Mimouni Yassine anf Jean-François Deliège
Evaluation of the quality of surface water of Oued Tensift using the water quality index International Journal Water Sciences and Environment Technologies
Vol. (vi), Issue 2, June 2021, pp. 56-65
ISSN Online: 1737-9350; ISSN Print: 1737-6688, Open Access
www.jiste.org
Scientific Press International Limited
Received: 14 May 2021 / Revised: 31 May 2021 / Accepted: June 2021 / Published: June 2021

Evaluation of the quality of surface water of Oued Tensift using the water quality index

Mimouni Yassine[1], Jean-François Deliège[1]
[1] PeGIRE laboratory, RU FOCUS-Aquapôle, University of Liège, Liège, Belgium

Abstract

The Tensift watershed knows an increasing industrial, touristic and agricultural development, which imposes pressure on its water resources. This study aims at assessing the water quality of the Oeud Tensift and three of its tributaries (Ourika, Rherhaya and Issil). The water quality index (WQI) determined from of eight physico-chemical parameters (T°C, pH, EC, BOD5, NH4, NO3 and NO2) was calculated taking into account the limit values of the Moroccan standard for drinking water and the Moroccan standard for surface water quality. In addition, the quality of water for irrigation was evaluated using the sodium absorption rate (SAR), the permeability index (PI) and the residual sodium carbonate index (RSC). Four sampling campaigns were conducted during 2015 for four stations distributed across the study area. In the upstream part of the basin the water quality remains exellent without much seasonal variation. At the downstream level of the basin, the quality is unsuitable for drinking purpose because of the presence of high concentrations of BOD5, ammonium and nitrite. In the downstream part of the basin, a deterioration trend from winter to summer is observed. In general, the results of SAR, PI and RSC showed that the water of the basin does not represent a problem for irrigation, with the exception of the SAR value for the Tensift station in October which exceed the limits set by the food and agriculture organization.

Key Words*:* Oued Tensift, Water quality, index, Irrigation

Évaluation de la qualité des eaux de surface de l'Oued Tensift à l'aide de l'indice de qualité des eaux

Résumé

Le bassin-versant de Tensift connaît un développement industriel, touristique et agricole accru, ce qui exerce une pression sur ses ressources en eau. Cette étude a pour objectif d'évaluer la qualité de l'eau de l'Oued Tensift et de trois de ses affluents (Ourika, Rherhaya et Issil). L'indice de qualité de l'eau (IQE) déterminé à partir de huit paramètres physico-chimiques (T°C, pH, EC, DBO5, NH4, NO3 et NO2) a été calculé en tenant compte des valeurs seuils non seulement de la norme marocaine relative à la qualité des eaux d'alimentation et de la norme marocaine de la qualité des eaux de surface. En outre, la qualité de l'eau pour l'irrigation a été évaluée à l'aide du taux d'absorption du sodium (SAR), l'indice de perméabilité (PI) et l'indice du carbonate de sodium résiduel (RSC). Quatre campagnes d'échantillonnages ont été effectuées durant l'année 2015 pour quatre stations réparties sur la zone d'étude. En amont du bassin, la qualité de l'eau reste excellente sans grande variation saisonnière. Au niveau de l'aval du bassin, la qualité est impropre à la consommation à cause de la présence de grandes concentrations de DBO5, d'ammonium et de nitrite. Dans l'aval du bassin, une tendance à la détérioration depuis l'hiver à l'été est remarquée. D'une façon générale, les résultats du SAR, PI et RSC ont montré que l'eau du bassin ne pose pas de problème pour l'irrigation, à l'exception de la valeur du SAR pour la station de Tensift en octobre qui dépassent les limites fixées par l'organisation des nations unies pour l'alimentation et l'agriculture.

Mots Cles : Oued Tensift, Indice, Qualité de l'eau, Irrigaion

[1] Corresponding author: yassine.mimouni@student.uliege.be

INTRODUCTION

Water is essential for the survival of humans and wildlife. In fact, it is one of the most precious natural resources. Water quality plays a crucial role in the socio-economic development of all countries [1], especially in rural areas where it is used for irrigation and human consumption. Today, water resources are under intense anthropogenic pressures that deteriorate their quality. The water quality is influenced by natural processes (such as rainfall, soil erosion, etc.), and by anthropogenic activities (such as agricultural, urban and industrial activities) [2]. Due to economic development and rapid growth of the world's population, the request for better quality water resources increased, however, surface water resources are limited and are gradually losing their usable properties [3].

Pollutant monitoring systems have a central role in the assessment of the quality of water bodies. These systems are based essentially on analyses of physico-chemical and bacteriological parameters and represent a source of information on the state of contamination of water bodies [4][5]. The assessment of water quality is usually communicated by a large amount of hydro-chemical and biological data and analyses [1], although these analyses give a precise idea of the status of water bodies, this makes the understanding more difficult for policy makers and managers [6]. However, and for a better representation of water quality, several countries and organizations have developed their own assessment system based on quality standards and indices [7].

The Tensift watershed is experiencing increasing industrial, touristic and agricultural development, putting pressure on its water resources already menaced by climate change. The Tensift River, which originates in the High Atlas Mountains, is impacted by this economic dynamic in the region [8]. Untreated sewage, industrial wastewater and oil mill wastes are a point source of pollution for Tensift. In addition, over-fertilization of agricultural land, excessive use of herbicides and insecticides in urban areas and soil erosion contaminate the river by leaching and represent a diffuse source of pollution [9].

