



# Assessment of the water quality in the main rivers of Morocco

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Received: 4 June 2022 / Accepted: 16 January 2023 / Published online: 13 February 2023  
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## Abstract

Throughout the world, the use of water resources is increasing with industrial development, agro-food, and economic and demographic growth, which causes the degradation of their quality by polluted discharges. This requires controls and monitoring of these natural resources. In order to develop a diagnostic of the level of pollution of the waters of these rivers and to evaluate the health risks, this work's focus was on the characterization of pollution by metallic trace elements (chromium, lead, and copper) of surface waters in the major Moroccan rivers. In addition, it should be noted that the analysis of metallic elements in sediments is an indicator of contamination of river water by trace metals. The chosen approach focused first on analyzing samples by inductively coupled plasma mass spectrometry. In this sense, six sampling campaigns were carried out at two campaigns per watercourse (dry period and wet period). All the samples analyzed for chromium are of good quality, with average concentrations of 1.75 µg/l for the lower Moulouya and 3.4 µg/l for Oum Er Rbia. On the other hand, 64% of the samples taken at the level of the Sebou are of poor quality with an average concentration of 181.25 µg/l, which exceeds three times the standard (50 µg/l). Regarding lead and copper, the analysis results show that the average concentrations are always lower than the quality values (average to excellent for the three rivers). The electrical conductivity values recorded in Oum Er Rbia and lower Moulouya are very high; 71% of the water analyzed in lower Moulouya is of poor quality. To perform this work, the results obtained were analyzed by calculating the existing correlations between the various parameters studied and determining the water pollution index to calculate the overall quality in each sampling station. It can be deduced that the water pollution index in the three rivers studied indicates that the overall quality of the Sebou varies from pure to heavily contaminated. In Oum Er Rbia, the quality is pure to moderately polluted, while in lower Moulouya the quality is pure for all sampling points.

**Keywords** Contamination · Water pollution index · Sebou · Oum Er Rbia · Lower Moulouya · Morocco

## Abbreviations

CE Electrical conductivity  
Cr Chromium  
Cu Copper

ICP-MS Inductively coupled plasma mass spectrometry  
ISO International Organization for Standardization  
Pb Lead  
PE Bouteilles en polyéthylène  
pH Potential hydrogen  
T°C Temperature in degrees Celsius  
USEPA United States Environmental Protection Agency  
WHO World Health Organization  
WPI Water Pollution Index

Responsible Editor: Amjad Kallel

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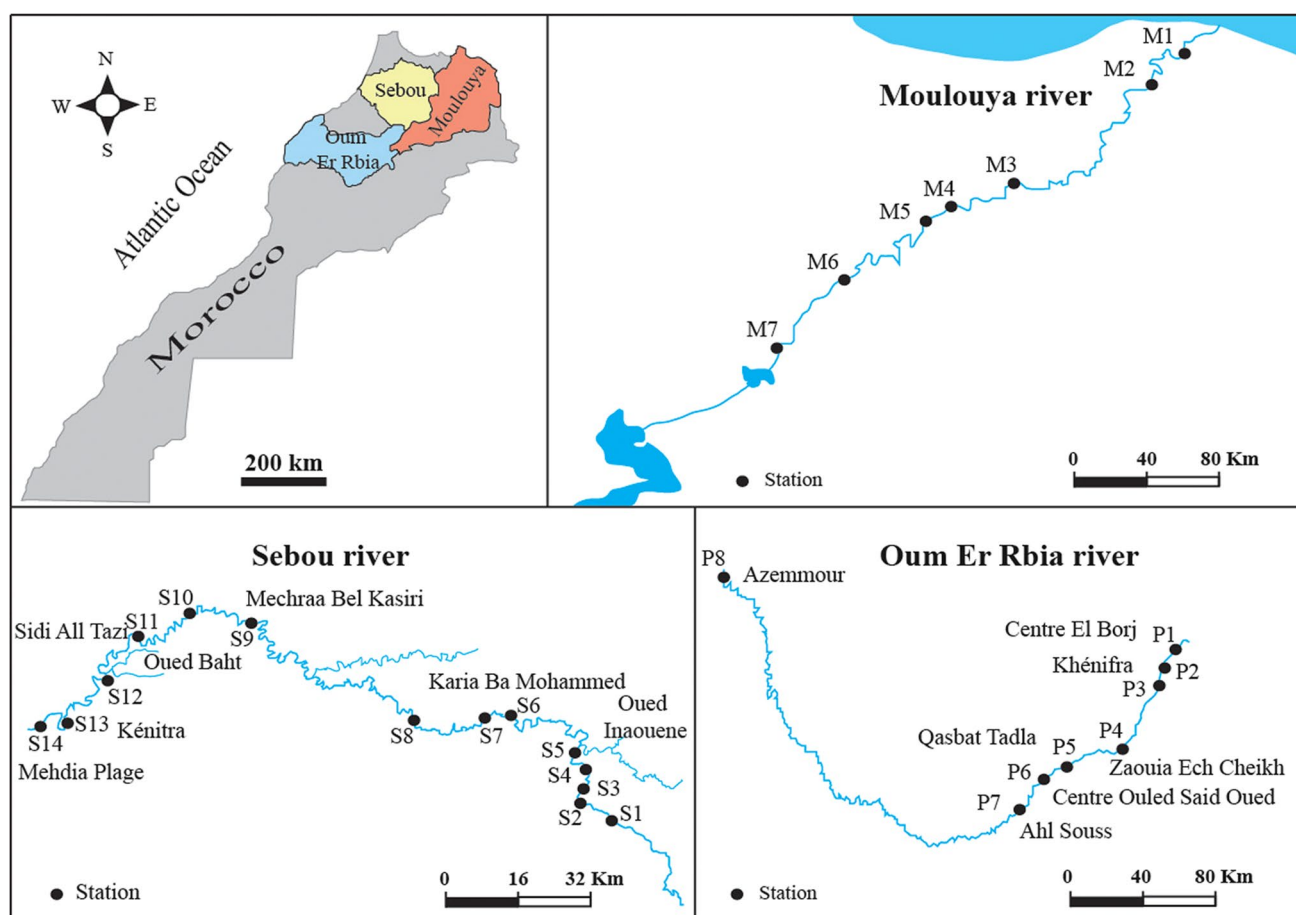
## Introduction

Water, like air, is considered essential to the survival of all people and all forms of life on earth. However, population growth and sustainable development (agricultural and industrial) lead to increased water resource exploitation, deteriorating its quality (Derwich et al. 2012). This influenced the

water's physicochemical and biological parameters (Mukate et al. 2019). Surface water is the most affected by pollution, given its exposure to anthropogenic activities (e.g., industrial metallurgical activity, and agriculture) (Imran et al. 2021; Oleiwi and Al-Dabbas 2022), rainfall, and related soil erosion, runoff on the geological substrate (Prasanna et al. 2012; Vasistha and Ganguly 2020). Consuming water tainted with heavy metals that do not degrade naturally in the environment (Nasrabadi 2015) can result in infections either directly or indirectly through the aquaculture food chain due to buildup (Sonone et al. 2020). This could lead to an imbalance in the biodiversity system (Prasanna et al. 2012). For this, metallic trace elements can be used to assess the quality and degree of pollution of surface water or as indicators of environmental quality that can guide decision-making for well-sustainable development (Kumar et al. 2018a, b). These metallic trace elements can increase depending on the discharge of untreated wastewater (Njuguna et al. 2020) or be influenced by climatic variations, which cause an increase in flood flows, generating significant accumulations in the downstream parts of the rivers (Gaagai et al. 2022). The study of variations in the water quality of rivers must be

performed on sufficient spatial and temporal scales (Wu et al. 2018). This evaluation is essential for monitoring and controlling the pollution of water resources and for identifying the main factors that contributed to these variations so that protective measures for water bodies may be put in place (Wu et al. 2018).

Morocco is among the countries on the southern Mediterranean coast characterized by the predominance of a semi-arid climate (Sebbar et al. 2011, 2012). It is traversed by a network of rivers that are essential for agriculture, drinking water use, and industrialization (Haddout et al. 2016). Indeed, surface water must be monitored to develop sustainable management plans to minimize pollution. Moreover, the three rivers targeted in this study are the lower Moulouya, the Oum Er Rbia, and the Sebou, classified as significant resources draining almost all of eastern, central, and western Morocco, with high flow rates. These three rivers are essential in water consumption and irrigation (Hayzoun et al. 2015). They are geographically located in the northern part of Morocco (Fig. 1) and occupy three watersheds differentiated by their hydrogeological and hydrodynamic location (Agoumi and Debbarh 2005; Jouilil et al. 2013; Zamrane



**Fig. 1** Location of sampling stations on Sebou (from S1 to S14), lower Moulouya (from M1 to M7), and Oum Er Rbia (from P1 to P8)

2016). Because of their geographical proximity, these rivers are susceptible to industrial, agricultural, and urban pollution caused by the discharge of untreated wastewater.

The objective of this study is to monitor the physicochemical quality (pH, temperature, dissolved O<sub>2</sub>, and electrical conductivity) and the spatio-temporal quality of metallic trace elements such as copper, lead, and chromium in two successive periods (dry and wet) in the surface waters of the three main rivers in Morocco (lower Moulouya, Oum Er Rbia, and Sebou). Subsequently, comparing these levels with a guide or standard values is done using indices developed to assess and monitor the quality of water polluted by heavy metals (Edet and Offiong 2002; Abdullah 2013; Selvam et al. 2015). In this work, the index (WPI) is used to determine the level of contamination by the metallic trace elements studied, taking into account the other physicochemical parameters such as temperature, dissolved O<sub>2</sub>, pH, and electrical conductivity in each sampling point. Therefore, using the index (WPI) in this study makes it possible to identify better and express the close relationship between the overall state of water quality in space and time, to integrate many elements into a single, meaningful index. Then, using this index would make it possible to reveal the main pollution parameters and deduce the location of quality waters (Singh et al. 2005; Kowalkowski et al. 2006; Bu et al. 2010; Fathi et al. 2018).

