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Evaluation of the Effects of Riparian Population Activities on the Physicochemical Quality of Water in a Mediterranean River: The Inaouene River (Taza, North East Morocco)

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Abstract: Mediterranean Rivers are often increasingly subjected to stress as a result of riparian population activities. This present study assessed the impact of human activities on the water quality of the Inaouene River in Morocco. For this purpose, water samples were collected from seven sampling stations along the River and analysed. The water of the Inaouene River is characterised by slightly alkaline water pH (7.32-7.59), electrical conductivity (1206.44-3674.14 µS cm^{-1}), very low level of dissolved oxygen (1.98-5.55 mg L^{-1}), BOD5 (45.42-328.7 mg L^{-1}), COD (112.71-468.46 mg L^{-1}). The results classify the Inaouene River's water in the "moderate to poor" quality range based on Moroccan standards. This water, which is characterised by moderate to severe organic contamination, is also distinguished by a significant allochthone charge from the different riparian urban centres. The multivariate analysis showed a decline in water quality and high amounts of organic matter, nitrogenous and phosphorus in urban centres downstream. Waters from stations located further away from domestic discharge points are less polluted and more oxygenated. Overall, these findings confirmed that the combined effect of anthropogenic activities and the seasonality characteristic of the Inaouene watershed is the main factor that determines water quality.

Key words: Physicochemical quality, organic pollution index, water, Inaouene River, Morocco.

Introduction

In developing countries, surface water pollution is the most common environmental problem (Walker et al., 2019). In these countries, increasing discharges of wastewater containing anthropogenic pollutants, combined with hydro-climatic changes, particularly in the Mediterranean region, are key factors contributing to an imbalance in the ecological environment, affecting both abiotic and biotic ecosystem components.

In the Moroccan context, the water potential is limited by successive periods of drought (Douguédroit, 1997) but it is also affected by the various domestic and industrial liquid pollution discharges. Indeed, wastewater, disposed off precariously and often without any adequate treatment, has a significant role in the degradation of aquatic environments (e.g., Sebou, Oum Er-Rbia) and may be the main cause of water scarcity and public health problems (Barakat, 2016; Foutlane et al., 2002; Taleb, 2006).

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The Inaouene River, constitutes a source of irrigation water, livestock watering, feeding the Idris I reservoir located 20 km northeast of Fez city, and recharging the local groundwater (ABHS, 2010). However, this hydrosystem has been impacted by liquid effluents, margins, and solid waste from riverside settlements (i.e., Taza, Bâb Marzouka, Oued Amlil et Bouhlou). This wastewater discharge volume continues to increase, particularly those of Taza city, estimated at 40354 m^3day^{-1} in 2019 and will reach 45278 m^3day^{-1} in 2030.

This work aims to assess the physicochemical quality of the Inaouene River water. More specifically, the study attempts to highlight and analyse the spatial evolution of different types of pollution, especially organic pollution in the hydrosystem using the organic pollution index (OPI) and identify the water typology and quality using a multivariate analysis of physicochemical data.

Materials and Methods

Study Area Description

The Inaouene River watershed occupies the eastern portion of the Sebou watershed. The studied area corresponds to the Inaouene upstream watershed and is spread over 2720 km^2 occupying the Idris I upstream reservoir area (Figure 1) (Naoura, 2011). A lithological contrast between both sides characterises this area, with impermeable marl formation on the northern side, and Paleozoic to Triassic-liasic formations with significant permeability on the south side (Lghamour et al., 2021; Vidal, 1977). The Inaouene River receives the essential water flows from the northern side corresponding to the main tributaries (i.e., Larbaa, Lahdar, and Lben streams). On the south side, the supply tributaries from the Middle Atlas are Boulajraf, Haddar, Bouhlou, and Matmata streams (Naoura, 2011). All these tributaries ensure an average flow of about 15.54 $m^3 s^{-1}$ recorded in the basin upstream at an altitude of 365 m (Bâb Marzouka station) (ABHS, 2010).