In addition, the WHO (World Health Organization) estimates that more than 2 billion people in the world do not have adequate access to safe water. At the level of the Tensift basin, a large part of the conventional water resources are used for drinking water supply (dam, surface water and groundwater) [10], however, anthropogenic activities degrade the quality of water for human consumption and increase the costs of their treatment, indeed, the study conducted by El Fadeli [11] on the quality of water for human consumption in the region of Marrakech, showed that some areas of the city consume water of poor quality and not conform to drinking water standards. Monitoring water quality and determining sources of pollution is absolutely necessary to protect public health and ecosystems.

Because of the large quantity of parameters analyzed, water quality assessment can be a complicated task for the general public and decision-makers. Water quality indices have the advantage of summarizing and simplifying a large amount of data into a single number that describes the overall state of water quality. Several indices have been developed by different scientists and organizations (e.g. US National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), etc.) [12,13]. The Water Quality Index (WQI) was originally developed by Horton in 1965 and since then it has been widely used to determine the state of water quality at a particular location and time [14, 15, 16]. Unlike the classical method of water quality assessment, which consists of comparing experimentally obtained parameter values with set thresholds, the WQI combines measurements of a set of parameters into a single index, allowing temporal and spatial monitoring of pollution [17,16].

MATERIALS AND METHODS

The objective of this study is to determine the level of contamination of the Tensift River and three of its tributaries (Ourika, Rheghaya and Issil). In order to identify the water quality class and to represent the spatio-temporal evolution of the pollution, we use the Water Quality Index (WQI) and the Moroccan standard for drinking water NM 03.7.001. We also determined the impact of the use of its waters for irrigation using the SAR, PI and RSC indices.

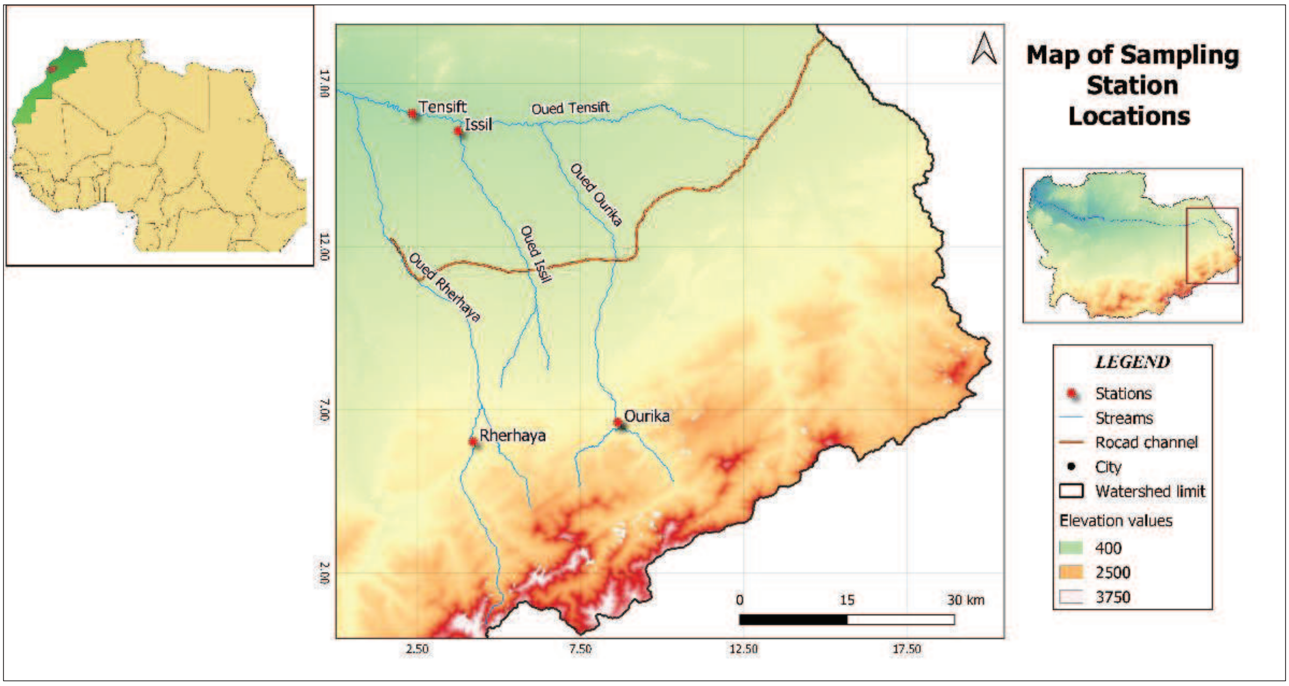
Study area

The Tensift watershed is located in the midwest of Morocco with an area of 24,800 km2, geographically the basin is divided into three areas, the High Atlas Mountains in the south, the Jbilet Massif in the north and a middle part composed of the Haouz plain and the Essaouira-Chichaoua plateau [18]. Oued Tensift crosses the basin from east to west over a length of 260 km and flows into the Atlantic Ocean. The climate of the basin is marked by a spatial heterogeneity of precipitation and temperature, the climate is arid to semi-arid in the jbilet and the Houz plain with precipitation of about 270 mm/year, while the mountains of the High Atlas are characterized by a humid climate and receive 800 mm/year of precipitation [19]. The Oued is mainly fed by the sub-basins of the high atlas; this part of the high-altitude basin receives large quantities of snow, which plays an important role in maintaining river flow [20]. The geology of the Tensift basin is complex [20], the high atlas is mainly composed of Precambrian metamorphic or eruptive formations and secondary formations dominated by limestones, sandstones, marls and clays [21]. The Haouz plain is made up of Quaternary alluvial deposits, the jbilet are essentially formed of schist and mica schist that belong to the Paleozoic era [22].