## Materials and methods

### Study site

The study areas are the lower Moulouya, Sebou, and Oum Er Rbia rivers (Fig. 1) which constitute the main rivers in Morocco. The Moulouya basin in eastern Morocco has an area of approximately 74,000 km<sup>2</sup> (Rixhon et al. 2017). It is located between 36 and 39° N and 5.5–7° W (Lamri et al. 2016; Fouzi et al. 2020). It is bounded to the northeast by the Mediterranean, to the northwest by the Beni-Bouyahi chain to the west by the mountains of the Eastern Rif and the folded Middle Atlas, to the south by the High Atlas (Lamri et al. 2016). With a length of more than 600 km, the Moulouya River is the longest Moroccan river that flows into the Mediterranean (Mabrouki et al. 2019; Fouzi et al. 2020). The river originates near the meeting point of the Middle and High Atlas mountain ranges and runs from the southwest to the northeast (Fouzi et al. 2020). This watershed is subdivided into three sub-basins: the Lower, the Middle, and the Upper Moulouya. Regarding the lower Moulouya, this study's subject is a basin with a diverse stratigraphy (Bouabdli et al. 2005). The second river studied is Sebou. The watershed of the said river is located in the northwest of Morocco with an area of 40,000 km<sup>2</sup> (Derwich et al.

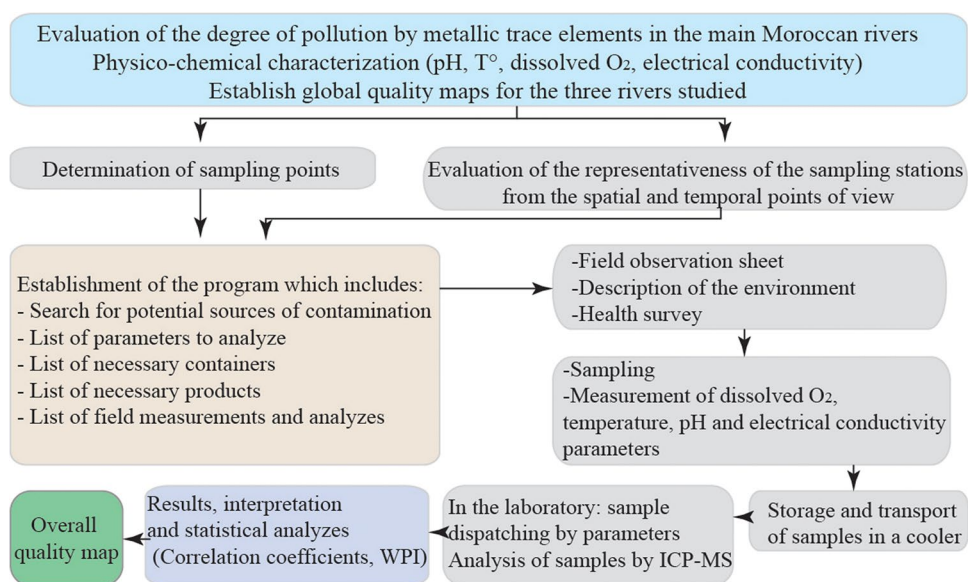
2012; Haddout et al. 2016; Kanga et al. 2020). It is delimited by the Rif Mountains to the north and by the Middle Atlas Mountains to the south, and the Saïs plateau is located between these two mountain ranges, in the lower part of the watershed. The Sebou sub-basin is made up of the great alluvial plain of Gharb (Kanga et al. 2020).

A combined 30% of the nation's potential surface water resources and 20% of its groundwater are mobilized by this basin. While the Gharb plain and the Saïs plateau were molded by permeable materials made by limestones, dolostones, conglomerates, and sandstones assigned to Mesozoic age, the Rif highlands are mostly defined by impermeable clay–marl formations from the Cretaceous (Piqué 1994; Hayzoun et al. 2015; Kanga et al. 2020). This watershed is drained by the Sebou river extending approximately 600 km from its source in the Middle Atlas to the Atlantic Ocean (Haddout et al. 2016). This river is divided into the upper, middle, and lower Sebou (Hayzoun et al. 2015).

The Oum Er Rbia basin is located in the center–west of Morocco. It originates in the Khenifra region at 32°56'22"N5°40'3"W, to the Atlantic Ocean (33°17'16"N8°20'32"W) (El Alami et al. 2020), and covers an area of 48,070 km<sup>2</sup> (Barakat et al. 2016; Zhim et al. 2019), and a length of 550 km from the Middle Atlas (Barakat et al. 2016; Strohmeier et al. 2020). It empties into the Atlantic Ocean at Azemmour city (Strohmeier et al. 2020). The three rivers studied receive significant pollutant loads generated by industrial and domestic discharges (El Hajjami et al. 2020). Fourteen stations were chosen along the Sebou (20 km upstream from Fez to the mouth at the port of Mehdiya), eight at Oum Er Rbia (from Khenifra to the mouth at Azemmour), and seven at lower Moulouya. These stations were chosen based on a variety of factors, including their accessibility to the land, the anthropogenic influences they are exposed to (close proximity to domestic and industrial discharges), agricultural areas, and representativeness (Fig. 2).

In this study, the samples taken for metallic trace elements are 28 from Sebou, 14 from lower Moulouya, and 16 from Oum Er Rbia. The other parameters (pH, electrical conductivity, T°C, and dissolved O<sub>2</sub>) are measured in situ (56 measurements for lower Moulouya, 64 sizes for Oum Er Rbia, and 112 for Sebou).

To describe and assess the overall quality of the surface waters of the rivers under study, the distribution of the values of each parameter (Cr, Cu, Pb, pH, T°C, CE, and dissolved O<sub>2</sub>) was determined. In addition, the study enriches scientific data on sediment pollution in rivers in developing countries and, subsequently, water contamination by trace metals. The results of this work provide a first comparison of the state of pollution of the three main Moroccan rivers for the first time in such work. Thus, this study makes it possible to develop a preliminary quality grid with a better

**Fig. 2** Adopted methodological flowchart

knowledge of the relationships between surface waters and their environments.

Despite being present in very small amounts in river water or sediment, metallic trace elements are poisonous and can result in life-threatening conditions like digestive and respiratory diseases. They thus present a significant risk of ecotoxicity for plants, soil, and aquatic species. Indeed, on a global scale, controlling the levels of these metallic elements is necessary. This work falls within this framework, which relates to evaluating and controlling pollution by metallic trace elements of main Moroccan rivers.

### Sampling and methods of analysis

In general, water samples are collected manually using containers tailored to each parameter, in the middle and at representative sites for flow (homogeneity and turbulence). In principle, sampling is done at a depth of about 30 cm below the surface and about 50 cm above the bottom, otherwise at mid-depth to avoid sampling the surface film (Acted 2006). All collected surface water samples were placed in the field in clean polyethylene (PE) bottles. Subsequently, these samples were acidified to  $\text{pH} < 2$  with nitric acid (2%  $\text{HNO}_3$ ) (Ceaq 2014), and transported at a low temperature (4 °C) to the laboratory (Zhaoyong et al. 2015). In addition, the measurement of the electrical conductivity was carried out according to standard NM ISO 7888 2001: rinsed the probe several times with demineralized water, then two to three times with the water to be examined, then agitated the investigation of the conductivity meter in the water sample until it stabilizes. The hydrogen potential is measured by an electrode immersed in the water to be measured (the reading is taken after stabilization of the pH meter) (NM ISO 10523 2012). Dissolved oxygen is determined by the

electrochemical method (NM ISO 5814 2014) using an electrochemical cell isolated from the sample by a selective gas-permeable membrane. Indeed, the water sample must flow continuously in front of the probe's membrane to exclude the possibility of an erroneous measurement due to the local consumption of oxygen at the level of the probe electrode.

The selection of sampling sites is based on a number of factors, including the ease of access to the area, the anthropogenic influences they are exposed to (close proximity to home and industrial wastes), agricultural areas, and representativeness. As a result, when sampling in the three rivers under study, we avoided collecting samples in dead zones, especially at locations with natural or man-made barriers.

### Analysis protocol

The determination of extractable metals in surface waters is based on the mineralization of the samples: in a 50 ml tube, introduce 40 ml of a sample and then add 0.8 ml of 20% HCl and 0.8 ml  $\text{HNO}_3$  20% (Ceaq 2014). After closing and shaking, the samples are heated in a digest block at 95 °C for 2 h. Then, after cooling and settling, the samples were analyzed by ICP-MS (Ceaq 2014).

In accordance with the process for validating chemical analysis methods, the analytical method is validated. These are the validation results:

For chromium:  $\text{LDM} = 0.005 \mu\text{g/l}$ ;  $\text{LQM} = 0.017 \mu\text{g/l}$ ; the sensitivity results in a slope of 0.9999; the recovery percentage is 94%; replicability (at a 95% confidence interval) is 2%; repeatability (at a 95% confidence interval) is 4%.

For copper: LDM=0.040 µg/l; LQM=0.133 µg/l; the sensitivity results in a slope of 0.9999; the recovery percentage is 98%; replicability (at a 95% confidence interval) is 3%; repeatability (at a 95% confidence interval) is 2%. For lead: LDM=0.003 µg/l; LQM=0.010 µg/l; the sensitivity results in a slope of 0.9999; the recovery percentage is 97%; replicability (at a 95% confidence interval) is 2%; repeatability (at a 95% confidence interval) is 3%.

### Results and discussions

Table 1 presents the reference values for classifying the waters analyzed for each parameter studied.

The physicochemical parameters obtained during this study are presented in Tables 2, 3, and 4.