Regarding the climate, the Inaouene River watershed is characterised by a semi-arid climate, marked by sharp seasonal contrasts and very marked irregularities in precipitation, which reaches 600 mm in a year. The temperatures range between 13.68°C and 29.97°C. The seasonal precipitation regime, established according to the Gaussen Ombrothermal diagram (Figure 2), during 2019 and 2020 is characterised by wet autumn and winter (October-May). The dry season is extended over

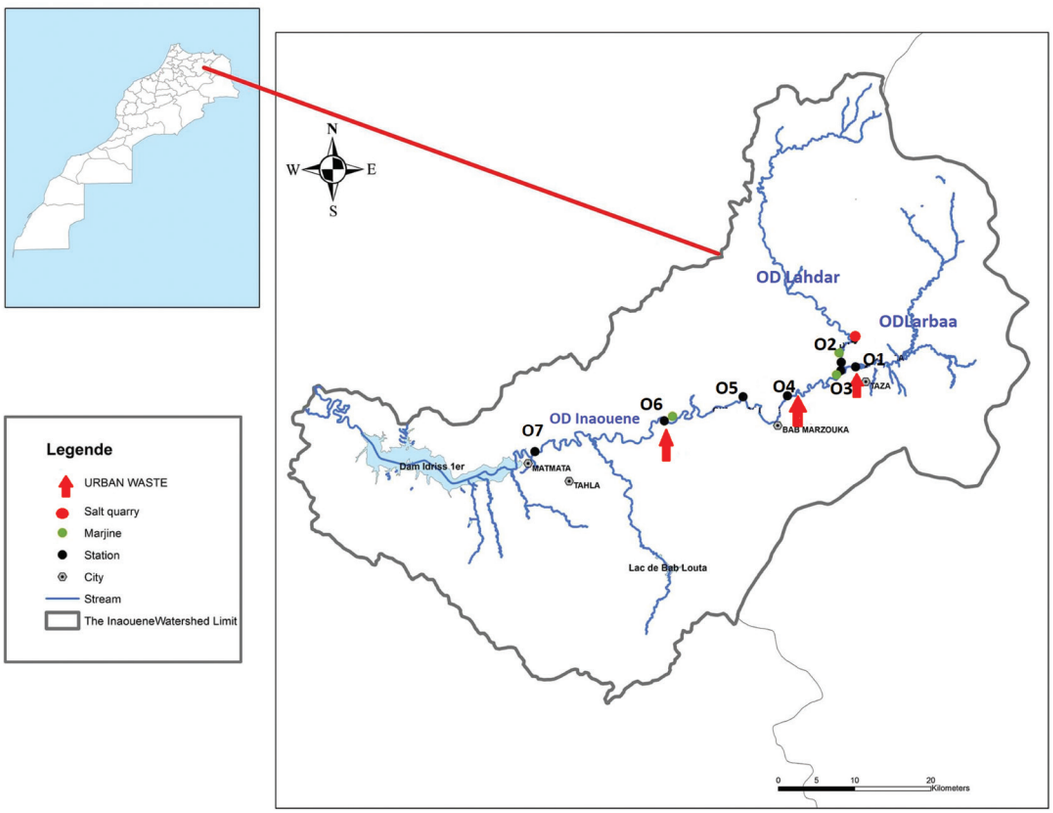

Figure 1: Map showing the Inaouene watershed and sampling stations along the Inaouene River.