Data sources

Water quality data was collected from the Tensift Water Basin Agency (TWBA), the agency responsible for water resource management in the basin. The database includes 16 water samples distributed over 4 stations, 3 stations located in the tributaries of Tensift (Ourika, Rheghaya and Issil) and one station located downstream of the city of Marrakech (Fig. 1). Four sampling campaigns were carried out in March, May, July and October 2015. The parameters selected to assess water quality are dissolved oxygen, water temperature, pH, electrical conductivity, biological oxygen demand (BOD), ammonium (NH^4), nitrate (NO^3) and nitrite (NO^2). A total of 120 physico-chemical analyses were used in this work.

Figure 1: Location of sampling stations



Water Quality Index

The Water Quality Index is a mathematical tool that describes the composite influence of different water quality parameters and communicates the results as a single nondimensional number [17], the WQI has been used in several studies, for example Sanchez assessed the water quality in the Las Rozas basin in Spain and demonstrated a simple method for calculating the WQI based on dissolved oxygen values [23]. In Morocco, Soumaila has developed a new WQI to assess water quality in the Sebou Basin [24]. In this study, we will use the water quality index based on the weighted arithmetic index method developed by Bowen in 1972 and used by Talhaoui in the Moulouya basin (Morocco) [25]. According to this index, water quality is assessed in five classes (Table 1) :

Table 1: Water quality classes using the weighted arithmetic index method [17].

WQI value	Rating of Water Quality	Grading
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very Poor water quality	D
Above 100	Unsuitable for drinking purpose	E

The water quality index is calculated by the equation:

$$WQI = \frac{\sum QiWi}{\sum Wi} \tag{1}$$

Wi is the relative weight, calculate for each parameter following the equation:

$$Wi = {}^{K}/_{Si} \tag{2}$$

Where

Si = standard value for the ith parameter of the Moroccan standard for drinking water [26] except for T° and BOD where the Moroccan standard for water quality was used [27].

k = proportionality constant, which can be calculated as:

$$K = \frac{1}{\sum({}^{1}/_{Si})} \tag{3}$$

Then, we calculate the quality rating scale Qi for each parameter according to the equation:

$$Qi = 100 \times \left[\frac{(Vi - Vo)}{(Si - Vo)}\right] \tag{4}$$

Where

Vi is estimated concentration of ith parameter in the analysed water en mg/l

Vo is the ideal value of this parameter in pure water

Vo = 0 (except pH =7.0 and DO = 14.6 mg/l)

Si = standard value for the ith parameter of the Moroccan standard for drinking water [26] except for T° and BOD where the Moroccan standard for water quality was used [27]

Evaluation of irrigation water quality

The quality of water for irrigation purposes can be evaluated by its salt concentration, in fact the salinity of irrigation water modifies the physical properties of soils and limits the capacity of roots to absorb water [28], in this study the sodium absorption rate (SAR), the permeability index (PI) and the residual sodium carbonate (RSC) were calculated (equations 5, 6 and 7) to evaluate the capacity of water for irrigation.

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

$$PI = \frac{Na^{+} + \sqrt{HCO3}}{Ca^{2+} + Mg^{2+} + Na^{+}} \times 100 \tag{6}$$

$$RSC = [HCO3^{-} + CO3^{2-}] - [Ca^{2-} + Mg^{2+}] \tag{7}$$

RESULTS AND DISCUSSION

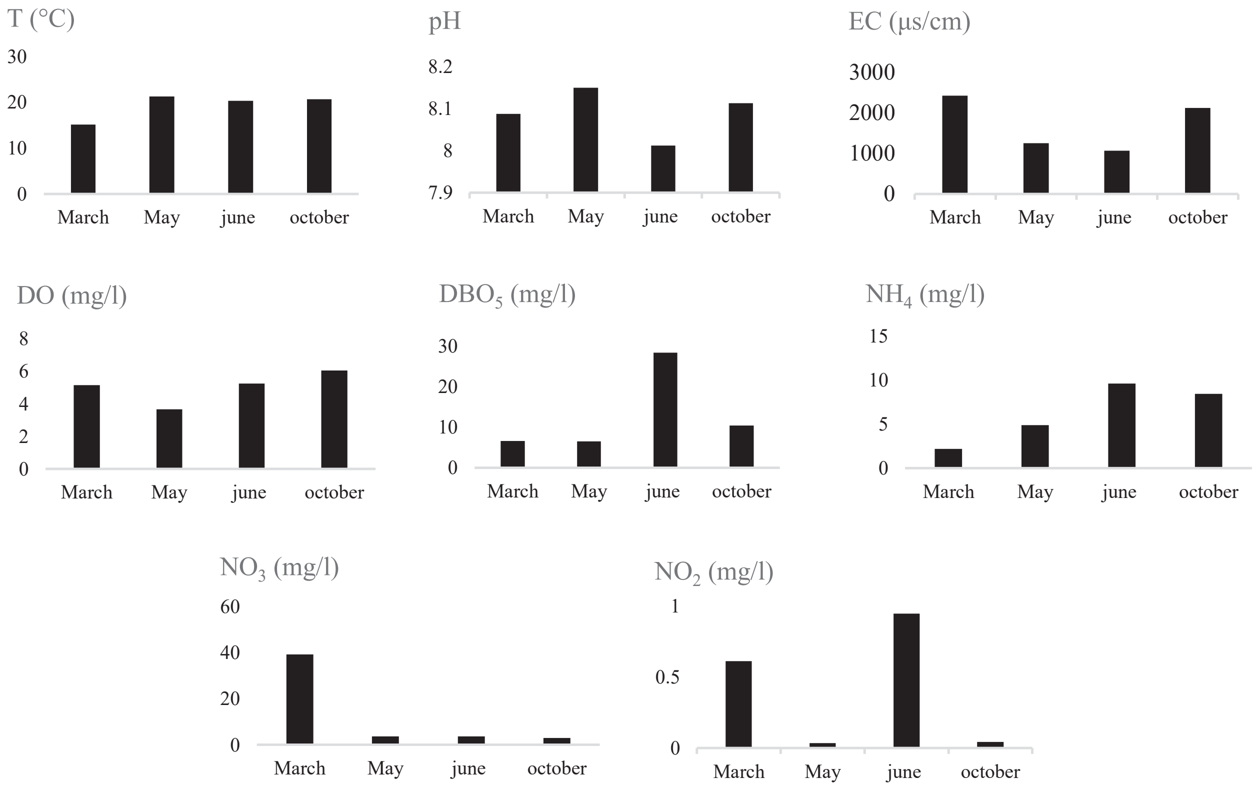
The physico-chemical properties of water