The samples examined in lower Moulouya had pH readings that ranged from 7.4 to 7.8 in August and from 7.1 to 7.6 in December (Table 2). For Oum Er Rbia (Table 3), the pH values vary from 7.4 to 8.4 in August and from 7.9 to 8.4 in December, while at the level of Sebou (Table 4), the pH varies from 7.7 to 8.4 in August and from 7.5 to 8.4 in December. According to the surface water classification grid BO-5062 (2002), these results show that the surface waters of the three rivers under study are excellent for pH values between 6.5 and 8.5. The hydrogen potential depends on several parameters, namely, the geological nature of the watershed crossed and the origin of the water (Belghiti et al. 2013). This parameter affects a variety of physicochemical equilibrium processes involving the water compartment, carbonates, bicarbonates, and dissolved carbon dioxide. Natural water typically has a pH between 6.0 and 8.5 (Belghiti et al. 2013).

**Table 1** Surface water quality grid according to order 1275-01 of 2002 (BO-5062 2002)

Parameter	Excellent	Good	Average	Poor	Very poor
pH	6.5–8.5	6.5–8.5	6.5–9.2	< 6.5ou > 9.2	< 6.5ou > 9.2
Temperature in °C	< 20	20–25	25–30	30–35	> 35
O <sub>2</sub> dissolved in mg/l	> 7	7–5	5–3	3–1	< 1
Conductivity at 20 °C in µs/cm	< 750	750–1300	1300–2700	2700–3000	> 3000
Cr in µg/l	≤ 50	≤ 50	≤ 50	> 50	-
Pb in µg/l	≤ 10	≤ 10	10–50	> 50	-
Cu in mg/l	≤ 0.02	0.02–0.05	0.05–1	> 1	-

**Table 2** Physicochemical parameters measured in the lower Moulouya River in 2019

Parameter	pH		T°C		Dissolved O <sub>2</sub> (mg/l)		CE (µS/cm)	
	August	December	August	December	August	December	August	December
M1	7.84	7.62	22.7	12.9	9.1	7.8	4950	5390
M2	7.62	7.42	24.5	13.1	8.2	8.1	3740	3820
M3	7.41	7.3	24.1	12.7	7.4	7.9	3450	3690
M4	7.45	7.31	23.6	12.5	7.7	7.5	3210	3580
M5	7.35	7.19	26.7	13.5	7.9	6.9	4010	3120
M6	7.42	7.12	27.4	13.4	6.8	8.4	2130	2070
M7	7.65	7.18	27.1	13	7.1	8.2	2140	1840

**Table 3** Physicochemical parameters measured in the Oum Er Rbia River in 2019

Parameter	pH		T°C		Dissolved O <sub>2</sub> (mg/l)		CE µs/cm	
	August	December	August	December	August	December	August	December
P1	8.25	7.94	22.8	13.2	5.2	8.9	2735	2442
P2	8.35	8.24	25.9	14.5	8	9.6	2647	2688
P3	8.31	8.36	27.8	15.7	5.9	7.9	7851	7554
P4	8.4	8.34	26.4	15.4	4.8	6.8	2954	1967
P5	7.77	8.27	27.4	16.1	4.2	7.5	2041	1374
P6	7.89	7.95	29.6	14.2	4.9	8	1897	1046
P7	7.9	8.3	29.4	14.8	5.9	7.4	1745	1263
P8	7.4	7.88	31.2	13	6.5	7.8	13,254	12,999



**Table 4** Physicochemical parameters measured in the Sebou River in 2019

Parameter	pH		T°C		Dissolved O <sub>2</sub> (mg/l)		CE (µs/cm)	
	August	December	August	December	August	December	August	December
Period	August	December	August	December	August	December	August	December
S1	8.40	8.10	23.7	15.2	8.4	9.7	1107	1011
S2	8.12	7.66	27.2	14.9	1.9	0.5	2710	1453
S3	8.20	8.10	27.9	16.1	4.2	5.1	1642	1153
S4	8.30	8.14	28.5	16	3.5	2.7	1114	1452
S5	8.30	8.20	28.6	15.4	5.2	1.1	971	1421
S6	7.90	7.89	27.9	15	5.2	5.4	1275	1102
S7	8.10	7.81	29.1	14.7	7.5	5.7	1501	1188
S8	8.40	7.98	27.8	15.7	7.4	6.8	1288	1257
S9	8.20	8.20	28.4	15.9	6	5.3	914	954
S10	8.20	8.40	29.8	14.9	5.2	6.1	1022	1203
S11	8.10	8.20	28.7	15.2	5.8	5.4	702	1145
S12	8.30	8.10	30.2	16.2	6.4	6.2	915	1487
S13	7.80	7.98	29.2	16.2	6.2	5.9	1234	1132
S14	7.70	7.50	30.7	15.3	5.9	4.5	11,966	11,805

The water temperature analyzed in lower Moulouya (Table 2) varies between 22.7 and 27.4 °C in August and between 12.5 and 13.5 °C in December, while for Oum Er Rbia (Table 3). The temperature measurements vary between 22.8 and 31.2 °C regarding Sebou (Table 4). The temperature varies between 23.7 and 30.7 °C in August and 14.7 and 16.2 °C in December.

These values indicate that the temperature in the three rivers studied is suitable in December, of good to average quality for the lower Moulouya in August, and of interest to poor quality for the Oum Er Rbia and the Sebou in August.

Furthermore, dissolved oxygen is an important factor in aquatic life. It enables the evaluation of surface water quality (Escoffier et al. 2016) while ensuring the self-purification of waterways, and the degradation of organic matter, odor, and taste (Bailey and Ahmadi 2014). In addition, O<sub>2</sub> promotes the growth of microorganisms via good oxygenation of aquatic environments (Garvey et al. 2007).

These are impacted by drought issues, particularly during summertime low flow times, which encourage biogeochemical changes that can result in water of poor quality (Gómez-Gener et al. 2020). As a result, dissolved oxygen is an excellent marker of waterway contamination and the growth of pathogenic organisms (Derwich et al. 2008; Belghiti et al. 2013).

Concentrations of dissolved O<sub>2</sub> in lower Moulouya vary from 7.1 (M7) to 9.1 mg O<sub>2</sub>/l (M1) in August and from 7.5 (M4) to 8.4 mg O<sub>2</sub>/l (M6) in December. These findings show that the sample zone exhibits good (7–5 mg of O<sub>2</sub>/l) to excellent (> 7 mg of O<sub>2</sub>/l) quality in all the stations examined (Table 1).

For Oum Er Rbia, dissolved O<sub>2</sub> is 4.2 mg O<sub>2</sub>/l (P5) to 8.0 mg O<sub>2</sub>/l (P2) in August and 6.8 mg O<sub>2</sub>/l (P4) to 9.6 mg O<sub>2</sub>/l (P2) in December; then, O<sub>2</sub> dissolved at the level of the river (Oum Er Rbia) is of average quality in 37% samples analyzed while 63% of these waters are of good–excellent. The contents of dissolved O<sub>2</sub> in Sebou

vary from 1.9 (S2) to 8.4 mg O<sub>2</sub>/l in August and from 0.5 (S2) to 9.7 mg O<sub>2</sub>/l (S1) in December. The low values at station 2 show that Oued Sebou receives high pollutant loads in both periods (wet and dry periods). The quality of O<sub>2</sub> dissolved in 14% of the samples taken in Oued Sebou is excellent, 57% good, 21% average, and 7% bad.

Electrical conductivity is a measure of how well water can transport electric current (Hayzoun 2014a). It provides an idea of the origin of water, dissolved salts, and mineralization (Belghiti et al. 2013).

The electrical conductivity in the lower Moulouya varies from 2130 (M6) to 4950 µs/cm (M1) in August and from 1840 (M7) to 5390 µs/cm (M1) in December. These values indicate that 71% of the samples analyzed from this river (lower Moulouya) are of inferior quality (> 3000 µs/cm), and 29% are of average quality (1300–2700 µs/cm) in the two sampling periods. The values of electrical conductivity in Oued Oum Er Rbia vary from 1745 (P7) to 13,254 µs/cm (P8) in August and from 1046 (P6) to 12,999 µs/cm (P8) in December. In fact, the electrical conductivity quality indicates that 25% of the water studied is of poor quality, while 75% is of average quality. For the Sebou River, the electrical conductivity is from 702 (S11) to 11,966 µs/cm (S14) in August and from 954 (S9) to 11,805 µs/cm (S14) in December. These values indicate that 71% of the analyzed waters of this Oued (Sebou) are of good quality, 21% are of average quality, and 7% are of poor quality (S14).