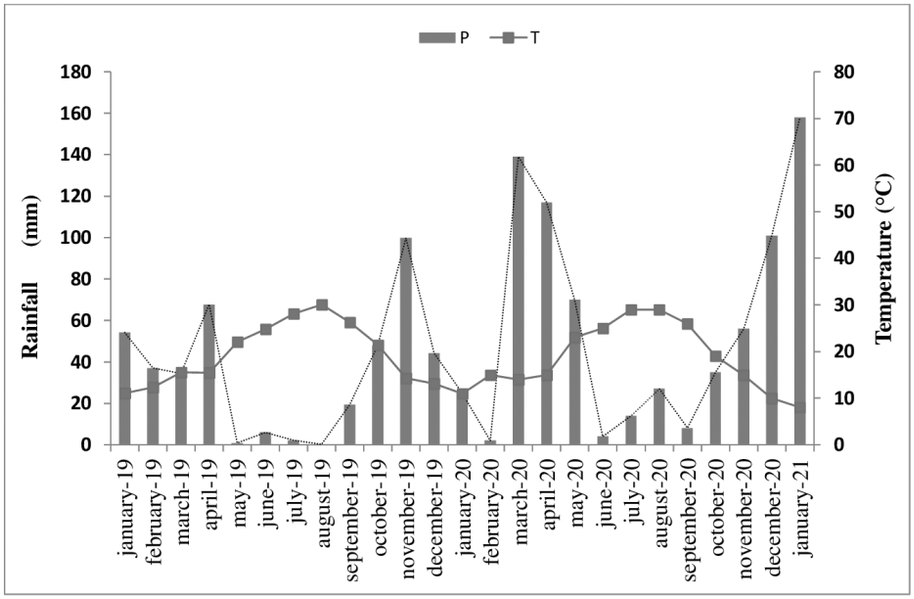

Figure 2: Guassen Ombrothermal diagram of Taza station for 2019 and 2020 (DRAT, 2021).

May-September in 2019. This long dry period leads to a decrease in the water flow due to the drying up of several tributaries (i.e., Lahdar, Amlil, and Mzawrou streams).

Sampling Stations and Working Methodology

During this study, which was conducted from May 2019 to March 2020, seven water sampling and measuring stations were selected along the Inaouene River (Figure 1). The physico-chemical characterisation of the waters was based on the measurement of 13 parameters. The sampling, transport and storage of water samples refer to the protocol defined by Rodier (AFNOR, 1999; Rodier, 2009). Some parameters were performed directly in situ: temperature, pH, electrical conductivity and dissolved oxygen using a multi-parameter CONSORT Model C535 Type, while the other parameters were analysed in the laboratory according to Rodier standard methods, total suspended solids (GFC membrane filtration (0.45 µm)), BOD5 was determined by an OXITOP, the COD was evaluated by oxidation with potassium dichromate at 148°C, nitrate (sodium salicylate method), nitrite (Zambelli reagent method), ammonium (Indophenol blue method), total phosphorus (Determination after oxidation with peroxydisulphate), orthophosphate (potassium antimony tartrate and a solution of ammonium molybdate), sulphate (precipitation in the hydrochloric medium in the presence of barium sulphates).

Data Processing

The organic pollution index (OPI) was used to study the spatio-temporal variations of the organic pollution degree of the Inaouene River's water (Leclercq and Maquet, 1987). This index is widely used to assess the organic pollution degree of Moroccan Rivers (Bahroun et al., 2011; Bekriet al., 2020; Fawzi et al., 2001; Mounjid et al., 2014). The water typology of the different studied stations was determined through the Principal Component Analysis (PCA), applied to a physicochemical data matrix of 77 samples and 13 parameters. The processing was performed using XLSTAT 2020 version software.

Results

The average temperatures of the Inaouene water fluctuate between 17.81°C (O_2) and 19.86°C (O_1) (Figure 3a). These temperatures vary moderately from one station to another, notwithstanding a slight increase at stations O_1, O_3, and O_6. These waters are slightly alkaline, with average pH values varying between 7.31 (O_1) and 7.59 (O_6) (Figure 3b), and remain relatively mineralised. Indeed, the mean EC values vary between 1206.44 μScm^{-1} (O_5) and 3674.14 μScm^{-1} (O_2), and follow a decreasing upstream-downstream gradient, despite the peak noted in the station O_2. Furthermore, the high mineralisation of water is enhanced by the sulphate concentrations which have an increasing