The statistical characteristics of the physico-chemical parameters (minimum, maximum, mean, standard deviation) and the temporal evolution of the monthly mean of the water quality parameters over the year are summarized in Table 2 and Figure 2. The water temperature varies between 9.9 °C recorded in March and 26.3 °C recorded in June, the water temperature is directly influenced by the temperature of the atmosphere. The pH is between 7.6 and 8.55, these values correspond to lightly alkaline water, its evolution during the year shows a small decrease during the month of June, low pH values increase the concentrations of heavy metals in ionic form that can be assimilated by organisms, while a high pH increases the concentrations of ammonia, which is toxic for aquatic life [29]. Conductivity is a numerical expression describing the quantity of mineral salts in solution, the monthly averages of electrical conductivity are respectively 2420, 1248, 1069 and 2114 µs/cm, these values are a little high and can be attributed to the high degree of anthropic activities such as urban waste and chemicals runoff from agricultural and beekeeping activities [30]. Dissolved oxygen has reached a maximum value of 10 mg/l and a minimum value of 0 mg/l, dissolved oxygen is an essential element for aquatic life, his concentration is influenced by several parameters such as salinity, temperature, photosynthetic activity and the presence of organic pollutants, a dissolved oxygen concentration of less than 1 mg/l indicates conditions close to anaiorobia, this situation results from a high oxidation of organic matter and nutrients by microorganisms, in this study the low values of dissolved oxygen is negatively correlated with BOD5, which indicates contamination by anthropogenic discharges. The BOD5 values tend to increase from March to reach a maximum of 111 mg/l in June, this increase can be explained by evaporation and the decrease of the flow in the summer months. Ammonium values oscillate between 0 and 39 mg/l and represent an increasing tendency from the month of March until the month of June when it reached its maximum value. Ammonium in water comes from the degradation of organic matter that contains nitrogen (e.g. protein, amino acid, etc.). The sources of ammonium contamination are agriculture and industrial and domestic activities. As for nitrate values, they vary from 0.12 to 70 mg/l, the main source of nitrate is agriculture, however, they can also come from domestic discharge and industrial activity [31], in this study, the maximum nitrate value is recorded in March, leaching from agricultural land due to rainy periods may explain this increase. Nitrite is considered as a transient molecule in the environment, nitrite oxidizes rapidly to nitrate, and is rarely found in high concentrations in ecosystem, moreover nitrite is more dangerous for the aquatic ecosystem, especially for fish [32]. In this study, nitrite peaks were recorded in March and June and reached critical concentrations (3.75 mg/l).

Table 2: Statistical variables of the physico-chemical parameters

		T	pH	EC	DO	DBO_5	NH_4	NO_3	NO_2
		°C		µs/cm	mg/l	mg/l	mg/l	mg/l	mg/l
Mars	**Max**	17	8,3	6330	9,2	13,3	8,65	72	1,37
	Min	9,9	7,9	136	0	0,23	0,02	5,01	0,01
	Moyenne	15	8	2420	5,15	6,6	2,18	39,12	0,61
	Ecart-type	3	0,16	2775	4	7	4	36	0.6
Mai	**Max**	24,9	8,40	1830	7,00	19,00	14,60	7,00	0,08
	Min	19,4	7,75	355	0,12	0,23	0,01	0,12	0,01
	Moyenne	21,2	8,15	1248	3,65	6,54	4,88	3,65	0,03
	Ecart-type	3,15	0,35	785	3,44	10,79	8,41	3,44	0,04
Juin	**Max**	26,3	8,30	2770	8,60	111,00	37,90	5,67	3,75
	Min	16,1	7,60	150	0,00	0,23	0,03	1,38	0,01
	Moyenne	20,3	8,01	1069	5,25	28,33	9,63	3,61	0,95
	standard deviation	4,3	0,31	1167	4,17	55,11	18,85	1,95	1,87
October	**Max**	25,5	8,55	4140	10,00	36,00	19,00	5,59	0,15
	Min	15,3	7,80	365	0,00	0,30	0,00	0,20	0,00
	Moyenne	20,7	8,11	2114	6,05	10,38	8,46	2,95	0,04
	standard deviation	4,3	0,32	1677	4,53	17,19	9,91	2,20	0,07

Figure 2: Monthly evolution of the averages of the physico-chemical parameters



Water quality assessment based on WQI calculation

In this study, the WQI calculation is based on the standard values of the Moroccan drinking water standard and the Moroccan water quality standard. Eight parameters were selected to calculate the index. An example of the calculation is shown in Table 2. The WQI averages (Fig. 3) show a large difference between stations. In general, the Ourika and Rherhaya stations represent excellent water quality with annual averages of WQI equal to 8.8 and 9.1 respectively, while the Tensift and Issil stations represent non-potable water for human consumption and their WQI far exceed the limits described by the index. The WQIs range between 6 and 3000 recorded respectively in the Oued Rherhaya station in October and in the Oued Issil station in June.