## Metal trace elements

### Chromium

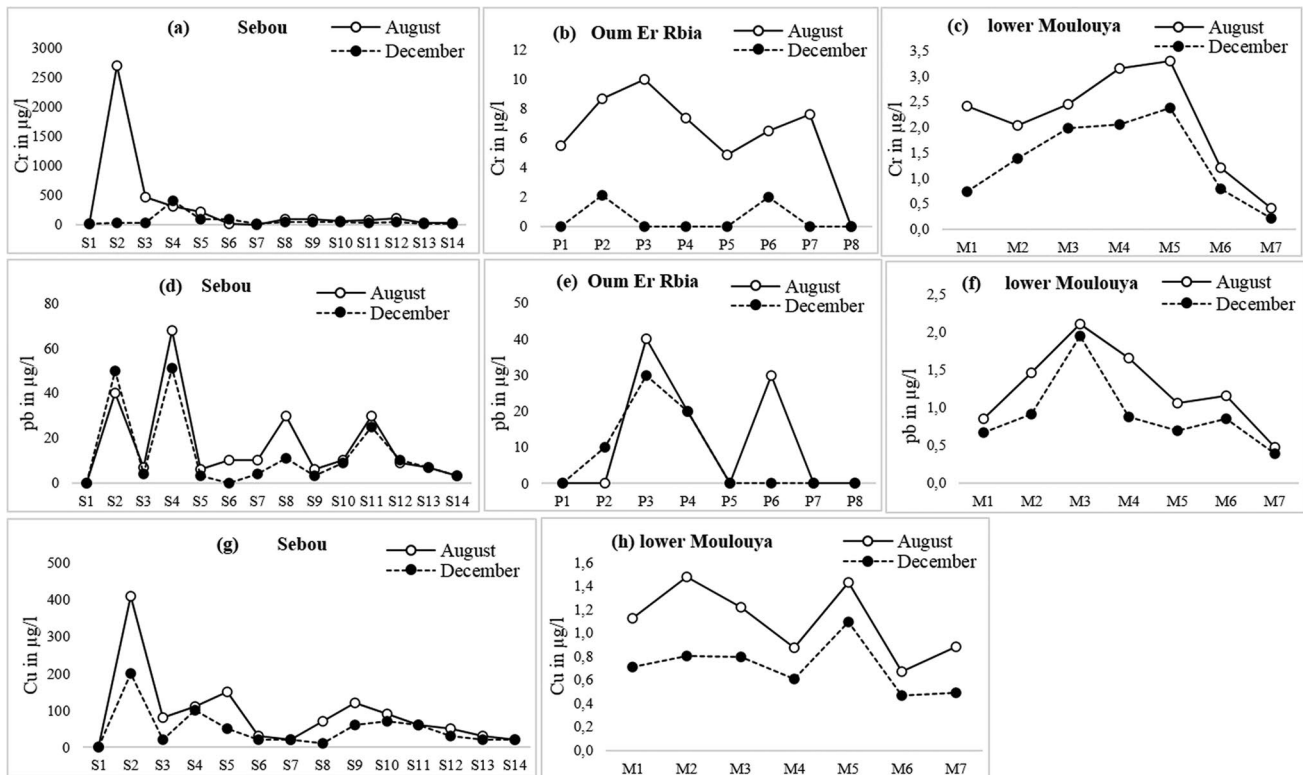
Trivalent chromium (Cr<sup>3+</sup>) and hexavalent (Cr<sup>6+</sup>) are the two predominant forms in nature and the most stable (He and Li 2020). Dissolved oxygen has a strong ability to reduce

hexavalent chromium to trivalent chromium (N'guessan 2008). Once Cr (III) is formed in aquatic environments, it precipitates rapidly. It accumulates in the sediments, which may act as a reservoir for river pollutants (N'guessan 2008). In water, the chromate ion ( $Cr^{3+}$ ) is more stable and less toxic than the chromate ion ( $Cr^{6+}$ ) (N'guessan 2008). Chromium concentrations in the water may have increased due to natural or industrial causes (tanneries, textile industries, surface treatment industry, and sludge from wastewater treatment plants) (Hayzoun 2014a).

The Cr recorded at Sebou shows Cr values (Fig. 3a) vary between 3 (S7) and 2700  $\mu g/l$  (S2) in August and 7  $\mu g/l$  (S1) at 410  $\mu g/l$  (S4) in December, with average concentrations of 298.6  $\mu g/l$  in August and 63.9  $\mu g/l$  in December. These values indicate that Sebou had poor quality ( $> 50 g/l$ ) in more than 64% of samples from August and 28% of samples from December. Generally, the contents found in August are higher than in December. This is explained on the one hand by the fact that the flow in the latter is higher than in August, which causes the dilution effect; on the other hand, by the increase in tanning activity after "Aid al Adha" which is increasing in the city of Fez.

Because of home discharges and effluents from boiler works, tanneries, and textile businesses, this pollution is

actually concentrated in the city's downstream area, particularly the station (S2) (Es-Sette et al. 2005). This is probably due to ceramic factories using chromium sulfate as a tanning agent (Hayzoun et al. 2014b). Indeed, the results are comparable to those obtained by other researchers (Foudeil et al. 2013; El Hajjami et al. 2021). In addition, for Oum Er Rbia, the Cr concentrations (Fig. 3b) vary from  $< 0.005$  (P8) to 10.0  $\mu g/l$  (P3) in August and from  $< 0.005$   $\mu g/l$  in 75% of samples analyzed (P1, P3, P4, P5, P7, and P8) and 2.1  $\mu g/l$  (P2) in December. The average concentrations in this river are 6.3  $\mu g/l$  in August and 0.5  $\mu g/l$  in December. These concentrations mean that Oued Oum Er Rbia has excellent quality in total chromium (Table 1). The Cr values for the lower Moulouya (Fig. 3c) range from 0.41 (M7) to 3.29 g/l (M5) in August (2019) and from 0.22 (M7) to 2.38 g/l (M5) in December (2019), with an average concentration of 2.13 g/l in August and 1.36 g/l in December. These values remain below 50  $\mu g/l$  according to decree 1275-01 of 2002 BO-5062 (2002): this translates into the excellent quality of water from lower Moulouya (class 1). The classification of average Cr contents in the three study sites is classified as follows: Cr (Sebou)  $>$  Cr (Oum Er Rbia)  $>$  Cr (lower Moulouya). This means that the Sebou River has experienced significant pollution due to textile activities and tanneries, especially at the stations near Fez.



**Fig. 3** The evolution of concentration in Cr, Cu, and Pb in Sebou (a, d, g), lower Moulouya (c, f, h), and Cr and Pb in Oum Er Rbia (b, e) in August and December 2019

## Lead

One of the heavy metals most frequently associated with human toxicity is lead. The aquatic ecosystem can be severely harmed by this trace element, which can occasionally accumulate and even go through biomagnification in species like fish and plants (Abubakar et al. 2015). For example, the presence of Pb in surface waters may result from the natural redistribution of components of the earth's crust or the discharge of industrial wastes (Methneni et al. 2020).

In Sebou (Fig. 3d), Pb varies between  $<0.003$  (S1) and  $68.0 \mu\text{g/l}$  (S4), with an average concentration of  $17.0 \mu\text{g/l}$  in August, while the levels recorded in December vary between  $<0.003$  (S1 and S6) and  $51.0 \mu\text{g/l}$  (S4) with an average concentration of  $12.9 \mu\text{g/l}$ . These values show that the Pb concentration of the samples taken at the Sebou level varies from excellent to good with a percentage of 50%, average with a percentage of 43%, and poor with a rate of 7% in August (Table 1). Thus, the quality in December varies from excellent to good with 64%, average with a percentage of 21%, and poor with a percentage of 14%. The lead in Oum Er Rbia River (Fig. 3e) in August has values varying between  $<0.003$  in five stations studied (P1, P2, P5, P7, and P8) and  $40.0$  (P3) with an average concentration of  $11.25 \mu\text{g/l}$ . In December, the Pb concentrations varied between  $<0.003 \mu\text{g/l}$  recorded in sampling points (P1, P5, P6, P7, and P8) and  $30 \mu\text{g/l}$  recorded in P3 with an average concentration of  $7.5 \mu\text{g/l}$ . These contents vary from excellent quality ( $\leq 10 \mu\text{g/l}$ ) with a percentage of 63% to medium quality ( $10\text{--}50 \mu\text{g/l}$ ) with a percentage of 37%. Studies on atmospheric fallout have revealed that rainfall is a source of Pb pollution, particularly in urban areas and close by these sites (Bounahkla et al. 2009; Lamprea 2009). Thus, lead pollution may result from both the geological structure of the earth and the enrichment of soil by this metallic element (Azzaoui et al. 2002; Derwich et al. 2008). Also, phosphorus and nitrogen fertilizer products contain Pb with  $3.5 \text{ mg/kg}$  (Azzaoui et al. 2002). In addition, landfills can also cause this pollution (Idlahcen et al. 2014). Indeed, the landfill of the city of Fez is located in a section of the Wadi Fez (Azzaoui et al. 2002).

The lead concentrations in the lower Moulouya river vary between  $0.47$  (M7) and  $2.11 \mu\text{g/l}$  (M3) with an average concentration of  $1.25 \mu\text{g/l}$  in August and between  $0.39$  (M7) and  $1.95 \mu\text{g/l}$  (M3) with an average concentration of  $0.90 \mu\text{g/l}$  in December. These values remain below  $10 \mu\text{g/l}$ , which translates into excellent quality for this river.

## Copper

Sebou has very high copper concentrations (Fig. 3g). In August, they range from  $0.040$  (S1) to  $410 \text{ g/l}$  (S2), while in December, they range from  $0.040$  (S1) to  $200 \text{ g/l}$  (S2). In the

dry period, Cu has a peak downstream from the city of Fez (S2); the concentrations recorded in this period are higher than those during the flood period. These copper inputs come from discharges from the city of Fez, mainly from artisanal activities in the old medina (Derwich et al. 2011). Indeed, the quality of surface water in Sebou varies from excellent (7%) to good (29%) and average (64%). For copper is lower Moulouya (Fig. 3h), the concentrations found vary from  $0.674$  (M6) to  $1.478 \mu\text{g/l}$  (M2), with an average concentration of  $1.097 \mu\text{g/l}$  in August and  $0.464$  (M6) to  $1.092 \mu\text{g/l}$  (M5) with an average concentration of  $0.709 \mu\text{g/l}$  in December. Generally, the dry period's copper concentrations are higher than those during the humid period. However, this river's quality is always excellent (lower Moulouya). At the Oum Er Rbia, the analysis of copper was marked by the total absence of this element in the samples taken during the two sampling periods (Wet and Dry).