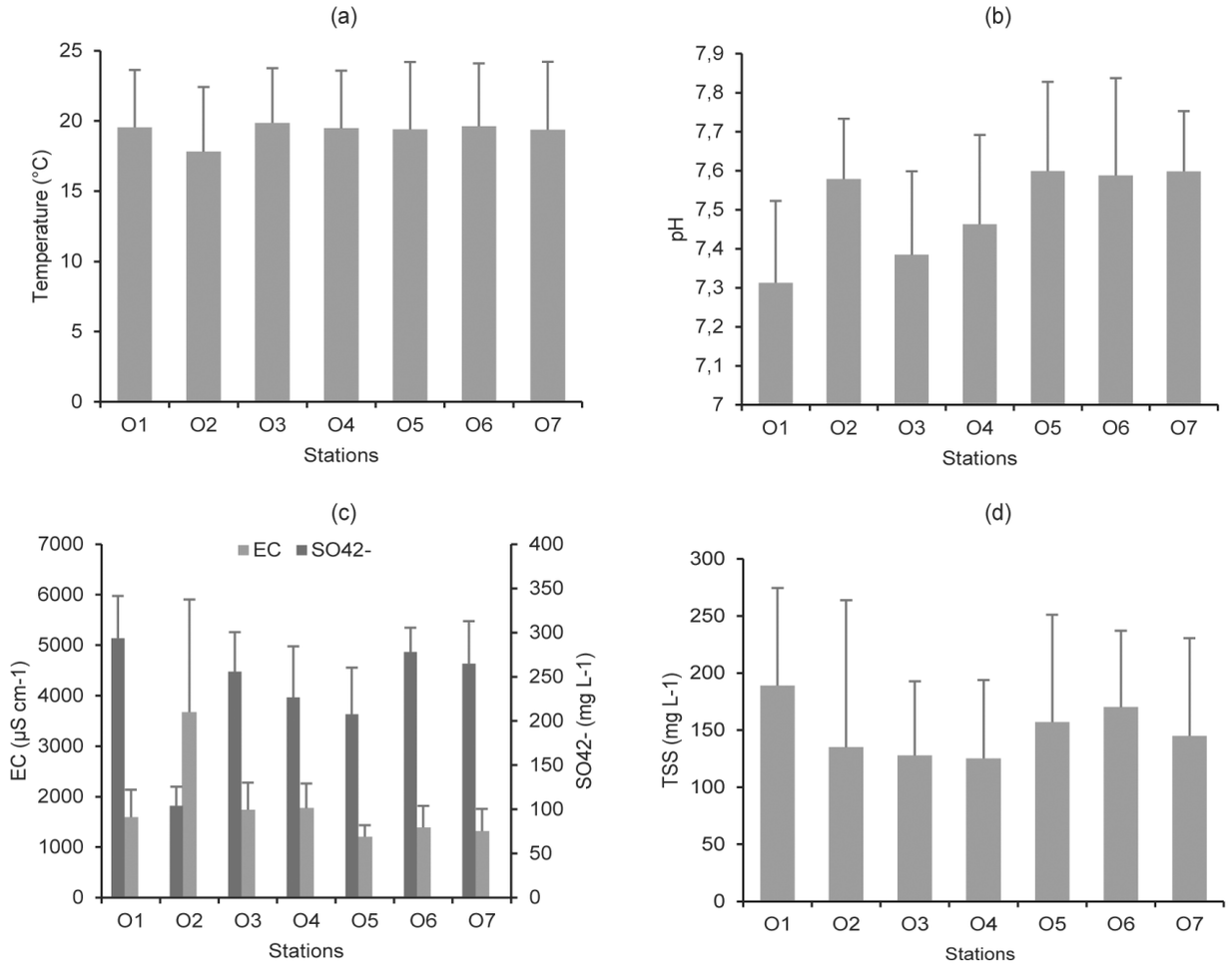

Figure 3: Spatial variation of the mean temperature (a), pH (b) EC and sulphate (c), and TSS (d) of Inaouene River's water

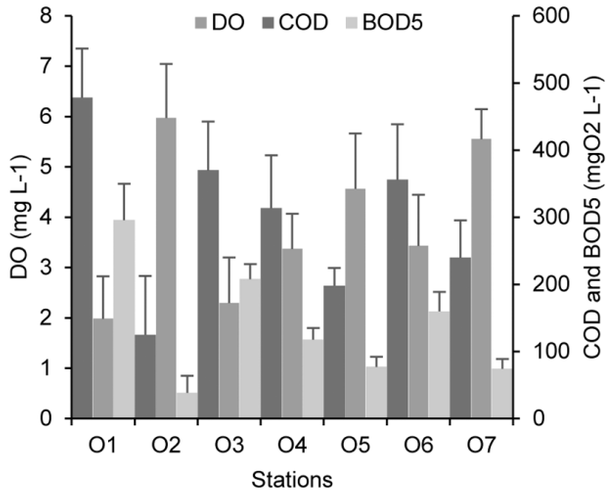

Figure 4: Spatial variation of the mean DO, BOD_5 and COD in Inaouene River's water.

upstream-downstream evolution. The mean values of this parameter fluctuate between 103.88 (O_2) and 293.59 mg L^{-1}(O_1) (Figure 3c). As for TSS, the mean values range between 125.36 mg L^{-1} recorded in station O_4 and 189.1 mg L^{-1} recorded in station O_1 (Figure 3d).