Figure 3: Annual Average Values of the WQI

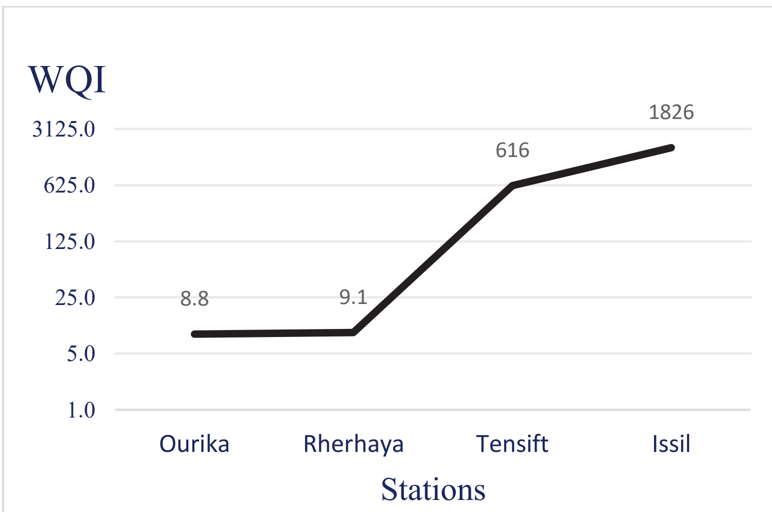


Table 3: Example of WQI calculation for the Ourika station in March 2015

Parameters	Si (mg/l)	1/Si	Wi	Vi	Qi	Qi * Wi
T	30	0,033	0,0072	9,9	33	0,240
Ph	8,5	0,118	0,025	7,9	60	1,544
EC	2700	0,0004	0,00008	136	5	0,0004
DO (mg/l)	5	0,125	0,043	9,2	56	2,460
DBO5 (mg/l)	5	0,2	0,043	0,23	4	0,201
NH4 (mg/l)	0.5	2	0,437	0,02	4	1,750
NO3 (mg/l)	50	0,02	0,0043	5,01	10	0,043
NO2 (mg/l)	0.5	2	0,437	0,01	2	0,875
		K=1/(∑(1⁄Si) = 0,218				
WQI = 7.11 and water quality class is excellent						

Evaluation of Irrigation Water Quality

In order to evaluate the quality of water for irrigation, the sodium adsorption ratio (SAR), the permeability index (PI) and the residual sodium carbonate (RSC) were calculated. The results are presented in Table 4. The SAR is a risk assessment of sodium on the soil, as high sodium concentration leads to crusts formation, reduces soil permeability and influences the rate of water absorption by plants. The SAR calculates the level of sodium exchangeable with calcium and magnesium, making it a good indicator of the danger posed by sodium [33]. SAR values in the study area range from a maximum of 10 recorded at the Tensift station to a minimum of 0.23 recorded at Ourika. Except the Tensift station in October, the mean SAR values do not exceed the limits set by the Food and Agriculture Organization (FAO) [34], which sets the value of 9 as the limit beyond which severe restrictions on use must be taken. The Permeability Index (PI) was developed by Doneen in 1964 to assess the suitability for long-term use of water with a high soluble salt concentration. Doneen defined three classes of water: class I with a permeability of more than 75%, water in this class is perfectly suitable for irrigation, class II with a permeability between 25 and 75% is considered suitable for irrigation and class III with a permeability of less than 25% where the water is unsuitable for irrigation [28]. In the study area, the averages are respectively 65% downstream and 70% upstream, which represents water suitable for irrigation. The lowest PI value is recorded at the Tensift station in March and it is equal to 58% which presents no risk to the soil. Water with a high carbonate concentration can present a risk to the soil, as the carbonate and bicarbonate ions react with calcium and magnesium and form a solid matter that tends to precipitate, increasing the relative portion of sodium ions in water. The RSC calculates the danger of using water with a high bicarbonate concentration, according to Wilcox [35], Water with a RSC lower than 1.25 meq/l does not present a risk for irrigation, water with values between 1.25 and 2.5 meq/l are marginal and water with a value higher than 2.5 meq/l is unsuitable for irrigation. The RSC values of the waters in the study area did not exceed 1.25 meq/l and as a result, they do not present any risk for irrigation use.