In Sebou, the average chromium concentration across the two sampling periods ( $181.25 \text{ g/l}$ ) was higher than the values found at Oum Er Rbia ( $3.4 \text{ g/l}$ ) and lower Moulouya ( $1.75 \text{ g/l}$ ). Similarly, the average chromium concentration in Sebou remains higher than in other studies carried out on different rivers (Table 5): Subarnarekha River in India (Singh and Giri 2014); Liao river and Yellow river in China (Gao et al. 2019) (with values of  $0.89 \mu\text{g/l}$ ,  $3.36 \mu\text{g/l}$ , and  $6.54 \mu\text{g/l}$  respectively). However, a comparison of Sebou's average Cr concentration with the WHO (2011) and USEPA (2012) limits reveals likely Cr contamination. Monitoring the water quality at the polluted locations is necessary for this.

Additionally, Sebou's average copper concentration over the course of the two sample periods ( $68.93 \text{ g/l}$ ) indicated higher Cu levels than those at lower Moulouya ( $0.9 \text{ g/l}$ ) and Oum Er Rbia ( $0.040 \text{ g/l}$ ). This remains superior to the results found by other researchers (Warnken and Santschi 2009, Singh and Giri 2014, and Gao et al. 2019) respectively on the Trinity Rivers-USA, Subarnarekha River-India, Liao River Basin-China, and yellow river basin-China. These concentrations show lower levels than those obtained by Munyao and Maritim (2013) in Sabaki River Mouth-Kenya ( $144 \mu\text{g/l}$ ). Regarding lead, Sebou and Oum Er Rbia have average concentrations higher than the values quoted by (Warnken and Santschi 2009; Munyao and Maritim 2013, Singh and Giri 2014, and Gao et al. 2019) at the Trinity-USA, Subarnarekha River India, Liao River Basin-China, and Yellow River Basin-China respectively. On the other hand, the study conducted by Munyao and Maritim (2013) in Sabaki River Mouth-Kenya presents (like Copper) a concentration ( $206.25 \mu\text{g/l}$ ) higher than those of the studied rivers. So, the comparison of the vulnerability of the rivers studied by ETM with other studies on international rivers (e.g., USA, China, India, Kenya) gives: (i) Cr (Sebou) > Cr (Yellow river in China) > Cr (Oum Er Rbia) > Cr (Liao river in china) > Cr (lower Moulouya) > Cr (Subarnarekha River in India); (ii)



**Table 5** Comparison of the concentrations (µg/l) of trace elements in water samples from the three rivers studied in Morocco and from other rivers around the world with the drinking water guidelines (WHO) and drinking water standard (USEPA)

	Cr	Cu	Pb	References
Sebou River, Morocco	181.25	68.93	14.9	This study
Oum Er Rbia River, Morocco	3.4	<0.040	9.38	
The lower Moulouya, Morocco	1.75	0.9	1.08	
Liao River Basin, China	3.36	1.03	0.03	Gao et al. (2019)
Yellow River Basin, China	6.54	2.68	0.208	Gao et al. (2019)
Trinity River, USA	-	1.15	0.03	Warnken and Santschi (2009)
Sabaki River Mouth, Kenya	-	144	206.25	Munyao and Maritim (2013)
Subarnarekha River, India	0.89	16.6	-	Singh and Giri (2014)
WHO	50	2000	10	WHO (2011)
USEPA	100	1300	-	USEPA (2012)

Cu (Sabaki River Mouth-Kenya) > Cu (Sebou) > Cu (Subarnarekha River in India) > Cu (Yellow river in China) > Cu (Trinity-USA) > Cu (Liao river in China) > Cu (lower Moulouya) > Cu (Oum Er Rbia); and (iii) Pb (Sabaki River Mouth-Kenya) > Pb (Sebou) > Pb (Oum Er Rbia) > Pb (lower Moulouya) > Pb (Yellow river in China) > Pb (Liao river in China) > Pb (Trinity-USA).

**Correlation coefficients**

The correlation measures the correspondence between the different associated values of two variables of a bivariate distribution (Langouet and Porlier 1991). The correlation can be positive, negative, strong, weak, or zero. So the values of this correlation range between 1 and -1 (Pottier 1994; Saporta 2006). This correlation coefficient is calculated with the following formula (Stancu et al. 2015):

$$\text{Correl}(X, Y) = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}}$$

where  $\bar{x}$  and  $\bar{y}$  are the averages of the samples of the studied matrices.

Tables 6, 7, and 8 present the matrix of correlation coefficients of metallic trace elements in the surface waters of the three rivers studied.

**Table 6** Correlation coefficient between the metallic trace elements studied in Sebou River

	Cr	Pb	Cu	pH	T°	CE	O <sub>2</sub>
Cr	<b>1</b>						
Pb	<b>0.64</b>	<b>1</b>					
Cu	<b>0.94</b>	<b>0.65</b>	<b>1</b>				
pH	-0.16	0.09	-0.02	<b>1</b>			
T°	-0.23	-0.01	-0.12	-0.21	<b>1</b>		
CE	-0.05	-0.15	-0.11	<b>-0.72</b>	0.32	<b>1</b>	
O <sub>2</sub>	<b>-0.75</b>	<b>-0.60</b>	<b>-0.82</b>	0.18	-0.22	-0.08	<b>1</b>

The results in Table 6 show strong positive correlations, at the Sebou level, between Cr/Pb, Cr/Cu, Pb/Cu, and strong negative correlations between Cr/dissolved O<sub>2</sub>, Pb/dissolved O<sub>2</sub>, Cu/dissolved O<sub>2</sub>, and pH/EC with values above 0.6. For the lower Moulouya (Table 7), there are positive correlations between Cr/Pb, Cr/Cu, Cr/CE, Cu/CE, pH/CE, dissolved pH/O<sub>2</sub>, and CE/dissolved O<sub>2</sub>; with values more than 0.5. However, negative correlations (anti-correlated) between pH/T°, T°/EC, and T°/dissolved O<sub>2</sub> were observed, while the correlation between Pb and Cu is weak. The correlations in Oum Er Rbia (Table 8), positive correlations greater than 0.5 between Cr/Pb, Cr/pH, Pb/pH, and a negative correlation between Cr and electrical conductivity with a value of -0.57.

**Water pollution index (WPI)**

The analyzed parameters were used to calculate WPI and classify each station’s water quality in each studied river. From the calculated values of WPI, the water quality is organized into six categories (very pure, pure, moderately polluted, polluted, impure, and heavily impure). The obtained index was considered an index of water pollution recognition (Zueva and Bobrov 2018).

The water pollution index (WPI) represents the sum of the ratios between the parameters analyzed and the normal values according to the following formula (Popovic et al. 2016) (Table 9):

**Table 7** Correlation coefficient between the metallic trace elements studied in the lower Moulouya River

	Cr	Pb	Cu	pH	T°	CE	O <sub>2</sub>
Cr	<b>1</b>						
Pb	<b>0.52</b>	<b>1</b>					
Cu	<b>0.63</b>	0.24	<b>1</b>				
pH	-0.19	-0.23	0.10	<b>1</b>			
T°	-0.39	-0.43	-0.17	<b>-0.67</b>	<b>1</b>		
CE	<b>0.51</b>	0.19	<b>0.57</b>	<b>0.72</b>	<b>-0.77</b>	<b>1</b>	
O <sub>2</sub>	-0.22	-0.14	0.12	<b>0.96</b>	<b>-0.60</b>	<b>0.69</b>	<b>1</b>

**Table 8** Correlation coefficient between the metallic trace elements studied in Oum Er Rbia River

	Cr	Pb	Cu	pH	T°	CE	O <sub>2</sub>
Cr	<b>1</b>						
Pb	<b>0.54</b>	<b>1</b>					
Cu	-	-	-				
pH	<b>0.80</b>	<b>0.55</b>	-	<b>1</b>			
T°	-0.10	0.21	-	-0.30	<b>1</b>		
CE	<b>-0.57</b>	0.11	-	-0.47	0.28	<b>1</b>	
O <sub>2</sub>	0.27	-0.16	-	0.08	-0.32	0.20	<b>1</b>

**Table 9** The reference values for the calculation of WPI

Parameter	Value	Retained value	Normative reference
Chromium total (mg/l)	0.05	0.05	WHO 2017, NM 03.7.001 (2020)
Copper (mg/l)	1	1	NM 03.7.001 (2020)
Lead (mg/l)	0.01	0.01	WHO 2017, NM 03.7.001 (2020)
pH	6.5–8.5	8	NM 03.7.001 (2020)
Dissolved O <sub>2</sub> (mg/l)	5–7 (good quality)	7	Order 1275–01 (2002)
Electrical conductivity (µS/cm) at 20 °C	2700 750–1300 (good quality)	1300	NM 03.7.001 (2020) Order 1275–01 (2002)
Temperature (°C)	25–30 (medium quality)	30	Order 1275–01 (2002)

$$WPI = \sum_{i=1}^n (C_i/S_i).1/n$$

where  $C_i$  is the measured concentration of each parameter in mg/l except for the pH, the T° in C, and the electrical conductivity in µS/cm;  $n$  is the number of parameters; and  $S_i$  is the maximum value of the Moroccan standard for surface water, water quality for food use, and Guidelines for drinking-water quality. The reference for dissolved O<sub>2</sub>, temperature, and electrical conductivity is the maximum value of class II (good quality) of Order 1275–01 (2002).

Table 10 gives the classification of water according to the water pollution index.

Based on the WPI values obtained, the three studied rivers are classified into different categories (Tables 11, 12, and 13). If  $WPI < 1$ , the watercourse is marked as pure; if  $WPI > 2$ , the waterway is polluted; and if  $WPI > 6$ , the

watercourse belongs to a group of highly polluted waters (Milanovic et al. 2011).

