class	Total samples	Percentage
0–25	Suitable for drinking	–	–
26–50	Slightly polluted	1	7
51–75	Moderately polluted	4	27
75–100	Severally polluted	–	–
>100	Unsuitable for human consumption	10	67

Table 10 Categorization for water quality assessment

Range	Water class	Total samples	Percentage
<0.2	Suitable for drinking	–	–
0.2–0.5	Slightly polluted	–	–
0.5–1	Moderately polluted	1	7
1–3	Severally polluted	6	40.00
>3	Unsuitable for human consumption	8	53

contribute to an increased mineralization rate of the water. These stations are characterized by high mineralization and a low organic load.

Water quality assessment through WQI and SPI

The water quality classification of the Ouislane River was based on the calculated values of the water quality indices. The obtained values of WQI and SPI are presented in Tables 9, 10, and 11, and their spatial distribution is shown in Figs. 9 and 10. The calculated WQI values ranged from 38.05 to 198.21, while the SPI values ranged from 0.99 to 5.51. A very variable quality characterized the waters of the Ouislane River. According to the WQI classification, 67% of water was unsuitable for human consumption (SR2, SR3, SR4, SR5, SR6, SR7, SR10, SR11, SR14, and SR15), 27% was moderately polluted (SR1, SR9, SR12, and SR13), and 7% was slightly polluted (SR8). Meanwhile, the SPI results showed that the water quality in the Ouislane River was dominated by water unsuitable for human consumption (53%) at SR2, SR4, SR5, SR6, SR7, SR10, SR11, and SR15 stations, followed by severally polluted (40%) water at SR1, SR3, SR9, SR12, SR13, and SR14 stations, then moderately polluted (7%) water at station SR8. The obtained maps were generated by applying IDW interpolation using Arc-GIS 10.8 software.

Theoretical and practical implications

The success of methods used to assess river water quality depends on the monitoring scale and the quality of the measured data. It is possible to extend its application by incorporating a regional perspective and providing strategic information to decision-makers and stakeholders. However, for water quality, it is crucial to have a comprehensive understanding of key hydrological conditions of the selected region to guarantee accurate and relevant results. The proposed assessment process provides decision-makers and stakeholders with a valuable tool that rationalizes their efforts. Adapting management strategies to situations identical to those used in this study can amplify the significance of its results. Ultimately, the long-term advantages extend

Table 11 Physicochemical composition and irrigation quality parameters of the river samples from the Ouislane subwatershed

Samples	Na^+ meq l^{-1}	Ca^{2+}	Mg^{2+}	K^+	HCO_3^-	SAR	RSC	% Na	WOI	SPI
SR1	2.23	2.71	2.33	0.45	2.770	1.41	− 2.27	28.89	56.81	1.43
SR2	1.65	2.305	2.08	0.42	3.393	1.11	− 0.992	25.56	136.43	3.82
SR3	1.29	2.28	1.86	0.37	2.491	0.90	− 1.649	22.24	101.48	2.90
SR4	1	2.25	2.02	0.06	2.262	0.68	− 2.008	18.76	109.61	3.24
SR5	1.09	2.2	2.02	0.05	2.786	0.75	− 1.434	20.34	150.40	4.15
SR6	1.69	2.26	2.05	0.08	2.426	1.15	− 1.884	27.80	124.40	3.45
SR7	2.93	2.44	2.02	0.22	2.999	1.97	− 1.461	38.50	147.99	4.04
SR8	2.34	2.45	2.01	0.18	3.393	1.57	− 1.067	33.52	38.05	0.99
SR9	1.8	2.96	2.04	0.11	3.245	1.14	− 1.755	26.05	54.65	1.61
SR10	2.34	3.07	2.2	0.22	2.147	1.44	− 3.123	29.89	185.43	5.14
SR11	2.34	3.76	2.8	0.15	3.720	1.29	− 2.84	25.86	198.21	5.51
SR12	2.71	3.87	3.04	0.14	3.720	1.46	− 3.19	27.77	56.10	1.35
SR13	2.78	4.01	3.05	0.18	3.442	1.48	− 3.618	27.74	73.70	1.86
SR14	2.55	3.68	3.01	0.14	4.081	1.39	− 2.609	27.19	116.10	3.00
SR15	1.95	3.14	2.46	0.25	4.212	1.17	− 1.388	25.00	162.34	4.40