Table 4: Average values of irrigation water quality assessment parameters

	Ourika (amont)	Tensift (aval)
SAR	0,45	6,8
PI	70%	65%
RSC	-0,27	-11,37

RESULTS AND GENERAL DISCUSSION

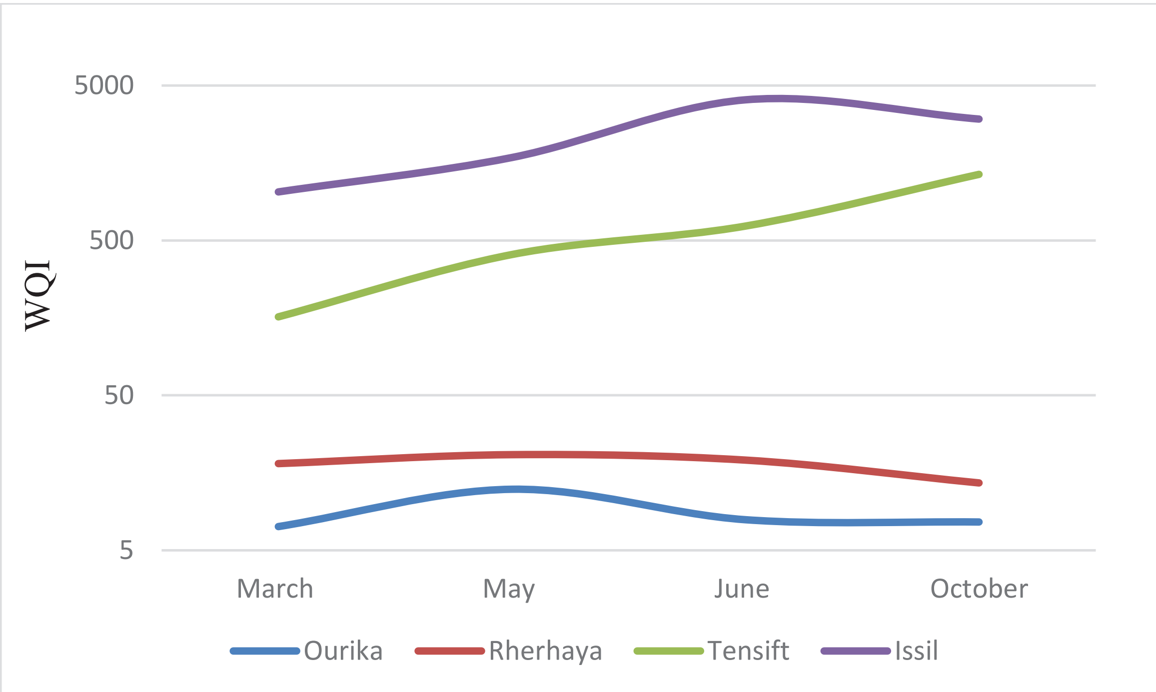
According to the results, the basin shows a clear spatial and temporal variation (fig. 4). The seasonal evolution shows a deteriorating trend from March to October, this variation is evident in the downstream part of the basin (Tensift and Issil), which varies from 142 in March to 1321 in October for the Tensift station and from 868 in March to 3000 in June for the Issil station. However, at the upstream level of the basin, the Ourika and Rheghaya stations show a stable WQI with no seasonal change. This is explained by the variation in rainfall and the flow of the Oueds between the different seasons. Indeed, the flow decreases in the dry months and becomes almost nil in the downstream part of the basin (Tensift and Issil), while effluent flows (urban domestic and industrial discharge) remain high and as a result the pollution rate increases.

Concerning the spatial evolution. Upstream-downstream variation is very evident. The upstream part of the basin (Ourika and Rheghaya) is characterized by excellent water quality, the WQI values in this area vary from 6 to 12, the sub-basins of Ourika and Rheghaya are characterized by low population and the absence of large agglomerations, moreover, the mountain topography reduces the extension of agricultural land, which explains the low water pollution in this area. All the physico-chemical parameters analyzed in the upstream part of the basin did not exceed the limit values recommended by the Moroccan drinking water standard.The downstream part of the basin, which includes the Tensift and Issil stations, represents during the whole study period an unsuitable water quality for drinking purpose, the WQIs in these stations reach extremely high values. The physico-chemical parameters responsible for this degradation are mainly BOD5, DO, ammonium and to a lesser extent, nitrate and nitrite.

The BOD5 reached concentrations of 111 mg/l measured at Issil, which is far above Moroccan standards for surface water. In fact, 85% of the BOD5 analyses in the downstream part of the basin exceed the limit set at 5mg/l. This quantity of organic matter discharged into the river severely reduces oxygen concentrations and causes an anoxia of the aquatic environment. As for ammonium, it is among the most polluting parameters, with a maximum concentration of 36 mg/l, 72 times higher than the limit value set by the Moroccan standard of potablity. Nitrate and nitrite contribute to the deterioration of water quality, 42% of the nitrite analyses in the downstream part of the basin exceed the limit value of 0.5 mg/l, while 28% of the nitrate values are above the limit of 50 mg/l. From these results it can be deduced that the degradation of the water quality is caused by human activity, and more precisely, it is due to the discharge of domestic wastewater, which increases the concentrations of BOD5 and ammonium in the water. In addition, intensive agriculture in the Haouz plain characterized by the use of fertilizers, contributes to the degradation of water resources and increases nitrate concentrations by soil leaching.

However, the stations of Tensift and Issil are located respectively downstream and in the surroundings of the city of Marrakech with a population estimated at 1 million habitants in 2014, this high population density is the cause of the important mineral and organic charge which degrades the water quality.

Figure 5: The evolution of the water quality index (WQI) of the surface waters of the Oued Tensift and three of its tributaries during the year 2015.