According to the calculation of the Sebou surface water pollution index, this river's water quality in August was pure quality in 50% of the samples, moderately polluted in 36%,

**Table 10** Water quality classification according to WPI (Lyulko et al. 2001; Milanovic et al. 2011)

WPI	Class	Characteristics
Very pure	I	≤ 0.3
Pure	II	0.3–1
Moderately polluted	III	1–2
Polluted	IV	2–4
Impure	V	4–6
Heavily impure	VI	> 6

**Table 11** WPI in Sebou River

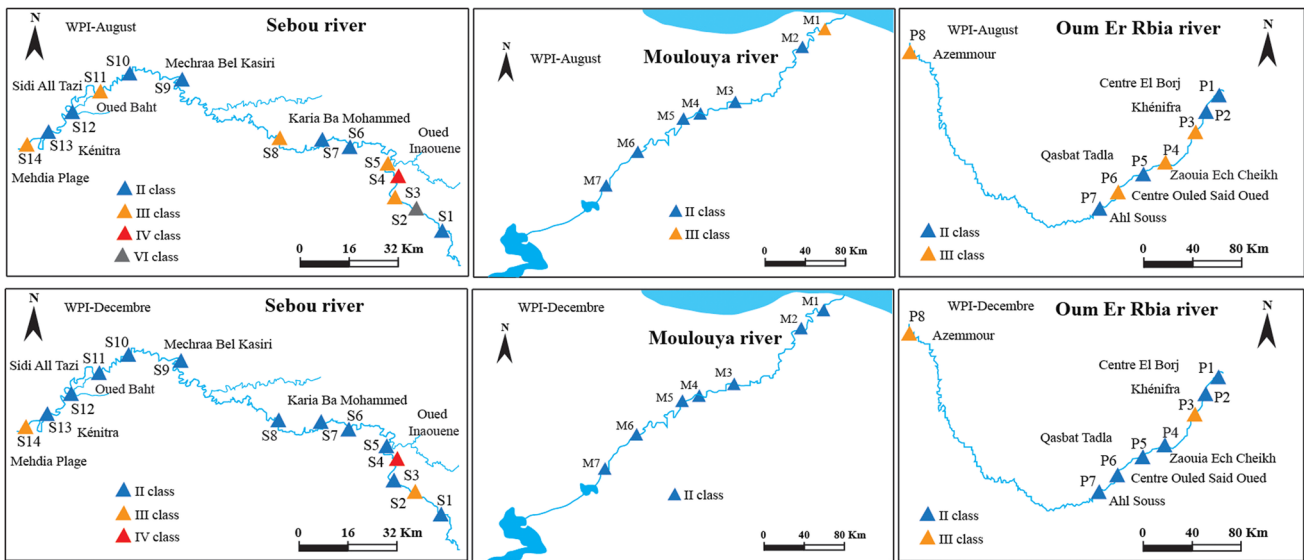
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
WPI-August	0.59	8.96	1.97	2.35	1.23	0.69	0.76	1.27	0.86	0.85	1.14	0.94	0.73	1.82
WPI-December	0.55	1.22	0.60	2.35	0.71	0.69	0.57	0.77	0.60	0.76	0.91	0.77	0.60	1.67

**Table 12** WPI in Oum Er Rbia River

	P1	P2	P3	P4	P5	P6	P7	P8
WPI-August	0.68	0.75	1.86	1.01	0.59	1.04	0.61	1.87
WPI-December	0.65	0.86	1.64	0.86	0.53	0.49	0.51	1.79

**Table 13** WPI in lower Moulouya River

	M1	M2	M3	M4	M5	M6	M7
WPI-August	1.00	0.86	0.81	0.79	0.89	0.66	0.65
WPI-December	0.96	0.80	0.79	0.75	0.69	0.60	0.57



**Fig. 4** Water pollution index (WPI) in each station at the level of the three rivers (Sebou, Oum Er Rbia, and lower Moulouya) in August and December 2019

impure in 7%, and very impure in 7% of the samples. On the other hand, in December, the quality of these waters was pure at 79%, moderately polluted at 14%, and impure at 7%. Regarding Oum Er Rbia (Table 12), the WPI values for August show that 50% of the water is of good quality and 50% is moderately polluted. Moreover, in December, the WPI values indicate that 75% of the water analyzed is pure while 25% is of average quality. For the lower Moulouya (Table 13), 86% is pure quality in August, while 100% of the water withdrawn in December is pure quality.

According to the WPI, surface water quality classification maps at each sampling station are established (Fig. 4).

### The limitations of the study

The assessment of metal pollution in river surface waters should always include discussing the study’s limitations. Several parameters can influence the diagnosis of river waters, in particular, the period and the sampling technique; the intense industrial discharges discharged without treatment into river waters since industrialists do not treat their effluents before discharge. These parameters may induce sources of error which could have led to an underestimation or an overestimation of the levels of metallic trace elements in the three rivers studied.

In addition, the problem of drought experienced by the study areas in recent years in the face of contamination due to the reduction in the flow of river water and concentration of pollution can also influence the results of the analysis of metallic traces.

The study of contamination by metallic trace elements was carried out in specific periods (August and December 2019). This might have a significant impact on how pollutant loads are estimated (over-estimate or under-estimate). For example, the sampling days could coincide with accidental spills at specific control points or water dilution due to the variation in flow rates. In addition, the accumulation of the metals studied in the sediment compartment and the bioaccumulation of trace metals by the plants can play an exciting role in the trace metal results obtained. Furthermore, the interactions between the different parameters, especially nitrogenous and phosphorus elements, pesticides, temperature, oxygen, and bacteriological parameters, can play an interesting role in the presence of metallic traces in the three rivers.

## Conclusion

The results of this study allowed for the identification and evaluation of the metallic pollution and physicochemical characteristics of the leading Moroccan rivers' surface waters. The physicochemical measurements in this study showed that the electrical conductivity measurements in the lower Moulouya and Oum Er Rbia are very high, showing that these rivers' waters are highly mineralized. Thus, we found that the rate of dissolved oxygen downstream of the city of Fez is meager (1.2 mg of O<sub>2</sub>/l for S2) because this area receives highly polluting organic loads. Indeed, assessing the degree of pollution by Cr, Cu, and Pb in the three rivers studied shows that the Sebou is the river most threatened by these metallic trace elements with average concentrations of 181.25 µg/l, 68.93 µg/l, and 14.90 µg/l, respectively. We have shown that the levels obtained from the metals analyzed in August remain higher than those in December. The overall water quality calculated by the global pollution index (WPI) shows that the quality of the Sebou River varies from pure to very impure; on the other hand, the quality of the lower Moulouya is pure in all the sampling points, and for Oum Er Rbia, the quality is pure to moderately polluted. Overall, this study shows that the surface waters of Oum Er Rbia and lower Moulouya are highly mineralized. This indicates that specific treatment of these waters is necessary if they are to be used for drinking water supply. This work also made it possible to diagnose the pollution of the surface waters of the Sebou river by metallic trace elements due to the industrial and agricultural intensification that this river is experiencing. Faced with this alarming situation, it is essential to

monitor the quality of the surface waters of the three rivers studied and the surrounding groundwater using appropriate tools and to watch all the parameters listed in the surface water quality grid. According to Decree 1275–01 of 2002, monitor, correct, and preserve natural resources that remain important for drinking water, irrigation, and industrialization. Generally, it is advisable to organize several analysis campaigns, which makes it possible to monitor the pollution of river water.

**Acknowledgements** The authors would like to thank Editor-in-Chief Abdullah M. Al-Amri, who welcomed our manuscript for publication. We also sincerely thank anonymous reviewers for their constructive comments that significantly improved the manuscript.

**Data availability** The datasets generated during and/or analysed during the current study are available from the corresponding author.

## Declarations

**Competing interests** The authors declare no competing interests.

## References

- Abdullah EJ (2013) Quality assessment for Shatt Al-Arab River using heavy metal pollution index and metal index. *J Environ Earth Sci* 3(5):114–120
- Abubakar AJ, Yusuf S, Shehu K (2015) Heavy metals pollution on surface water sources in kaduna metropolis, nigeria. *Science World Journal Vol 10 (No 2) 2015*. ISSN 1597–6343
- Agence de l'eau Loire-Bretagne (Acted) 2006. Le prélèvement d'échantillons en rivière techniques d'échantillonnage en vue d'analyses physico-chimiques. ISBN 10 : 2–916869–00–X ISBN 13 : 978–2–916869–00–1
- Agoumi A, Debbarh A (2005) Ressources en eau et bassins versants du Maroc : 50 ans de développement, report prepared within the framework of the « water: management of scarcity » organized by the Association of Moroccan Engineers of Bridges and Roads, pp. 13–62, Morocco
- Arrêté N°1275–01(2002) Arrêté conjoint du ministre de l'équipement et du ministre chargé de l'aménagement du territoire, de l'urbanisme, de l'habitat et de l'environnement du 10 chaabane 1423 (17 octobre 2002) définissant la grille de qualité des eaux de surface BO-5062, (2002)
- Azzaoui S, Hanbali ME, Leblanc M (2002) Note technique—Cuivre, plomb, fer et manganèse dans le bassin versant du Sebou; Sources d'apport et impact sur la qualité des eaux de surface. *Water Qual Res J* 37(4):773–784. <https://doi.org/10.2166/wqrj.2002.052>
- Bailey RT, Ahmadi M (2014) Spatial and temporal variability of in-stream water quality parameter influence on dissolved oxygen and nitrate within a regional stream network. *Ecol Model* 277:87–96
- Barakat A, El Baghdadi M, Rais J, Aghezzaf B, Slassi M (2016) Assessment of spatial and seasonal water quality variation of Oum Er Rbia River (Morocco) using multivariate statistical techniques. *Intl Soil Water Conserv Res* 4(4):284–292. <https://doi.org/10.1016/j.iswcr.2016.11.002>
- Belghiti ML, Chahlaoui A, Bengoumi D, El Moustaine R (2013) Etude de la qualité physico-chimique et bactériologique des eaux souterraines de la nappe plio-quaternaire dans la région de Meknès (Maroc). *arhyss Journal*, ISSN 1112-3680, n°14, Juin 2013, pp. 21-36