Fig. 9 Ouislane River water quality index (WQI) for suitability assessment for irrigation activity
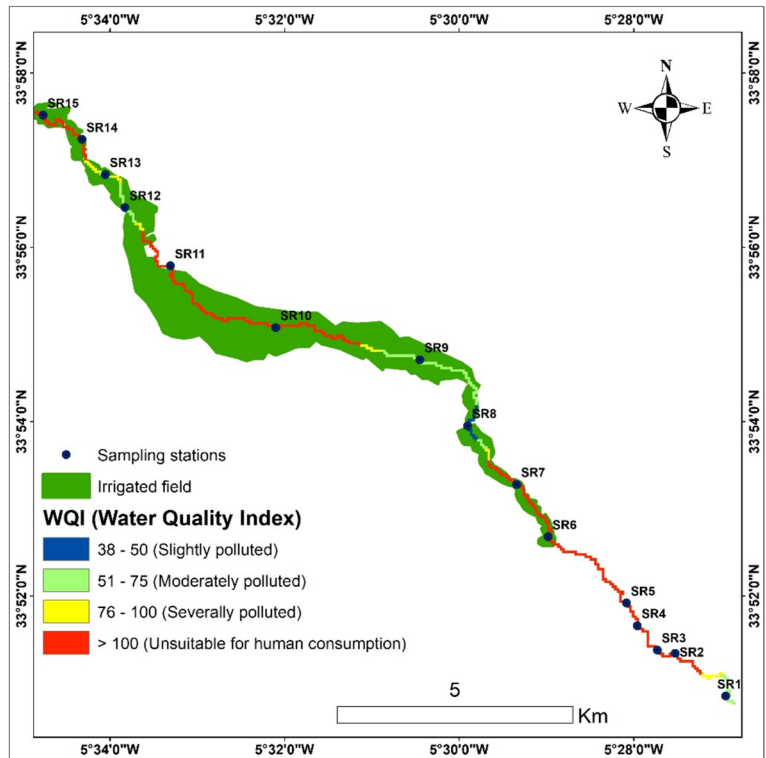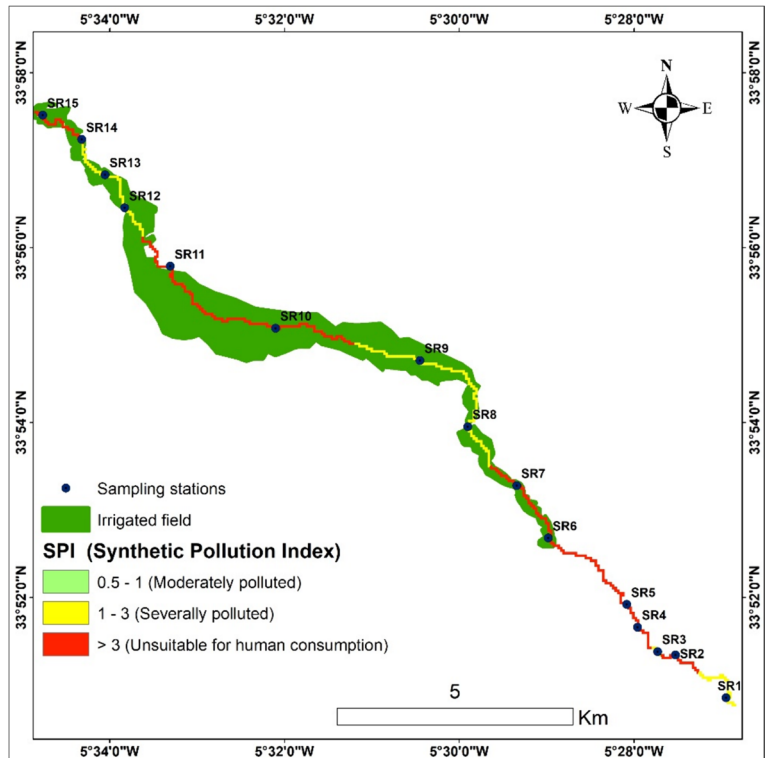

Fig. 10 Ouislane River synthetic pollution index (SPI) for suitability assessment for irrigation activity

to the natural environment and socioeconomic structure of the region.