CONCLUSION

This study is carried out to determine the water quality of the Oued Tensift and three of its tributaries, data were collected from the Tensift basin agency and it covers the year 2015, eight physico-chemical parameters were selected to carry out this work. The WQI was applied to assess the quality of the basin water, then the SAR, PI and RSC were used to determine the impact of water use for irrigation purposes. The results obtained showed a large difference between upstream and downstream of the basin, and the parameters analyzed varied significantly. The average values of the WQI ranged from 8.8 to 1826, these results show that the water quality in the upstream basin is classified as excellent while the downstream basin is characterized by an unusable water for drinking prupose. In addition, water quality shows a clear seasonal variation, mainly in the downstream part of the basin with an increasing trend from the humid to the dry season, with higher values recorded in June and October and lower values recorded in March and May. Seasonal variance is mainly due to the change in precipitation and flows between the dry and wet months, while spatial variation is caused by activities concentrated in the downstream part of the basin. The main sources of quality deterioration are urban and domestic discharges loaded with organic and mineral matter, causing an increase in BOD5, ammonium and nitrite concentrations. On the other hand, agriculture increases nitrate concentrations in the water mainly in the downstream part of the basin. Contamination is mainly due to soil runoff during flood periods, which explains the increase in values during rainy periods. In addition, the analysis of SAR, PI and RSC parameters shows that the water can be used for irrigation, The SAR values ranged from 0.45 to 6.8, the PI were found to be between 65% an 70% and the RSC did not exceed 1.25 meq/l. The values of the indices do not show any risk for the soils as they do not exceed the limits imposed by FAO, excepted the Tensift station which recorded high SAR values in dry period which requires a treatment of these waters before their use.

Acknowledgments

We would like to thank the tensift basin agency for providing the data used for this work. We are also grateful to Prof N. Ouazzani for our useful discussion.

REFERENCES

[1] T. Abbasi et S. A. Abbasi, « Why Water-Quality Indices », in Water Quality Indices, Elsevier, 2012, p. 3-7.

[2] Z. Wu, X. Wang, Y. Chen, Y. Cai, et J. Deng, « Assessing river water quality using water quality index in Lake Taihu Basin, China », Sci. Total Environ., vol. 612, p. 914-922, 2018, doi: 10.1016/j.scitotenv.2017.08.293.

[3] M. Kavurmacı et C. B. Karakuş, « Evaluation of Irrigation Water Quality by Data Envelopment Analysis and Analytic Hierarchy Process-Based Water Quality Indices: the Case of Aksaray City, Turkey », Water. Air. Soil Pollut., vol. 231, no 2, p. 55, févr. 2020, doi: 10.1007/s11270-020-4427-z.

[4] G. Matta, A. Kumar, P. K. Naik, A. K. Tiwari, et R. Berndtsson, « Ecological analysis of nutrient dynamics and phytoplankton assemblage in the Ganga River System, Uttarakhand », Taiwan Water Conserv., vol. 66, no 1, p. 1-12, 2018.

[5] B. Zhang et al., « Hydrochemical characteristics and water quality assessment of surface water and groundwater in Songnen plain, Northeast China », Water Res., vol. 46, no 8, p. 2737-2748, 2012, doi: 10.1016/j.watres.2012.02.033.

[6] C. G. Cude, « OREGON WATER QUALITY INDEX A TOOL FOR EVALUATING WATER QUALITY MANAGEMENT EFFECTIVENESS ' quality issues by the public and policy makers . tors and other water resource policy makers via sible on the internet (http://www.deq.state.or.us/ annual McKenzie », vol. 37, no 1, p. 125-137, 2001.

[7] S. Errochdi, M. El Alami, N. Bennas, B. Belqat, M. Ater, et F. Fdil, « Study of physicochemical and microbiological quality of two north Moroccan hydrographic networks: Laou and Tahaddart », Mediterranee, vol. 118, no 1. Presses Universitaires de Provence, p. 41-51, mars 11, 2013, doi: 10.4000/mediterranee.6221.

[8] JICA, « Etude du plan de gestion intégrée des ressources en eau dans la plaine du Haouz royaume du Maroc », p. 138, 2007.

[9] B. He et al., « Analyse de la qualité de l'eau et estimation des nutriments en rivière à l'aide de l'imagerie de télédétection Quick Bird », Hydrol. Sci. J., vol. 57, no 5, p. 850-860, 2012, doi: 10.1080/02626667.2012.683792.

[10] BANQUE DE DEVELOPPEMENT, « Projet : APPROVISIONNEMENT EN EAU DE LA REGION DE MARRAKECH », 2012.

[11] S. El-fadeli, RR. Bouhouch, et H. Benmazhar, « Caractérisation de la qualité physico- chimique et minéralogique de l ' eau de consommation de quatre zones de la ville de Marrakech-Maroc (Characterization of physico-chemical and mineralogical quality of drinking water from four areas of the city of Ma », vol. 6, no July, p. 2437-2445, 2015.

[12] T. Poonam, B. Tanushree, et C. Sukalyan, « Water quality indices- Important tools for water quality assessment : A review », Int. J. Adv. Chem., vol. 1, no 1, p. 15-28, 2013.

[13] A. Lumb, TC. Sharma et JF. Bibeault, « A Review of Genesis and Evolution of Water Quality Index (WQI) and Some Future Directions », p. 11-24, 2011, doi: 10.1007/s12403-011-0040-0.

[14] AK. Batabyal et S. Chakraborty, « Hydrogeochemistry and Water Quality Index in the Assessment of Groundwater Quality for Drinking Uses », no August 2016, 2015, doi: 10.2175/106143015X14212658613956.

[15] W. Bengal, P. R. Chatterjee, et M. Raziuddin, « STUDIES ON THE WATER QUALITY OF A WATER BODY AT ASANSOL », vol. 6, no 2, p. 289-292, 2007.