- BO-5062 (2002) Arrêté Ministériel N°1275–01, 2002 du Royaume du Maroc définissant le Grille de Qualité des Eaux de Surface
- Bouabdli A, Saïdi N, M'Baret S, Escarre J, Leblanc M (2005) Oued Moulouya: vecteur de transport des métaux lourds (Maroc). *Revue Des Sciences De L'eau / Journal of Water Science* 18(2):199–213. <https://doi.org/10.7202/705556ar>
- Bounakhla M, Bounakhla Z, Zahry F, Tahri M, Zghaid M, Doukali A, Benkirane O, Saïdi N (2009) Contribution à l'étude de la contamination métallique de *Mytilus edulis* au niveau de l'embouchure de Sebou. *Phys Chem News* 45(2009):17–21
- Bu HM, Tan X, Li SY, Zhang QF (2010) Temporal and spatial variations of water quality in the Jinshui River of the South Qinling Mts. China. *Ecotoxicol Environ Saf* 73(5):907–9130
- Ceaq (centre d'Expertise en Analyse Environnementale du Québec) (2014) Détermination des métaux : méthode par spectrométrie de masse à source ionisante au plasma d'argon. MA. 200–Mét 1.2, Rév. 5, Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques du Québec, 36 p
- Derwich E, beziane Z, benaabidate L, belghyti D (2008) Evaluation de la qualité des eaux de surface des oueds Fès et Sebou utilisées en agriculture maraîchère au Maroc. *Larhyss Journal*, ISSN 1112-3680, n° 07, Juin 2008, pp. 59-77
- Derwich E, Benziane Z, Benaabidate L (2011) Diagnostic of physico-chemical and bacteriological quality of fez wastewaters rejected in Sebou River: Morocco. *Environ Earth Sci* 63(4):839–846. <https://doi.org/10.1007/s12665-010-0754-5>
- Derwich E, Benziane Z, Benaabidate L, Lahrach A, Boushaba A (2012) Chrome, Plomb, Zinc, Cuivre et Nickel dans le bassin versant du Sebou: sources d'apport et impact sur la qualité des eaux de surface. Actes du 21<sup>ème</sup> colloque international des bassins sédimentaires. Fés ISSN 0374–9789
- Edet A, Offiong O (2002) Evaluation of water quality pollution indices for heavy metal contamination monitoring. A study case from Akpabuyo-Odukpani area, Lower Cross River Basin (southeastern Nigeria). *GeoJournal* 57 (4):295–304
- El Alami A, Fattah A, Chait A (2020) A survey of the Eurasian Otter *Lutra lutra* and human-otter interaction in the middle Oum Er Rbia river, Morocco. *IUCN Otter Spec Group Bull* 37(4):219–231
- El Hajjami S, Souabi S, El Alami M, Taleb A (2020) Spatio-temporal evaluation of the contamination by metallic trace elements of the surface waters of Oued Sebou, Morocco. In: Ezziyani, M. (Ed.), *Advanced intelligent systems for sustainable development (AI2SD'2019)*. AI2SD 2019. *Advances in Intelligent Systems and Computing*, Vol. 1104. Springer, Cham. [http://doi-org-443.webvpn.fjmu.edu.cn/10.1007/978-3-030-366711\\_56](http://doi-org-443.webvpn.fjmu.edu.cn/10.1007/978-3-030-366711_56)
- El Hajjami S, Abriak N, Souabi S, El Alami M (2021) Study of metallic contamination of Oued Sebou sediments, Morocco. *Environmental Technology & Innovation*, 23, 101680. doi: <https://doi.org/10.1016/j.eti.2021.101680>
- Escoffier N, Bensoussan N, Vilmin L, Flipo N, Rocher V, David A, Métivier F, Groleau A (2016) Estimating ecosystem metabolism from continuous multi-sensor measurements in the Seine River. *Environ Sci Pollut Res* 25(24):23451–23467
- Es-Sette B, Ajdor Y, Zidane F, Fakhraddine A (2005) Foutlane A (2005) Évolution des métaux traces dans les eaux de l'oued Sebou en période humide — approche par modélisation mathématique. *Water Qual Res J* 40(2):222–232
- Fathi E, Zamani-Ahmadmahmoodi R, Zare-Bidaki R (2018) Water quality evaluation using water quality index and multivariate methods, Beheshtabad River, Iran. *Applied Water Science*, 8(7). doi:<https://doi.org/10.1007/s13201-018-0859-7>
- Foudeil S, Bounouira K, Amsil H, Bounakhla M, Ait Lyazidi S, Benyaich F, Haddad M (2013) Evaluation de la pollution en métaux lourds dans l'oued Sebou (Maroc). *Sci. Lib Editions Mersenne* 2111–4706, 5 (130906)
- Fouzi TA, Youness M, Bouchra L, Ali B (2020) Spatio-temporal typology of the physico-chemical parameters of a large North African river: the Moulouya and its main tributaries (Morocco). *Afr J Aquat Sci* 1–11. <https://doi.org/10.2989/16085914.2020.1727832>
- Gaagai A, Aouissi HA, Krauklis AE, Burlakovs J, Athamena A, Zekker I, Chenchouni H (2022) Modeling and risk analysis of dam-break flooding in a semi-arid montane watershed: a case study of the Yabous Dam Northeastern Algeria. *Water* 14(5):767. <https://doi.org/10.3390/w14050767>
- Gao B, Gao L, Gao J, Xu D, Wang Q, Sun K (2019) Simultaneous evaluations of occurrence and probabilistic human health risk associated with trace elements in typical drinking water sources from major river basins in China. *Sci Total Environ* 666:139e146. <https://doi.org/10.1016/j.scitotenv.2019.02.148>
- Garvey JE, Whiles MR, Streicher D (2007) A hierarchical model for oxygen dynamics in streams. *Can J Fish Aquat Sci* 64(12):1816–1827
- Gómez-Gener L, Lupon A, Laudon H, Sponseller RA (2020) Drought alters the biogeochemistry of boreal stream networks. *Nat Commun* 11:1795. <https://doi.org/10.1038/s41467-020-15496-2>
- Haddout S, Maslouhi A, Magrane B, Igouzal M (2016) Study of salinity variation in the Sebou River Estuary (Morocco). *Desalin Water Treat* 57(36):17075–17086. <https://doi.org/10.1080/19443994.2015.1091993>
- Hayzoun H (2014a) Caractérisation et quantification de la charge polluante anthropique et industrielle dans le bassin du Sebou. Autre. Université de Toulon; Université Sidi Mohamed ben Abdellah (Fès, Maroc). *Faculté des Sciences et Techniques*. Français. NNT: 2014aTOUL0007. Tel-01123738
- Hayzoun H, Ouammou A, Saïdi O, Khalil F, Bouayyadi L (2014b) Evaluation de la qualité bactériologique et chimique du Sebou, Maroc. *J Mater Environ Sci* 5(S2):2438–2443. ISSN : 2028–2508
- Hayzoun H, Garnier C, Durrieu G, Lenoble V, Le Poupon C, Angeletti B, A, Mounier S (2015) Organic carbon, and major and trace element dynamic and fate in a large river subjected to poorly-regulated urban and industrial pressures (Sebou River, Morocco). *Sci Total Environ* 502:296–308. <https://doi.org/10.1016/j.scitotenv.2014.09.014>
- He X, Li P (2020) Surface water pollution in the middle Chinese Loess Plateau with special focus on hexavalent chromium (Cr6+): occurrence, sources and health risks. *Expo Health*. <https://doi.org/10.1007/s12403-020-00344-x>
- Jazouli AE, Barakat A, Khellouk R, Rais J, Baghdadi ME (2019) Remote sensing and GIS techniques for prediction of land use land cover change effects on soil erosion in the high basin of the Oum Er Rbia River (Morocco). *Remote Sens Appl Soc Environ* 13:361–374. <https://doi.org/10.1016/j.rsase.2018.12.004>
- Idlahcen A, Souabi S, Taleb A, Zahidi K, Bouezmarni M (2014) Evaluation de la pollution générée par les lixiviats de la décharge publique de la ville de Mohammedia et son impact sur la qualité des eaux souterraines. *Sci Study Res Chem Chem Eng Biotechnol Food Industry* 15(1):035–050. ISSN 1582–540X
- Imran U, Weidhaas J, Ullah A, Shaikh K (2021) Risk associated with spatio-temporal variations in trace metals and a metalloid in a major freshwater reservoir of Pakistan. *Human Ecol Risk Assess Intl J* 27(2):431–450. <https://doi.org/10.1080/10807039.2020.1729090>
- Jouilil I, Bitar K, Salama H, Amraoui A Mokssit A, Tahiri M (2013) Sécheresse météorologique au bassin hydraulique OUM ER RBIA durant les dernières décennies. *Larhyss J* 12:109–127
- Kanga IS, Chikhaoui NM, M, (2020) Groundwater quality assessment using water quality index and geographic information system based in Sebou River Basin in the North-West region of Morocco. *Int J Energ Water Res* 4:347–355. <https://doi.org/10.1007/s42108-020-00089-y>
- Kowalkowski T, Zbytniewski R, Szpejna J, Buszewski B (2006) Application of chemometrics in river water classification. *Water*