Discussion

This study was undertaken to assess the water quality of the Ouislane River using new methods. The novelty of this research project focused on the integration of WQI and SPI results into a GIS environment, based on recent input data as physicochemical parameters and field observations. These results were then compared with irrigation water quality parameters to assess the suitability of water for irrigation purposes in the Ouislane subwatershed. The obtained hydrochemical element results indicate that the concentrations of cations were in the order $Ca^{2+} > Na^+ > Mg^{2+} > K^+$, while $Cl^- > HCO_3^- > SO_4^{2-}$ and NO_3^- for anions. These measured water variables cannot be considered to provide discrete conclusions on the extent to which river water quality deviates from the irrigation standard. The assessment of the suitability of water for irrigation use was made using the water quality index (WQI), synthetic pollution index (SPI), and three irrigation water quality parameters, viz. the sodium adsorption ratio (SAR), percent sodium (%Na^+), and residual sodium carbonate (RSC). Fifteen physicochemical parameters were analyzed to achieve the study objectives. According to the WQI and SPI indices (Tables 9 and 10), 67% and 53% of the total water samples were unsuitable for human consumption, while 27% and 7% were moderately polluted, respectively, and 7% was slightly polluted according to the WQI and 40% was severally polluted according to SPI. The SAR, %Na^+, and RSC parameters were found to lie in the good and permissible ranges, confirming the suitability of the water for irrigation use while a few water treatments are needed to render the water fit for drinking use. The Piper diagrams showed a predominance of facies chloride type (Cl^-), a dominance of ions presenting a mixed type (Cl^-, SO_4^{2-}, NO_3^-, Ca^{2+}, and Mg^{2+}), and a codominance type (Ca^{2+}, Mg^{2+}, Na^+, and K^+). Meanwhile, the Wilcox plots showed the good to permissible water category (C_3S_1), indicating the acceptability of all the investigated water for irrigation use. In addition, the main point sources of water pollution were untreated industrial (SR5 and SR6) and domestic wastewater (SR1, SR3, SR4 SR9, and SR10) and landfill (SR2 and SR7), while the main source of diffuse pollution was agriculture (SR8, SR10, SR11, SR12, SR13, SR14, and SR15). The pollution levels in the Ouislane River were quite high and had contaminated the river's course for several kilometers. Moreover, as the Ouislane River was used for irrigating crops, significant public health issues could develop. The obtained results and the previous studies highlight the urgent need

to construction wastewater management plans for remediation and improvement of the water quality of the Ouislane River, which is one of the main sources of water in the R'Dom watershed.

According to the principal component analysis, the results indicate a high degree of mineralization and organic load, linked to and associated with the lithological facies or soil type crossed by the river and reinforced by the wastewater of both domestic (Ouislane Commune) and industrial (Sidi Slimane Moul Al Kifane) activities, agriculture (El Addouli et al. 2011), and spring water. Most of the physicochemical parameters analyzed in the Ouislane River closely resemble results obtained in previous studies. By comparing the physicochemical analysis results of the Ouislane River with other studies of the Ouislane River (El Addouli et al. 2011), the Khoumane River (Moussa et al. 2012), and the Boufakrane River (Abrid et al. 2011; Taha et al. 2020), a strong similarity is observed in their findings and those obtained in the selected study area. The obtained results were confirmed and validated by the work of the water quality evaluation and determining the major sources of contamination, using the water quality index (WQI) and multivariate statistics in the Sebou watershed. It was observed that approximately 73% of the investigated water in the Sebou watershed was of poor to very poor quality, which can be attributed to intense agricultural, industrial, and urban activities (Chadli and Boufala 2021). Accordingly, the results of the monitoring of physicochemical variables and fecal contamination in surface waters of the Inaouene River, Upper Sebou, Morocco (Sghiouer et al. 2022) illustrate a strong similarity to the results observed for the Ouislane River. According to a study on the surface water quality in the Sebou Basin (Soumaila et al. 2021), the water quality of rivers improved during the wet season compared with the dry season. However, several river portions, including the central part of the R'Dom watershed representing the Meknes City, Fez (north of the City of Fez), and Inaouene, remain polluted and cannot be used for human or animal consumption without advanced treatment. Ouislane River provides a good example, under Mediterranean weather conditions, of severe pollution resulting from hydrochemical conditions strongly affected by domestic, agricultural, and industrial activities. According to the irrigation water quality evaluation of the Srou River (Middle Atlas, Morocco), there is a small difference in terms of some physicochemical parameters, with a slight similarity in hydrochemical facies according to Piper and Wilcox diagrams (Karroum et al. 2019a). The primary influence on water quality in Ouislane River was identified to be the mineralogy of the water, primarily derived from the interaction of water with geological facies in the region (Fig. 2).