[16] N. M. Gazzaz, M. Kamil, A. Zaharin, et H. Juahir, « Artificial neural network modeling of the water quality index for Kinta River (Malaysia) using water quality variables as predictors », Mar. Pollut. Bull., vol. 64, no 11, p. 2409-2420, 2012, doi: 10.1016/j.marpolbul.2012.08.005.

[17] S. Tyagi, B. Sharma, P. Singh, et R. Dobhal, « Water Quality Assessment in Terms of Water Quality Index », Am. J. Water Resour., vol. 1, no 3, p. 34-38, 2020, doi: 10.12691/ajwr-1-3-3.

[18] Y. Hajhouji, « Modélisation hydrologique du bassin versant de l'oued Rheraya et sa contribution à la recharge de la nappe du Haouz (bassin du Tensift, Maroc) », 2019.

[19] O. Tanouti et F. Molle, « The re-appropriation of water in overexploited river basins. The case of the Tensift river basin (Morocco) », Etud. Rurales, vol. 192, no 2, p. 79-96, févr. 2013, doi: 10.4000/etudesrurales.9902.

[20] a. Chaponnière, « Fonctionnement hydrologique d'un bassin versant montagneux semi-aride Cas du bassin versant du Rehraya (Haut Atlas marocain) », Paris-Grignon [Hydrologic Funct. a, p. 1-268, 2005, [En ligne]. Disponible sur: http://www.documentation.ird.fr/hor/fdi:010047426.

[21] S. Riad, « Typologie et analyse hydrologique des eaux superficielles a partir de quelque bassins versant représentatifs du Maroc », 2003. Consulté le: juin 28, 2020. [En ligne]. Disponible sur: http://www.univ-lille1.fr/bustl.

[22] M. El Mrabet, D. Abdelmalek, S. El Hajjaji, et A. Maaroufi, « Long-term assessment of surface and groundwater quality in Tensift region , Morocco », no February 2020, 2016.

[23] E. Sánchez et al., « Use of the water quality index and dissolved oxygen deficit as simple indicators of watersheds pollution », Ecol. Indic., vol. 7, no 2, p. 315-328, avr. 2007, doi: 10.1016/j.ecolind.2006.02.005.

[24] K. I. Soumaila, C. Mohamed, et N. Mustapha, « Water Quality Assessment Using a New Proposed Water Quality Index: A Case Study from Morocco », Int. J. Environ. Agric. Biotechnol., vol. 4, no 4, p. 957-972, 2019, doi: 10.22161/ijeab.4411.

[25] A. Talhaoui, A. El Hmaidi, H. Jaddi, H. Ousmana, et I. Manssouri, « Calcul De L'indice De Qualité De L'eau (IQE) Pour L'évaluation De La Qualité Physico-Chimique Des Eaux Superficielles De L'Oued Moulouya (NE, Maroc) », Eur. Sci. J. ESJ, vol. 16, no 2, p. 64-85, 2020, doi: 10.19044/esj.2020.v16n2p64.

[26] Snima, « Qualite Des Eaux D ' Alimentation Humaine », Norme Marocaine NM 03.7.001, p. 1-14, 2001.

[27] Norme marocaine de la qualité des eaux de surface, « Bulletin Oficiel du 30 Ramadan 1423 (5décembre 2002) ». .

[28] A. Merouche, S. Selvam, Y. Imessaoudene, et C. N. Maten, « Assessment of dam water quality for irrigation in the northeast of catchment Cheliff-Zahrez, Central Algeria », Environ. Dev. Sustain., vol. 22, no 6, p. 5709-5730, 2020, doi: 10.1007/s10668-019-00447-9.

[29] Y. C. DE VILLERS Juliette, SQUILBIN M, « Fiche les données de l'IBGE : "L'eau à Bruxelles" Qualité physico-chimique et chimique des eaux de surface Institut Bruxellois pour la Gestion de l'Environnement / Observatoire des Données de l'Environnement. 2, 3-4. », 2005.

[30] R. Kangabam Das, S. D. Bhoominathan, S. Kanagaraj, et M. Govindaraju, « Development of a water quality index (WQI) for the Loktak Lake in India », Appl. Water Sci., vol. 7, no 6, p. 2907-2918, 2017, doi: 10.1007/s13201-017-0579-4.

[31] I. S. Kanga, M. Naimi, et M. Chikhaoui, « 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. Energy Water Resour., vol. 4, no 4, p. 347-355, 2020, doi: 10.1007/s42108-020-00089-y.

[32] Julie Corriveau, « Étude des concentrations toxiques de nitrite dans les cours d'eau d'un bassin versant agricole Human Impacts on Aquatic Ecosystems Processes Canada Centre for Inland Waters Eric van Bochove Agriculture et Agroalimentaire Canada », 2009.

[33] S. K. Sundaray, B. B. Nayak, et D. Bhatta, « Environmental studies on river water quality with reference to suitability for agricultural purposes: Mahanadi river estuarine system, India - A case study », Environ. Monit. Assess., vol. 155, no 1-4, p. 227-243, 2009, doi: 10.1007/s10661-008-0431-2.

[34] FAO, « Qualité de l'eau pour l'agriculture ». http://www.fao.org/3/T0234E/T0234E01.htm (consulté le mars 03, 2021).

[35] B. L. V Wilcox et D. C. November, « Classification and Use of Irrigation Waters UNITED STATES DEPARTMENT OF AGRICULTURE ».