In this river, the water oxygenation remains low and globally follows an increasing upstream-downstream gradient with average DO contents varying between 1.98 (O_1) and 5.55 mg L^{-1} (O_7) despite a peak of 5.97 mg L^{-1} in station O_2 (Figure 4). For organic matter load, the mean BOD_5 values vary between 45.42 mg L^{-1} (O_2) and 328.7 mg L^{-1} (O_1), whereas COD values fluctuate between 112.71 and 468.46 mg L^{-1}, noted in the same stations.

The nitrogenous load, the mean NH_4^+ and NO_2^- contents vary between 0.64 mg L^{-1} (O_2) and 1.5 mg L^{-1} (O_1) for the first parameter, and between 0.53 and 1.41 mg L^{-1} found respectively in the

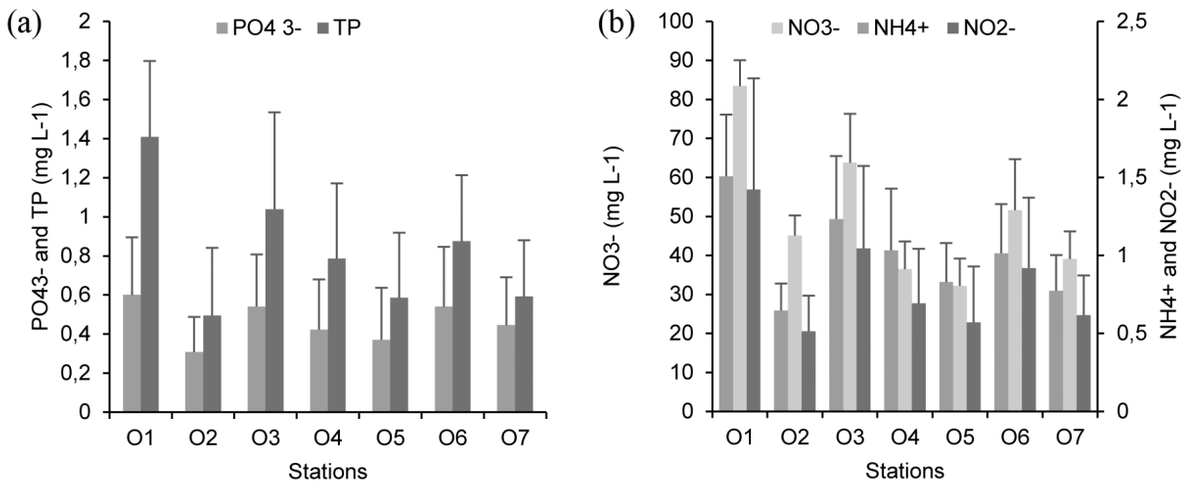

Figure 5: Spatial variation of the mean content of phosphorus (a) and nitrogenous (b) elements of Inaouene River's water.

same stations (O_2 and O_1) for the second parameter (Figure 5a). As for NO_3^-, the mean concentrations range between 32.16 mg L^{-1} (O_5) and 83.43 mg L^{-1} (O_1). For phosphorus pollution, the maximum means are noted in station O_2 for TP (1.40 mg L^{-1}) and PO_4^{3-}(0.59 mg L^{-1}). While station O_1 records the minimum average contents of these two nutrients (Figure 5b).

The OPI index results reveal high organic pollution degrees in the water, ranging from high organic pollution (O_2, O_5, and O_7) to very high (O_1, O_3, O_4, and O_6) (Table 1).