The research suggests that the SAR, %Na^+, and RSC show promise as tools for assessing water quality to support decision-making regarding water use for irrigation at

the basin level. The high level of nitrate at unpolluted sites confirms the limited role played by agricultural activities in the pollution of the Ouislane River compared with the low nitrate levels in the Fez River (Perrin et al. 2014). Generally, these irrigation waters of the Ouislane River can be used with certain precautionary measures such as mixing the irrigation waters with less polluted water sources, providing organic matter, and cultivating crops that are resistant to pollution. In the study area, industrial wastewater is discharged directly into the river. Industrial wastewater differs according to the type of company activity (with biodegradable or not biodegradable organic matter, oils, heavy metals, and saline water). In general, industrial activity is a major consumer of water and the source of a large quantity of effluents loaded with micropollutants and other undesirable elements (heavy metals, solvents, hydrocarbons, pathogenic microorganisms, and nutrients that stimulate the growth of algae). The discharge of wastewater into Ouislane River leads to a degradation of water quality. Toxic substances in wastewater could have serious consequences for aquatic environments. These chemicals could have caused biological perturbations, leading to various problems in the reproduction, growth, or immune system of aquatic organisms. Irrigation water quality assessment is crucial for agricultural productivity and environmental sustainability. It helps optimize crop growth, minimize crop disease risks, and conserve water resources. Assessing water quality is part of global efforts to address water scarcity and enhance food security. However, limitations in materials and data availability may affect accuracy. Future developments could include advanced technologies for monitoring water quality.

Conclusions

The Ouislane subwatershed is located in the central part of the R'Dom watershed in the north of Morocco. This research project introduced a novel approach by integrating water quality index (WQI) and synthetic pollution index (SPI) results into a GIS environment to evaluate the suitability of water for irrigation and comparing the integrated results with irrigation water quality parameters. The study aimed to assess the impact of domestic, industrial, and agricultural activities on the water quality. Several water quality parameters were determined for 15 sites along the river. The water quality assessed using these integrated techniques indicated that the river water was acceptable for irrigation, being slightly, moderately, and severely polluted, and requiring appropriate treatment for any kind of use. Comparing these results with the irrigation water quality parameters (SAR, Na%, and RSC) and water irrigation standards shows that the water quality at all the investigated sites was suitable for irrigation. According to the principal component analysis,

the elevated levels of mineralization were the primary factors influencing the water quality status at most stations. This observation can be attributed to their stronger correlation with F1 of the PCA, which explains 45.61% of the water quality variance. The high concentration of chemical elements in the water results from the interaction between water and the geological rocks that are characteristic of the region. This study has some limitations due to the data availability, because it only assesses water quality in the Ouislane River during the March/May 2022 campaign. Environmental conditions and pollution levels can vary significantly throughout the year owing to seasonal changes, variable agricultural practices, and industrial activities. As a result, the results may not fully represent the long-term water quality status of the river. It is recommended in the future to conduct longitudinal studies spanning multiple seasons and years to offer a deeper understanding of the temporal and spatial variability of water quality parameters, thereby identifying trends and long-term pollution impacts. Additionally, pretreatment of domestic and industrial wastewater is necessary before discharge into the river.

Improvement in water quality is closely associated with reducing sources of pollutants discharged into the river and the establishment of monitoring stations by the responsible authorities. The aspects of this study can be incorporated into future research projects, and the aim will be to continually refine and extend the applicability of these water quality assessment techniques, ultimately contributing to more efficient and sustainable water resource management practices. The results of this research project are intended to be useful for policy and decision-makers involved in water resource management. The findings could help inform decisions related to water quality, irrigation practices, and environmental conservation.

Availability of data and materials All data generated or analyzed during this study are included in this published article.

Declarations

Conflict of interest The authors declare no conflicts of interest.

Ethical approval Not applicable.

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