- Res 40:744–752. <https://doi.org/10.1016/j.watres.2005.11.042>. (PMID: 16442142)
- Kumar V, Sharma A, Minakshi, Bhardwaj R, Thukral AK (2018a) Temporal distribution, source apportionment, and pollution assessment of metals in the sediments of Beas River, India. *Hum. Ecol. Risk Assess.* <https://doi.org/10.1080/10807039.2018.1440529>
- Kumar V, Sharma A, Kumar R, Bhardwaj R, Thukral AK, Rodrigo-Comino J (2018b) Assessment of heavy-metal pollution in three different Indian water bodies by combination of multivariate analysis and water pollution indices. *Hum Ecol Risk Assess.* <https://doi.org/10.1080/10807039.2018.1497946>
- Lamprea K (2009) Caractérisation et origine des métaux traces, hydrocarbures aromatiques polycycliques et pesticides transportés par les retombées atmosphériques et les eaux de ruissellement dans les bassins versants séparatifs péri-urbains (Doctoral dissertation, Ecole Centrale de Nantes (ECN))
- Lamri D, Hassouni T, Loukili A, Lamrioui D, Belghyti D, Chahlaoui A (2016) Contribution à la connaissance de la diversité faunistique du bassin versant de la Moulouya (Maroc) [Contribution to the knowledge of fauna diversity in the Moulouya River Basin (Morocco)]. *J Mater Environ Sci* 7(6):2034–2041. <https://doi.org/10.25518/2030-6318.3525>
- Langouet G, Porlier JC (1991) *Mesure et statistique en milieu éducatif*. ISBN: 271010878X 9782710108788. Numéro OCLC: 30370178. 204 p. 4e éd
- Lyulko I, Ambalova T, Vasiljeva T (2001) To integrated water quality assessment in Latvia. Nunspeet, Netherlands, In MTM (Monitoring Tailor-Made). III Proceedings of International Workshop on Information for Sustainable Water Management 449–452
- Mabrouki Y, Fouzi Taybi A, Skalli A, Sánchez-Vialas A (2019) Amphibians of the Oriental Region and the Moulouya River Basin of Morocco: distribution and conservation Notes. *Basic Appl Herpetol* 33(2019):19–32. <https://doi.org/10.11160/bah.134>
- Methneni N, Gonz'alez JAM, Van Loco J, Anthonissen R, Van de Maele J, Verschaeve L, Fernandez-Serrano M, Ben Mansour H (2020) Ecotoxicity profile of heavily contaminated surface water of two rivers in Tunisia. *Environ Toxicol Pharmacol* 82:103550
- Milanovic A, Milišević D, Brankov J (2011) Assessment of polluting effects and surface water quality using water pollution index: a case study of hydro – system Danube – Tisa – Danube, Serbia. *Carpathian J Earth Environ Sci* 6(2):269–277
- Mukate S, Wagh V, Panaskar D, Jacobs JA, Sawant A (2019) Development of new integrated water quality index (IWQI) model to evaluate the drinking suitability of water. *Ecol Ind* 101:348–354. <https://doi.org/10.1016/j.ecolind.2019.01.034>
- Munyao TM, Maritim PK (2013) Assessment of trace metals in sediment and water from Sabaki River Mouth, Kenya. *Int J Curr Res* 5(2):001–006. ISSN: 0975–833X
- N'Guessan YM (2008) *Dynamique des éléments traces dans les eaux de surface des bassins versants agricoles de Gascogne*. Unpublished Thesis (Doctorat d'National). University, Toulouse, France. pp 253
- Nasrabadi T (2015) An index approach to metallic pollution in river waters. *Int J Environ Res* 9(1):385–394. <https://doi.org/10.22059/IJER.2015.910>
- Njuguna SM, Onyango JA, Githaiga KB, Gituru RW, Yan X (2020) Application of multivariate statistical analysis and water quality index in health risk assessment by domestic use of river water. Case study of Tana River in Kenya. *Process Saf Environ Prot* 133:149–158
- NM ISO 10523 (2012) *Qualité de l'eau – Détermination du pH*
- NM ISO 5814 (2014) *Qualité de l'eau – Dosage de l'oxygène dissous - Méthode électrochimique à la sonde*
- NM ISO 7888 (2001) *Qualité de l'eau – Détermination de la conductivité électrique*
- NM 03.7.001 (2020) *Relative à la qualité des eaux d'alimentation humaine*
- Oleiwi AS, Al-Dabbas M (2022) Assessment of Contamination along the Tigris River from Tharthar-Tigris Canal to Azizziyah. *Middle of Iraq Water* 14(8):1194. <https://doi.org/10.3390/w14081194>
- Piqué A (1994) *Géologie du Maroc. Les domaines régionaux et leur évolution structurale*. Edition Pumag, Marrakech, 284p
- Popovic NZ, Duknic JA, Atlagic JZ, Rakovic MJ, Marinkovic NS, Tubic BP, Paunovic MM (2016) Application of the water pollution index in the assessment of the ecological status of rivers: a case study of the Sava River Serbia. *Acta Zoologica Bulgarica* 68(1):97–102
- Pottier P (1994) Mesures de la liaison entre deux variables qualitatives : relation entre un coefficient de corrélation généralisé et le  $\chi^2$ . *Revue de statistique appliquée*, tome 42, no 1 (1994), p. 41–61
- Prasanna MV, Praveena SM, Chidambaram S, Nagarajan EA (2012) Evaluation of water quality pollution indices for heavy metal contamination monitoring: a case study from Curtin Lake, Miri City East Malaysia. *Environ Earth Sci* 67(7):1987–2001. <https://doi.org/10.1007/s12665-012-1639-6>
- Rixhon G, Bartz M, El Ouahabi M, Szemkus N, Brückner H (2017) Contrasting terrace systems of the lower Moulouya River as indicator of crustal deformation in NE Morocco. *J Afr Earth Sc* 126:45–57. <https://doi.org/10.1016/j.jafrearsci.2016.11>
- Saporta G (2006) *Probabilités, analyse des données et statistique*. Editions TECHNIP, 2006 - 622 pages. ISBN 2710808145, 9782710808145
- Sebbar A, Badri W, Fougrach H, Hsaine M, Saloui A, (2011) Etude de la variabilité du régime pluviométrique au Maroc septentrional (1935–2004). *Sciences Et Changements Planétaire/sécheresse* 22(3):139–148
- Sebbar A, Hsaine M, Fourgach H, Badri W (2012) Etude des variations climatiques de la région centre du Maroc. *Les climats régionaux : observation et modélisation*, 709–714
- Selvam S, Venkatramanan S, Singaraja C (2015) A GIS-based assessment of water quality pollution indices for heavy metal contamination in Tuticorin Corporation, Tamilnadu India. *Arab J Geosci* 8(12):10611–10623
- Singh AK, Giri S (2014) Risk assessment, statistical source identification and seasonal fluctuation of dissolved metals in the Subarnarekha River, India. *J Hazard Mater* 265:305–314
- Singh KP, Malik A, Sinha S (2005) Water quality assessment and apportionment of pollution sources of Gomti river (India) using multivariate statistical techniques—a case study. *Analytica Chimica Acta* 538(1–2):355–374
- Sonone SS, Jadhav S, Sankhla MS, Kumar R (2020) Water contamination by Heavy metals and their toxic effect on aquaculture and human health through food chain. *Platinum* 10(2): 2148–2166
- Stancu A, Calin C, Pantea O, Ene C (2015) Identification of correlations between chemical substances and sensory characteristics of Feteasca Alba via Bravais-Pearson coefficient. *Rev Chim (Bucharest)* 66:778
- Strohmeier S, López López P, Haddad M, Nangia V, Karrou M, Montanaro G, Boudhar A, Linés C, Veldkamp T, Sterk G (2020) Surface runoff and drought assessment using global water resources datasets - from Oum Er Rbia Basin to the Moroccan Country Scale. *Water Resour Manage* 34:2117–2133. <https://doi.org/10.1007/s11269-019-02251-6>
- USEPA (U.S. Environmental Protection Agency) (2012) *Edition of the drinking water standards and health advisories*. Environmental Protection Agency, Washington, DC
- Vasistha P, Ganguly R (2020) Assessment of spatio-temporal variations in lake water body using indexing method. *Environ Sci Pollut Res* 27:41856–41875. <https://doi.org/10.1007/s11356-020-10109-3>
- Warnken KW, Santschi PH (2009) Delivery of trace metals (Al, Fe, Mn, V Co, Ni, Cu, Cd, Ag, Pb) from the Trinity river

- watershed towards the ocean. *Estuar Coast* 32:158–172. <https://doi.org/10.1007/s12237-008-9088-x>
- WHO (2011) Guidelines for drinking water quality, 4th edn. 38:104–108
- WHO (2017) Guidelines for drinking-water quality: fourth edition incorporating the first addendum. World Health Organization, Geneva. Licence: CC BY-NC-SA 3.0 IGO
- Wu Z, Wang X, Chen Y CY, Deng J (2018) Assessing river water quality using water quality index in Lake Taihu Basin, China. *Sci Total Environ* 612:914–922. <https://doi.org/10.1016/j.scitotenv.2017.08.293>
- Zamrane Z (2016) Recherche d'indice de variabilité climatique dans des séries hydroclimatique au Maroc: identification, positionnement temporel, tendances et liens avec les fluctuations climatiques : cas des grands bassins de la Moulouya, du Sebou et du Tensift. Thèse de Doctorat. Université Cadi Ayyad (Maroc) et Université de Montpellier II (France), p 198 (in French)
- Zhaoyong Z, Abuduwaili J, Fengqing J (2015) Heavy metal contamination, sources, and pollution assessment of surface water in the Tianshan Mountains of China. *Environ Monit Assess* 187:33. <https://doi.org/10.1007/s10661-014-4191-x>
- Zhim S, Larabi A, Brirhet H (2019) Analysis of precipitation time series and regional drought assessment based on the standardized precipitation index in the Oum Er-Rbia basin (Morocco). *Arab J Geosci* 12:507. <https://doi.org/10.1007/s12517-019-4656-x>
- Zueva NV, Bobrov AA (2018) ISSN 1995–0829, *Inland Water Biology*, 2018, Vol. 11, No. 1, pp. 34–41. Use of macrophytes in assessing the ecological status of small river (by the example of the Okhta River, St. Petersburg). <https://doi.org/10.1134/S1995082917040137>

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