The analysis of the PCA results applied to the physicochemical data shows that the F1 axis explains 74.68% of the total data variability, while the F2 axis explains 15.12% (Figure 6). The F1 axis, which is defined by the parameters: temperature, DO, pH, EC, TSS, BOD_5, COD, NH_4^+, NO_2^-, NO_3^-, SO_4^{2-}, PO_4^{3-} and TP, reflects the organic pollution degree as well as the eutrophication of waters. The F2 axis is essentially defined by EC and reflects a water mineralisation gradient (Figure 6).

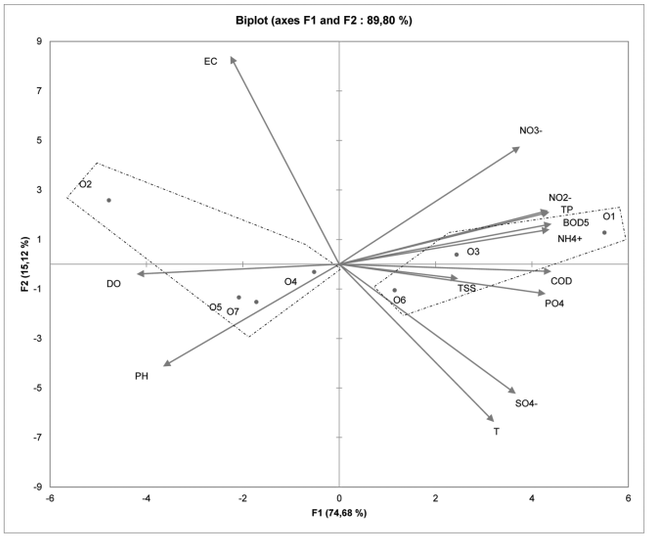

Figure 6: Representation of the PCA, performed on the physicochemical data: Projection of parameters and studied stations on the F1*F2 factorial plane. T: Temperature, EC: Electrical Conductivity, DO: Dissolved Oxygen, TSS: Total Suspended Solids.

Table 1: OPI index of Inaouene River's water

Station	O_1	O_2	O_3	O_4	O_5	O_6	O_7
Minimum	1.5	2	1.5	1.75	1.75	1.5	1.75
Maximum	2	2.25	2.25	2.25	2.25	2.25	2.25
Average	1.75	2.17	1.87	1.97	2.07	1.87	2.25
Standard deviation (SD)	0.16	0.18	0.21	0.24	0.16	0.27	0.14
Coefficient of variability (%)	10.5	8.67	11.33	12.58	8.13	14.4	7
Cartography	Red	Orange	Red	Red	Orange	Red	Orange

Discussion

In our study area, several urban and suburban centres and human activities are developing and producing increasing amounts of liquid and solid discharges. These wastes are dumped into the Inaouene River and its tributaries often without any prior treatment and contribute to the degradation of their overall ecological status. The physicochemical monitoring of these rivers' water quality allows for elucidating the impacts of these discharges on the composition and physicochemical characteristics of water.

In this river, the global stabilisation of water temperatures is linked to the stabilisation of local hydrological conditions in the Inaouene basin, which is influenced in particular by hydroclimatic and geophysical factors. However, given this spatial stability, the impact of the wastewater discharges on water temperatures remains limited in this river. As for pH, it seems that the low alkalinity of water, already reported by Laaraj et al. (2020) and Rezouki et al. (2021) in the same River, is due to the nature of soils and geological layers crossed mainly liasic dolomite. Referring to the Moroccan standards of surface water quality "MSSWQ" (SEEE, 2002), these average temperature and pH values indicate that the water quality of the Inaouene River is excellent.

The excessive water mineralisation of the Inaouene River is a characteristic of Mediterranean Rivers but we further believe that it has an anthropogenic origin attributed to the wastewater discharges from the riparian agglomerations and the leaching of fertilised soils. In addition to these anthropogenic sources, sulphate in natural waters is derived from the pre-rifian aquifer's saliferous and gypsum layers (Naoura, 2011). These high sulphate concentrations qualify water of poor to moderate quality according to the MSSWQ (SEEE, 2002).

In Rivers, the TSS load varies according to the season and the water flow regime. In our river, the stations with the highest average TSS loading were those influenced by liquid and solid discharges, as well as river sand extraction activities (O_1, O_3, O_6, and O_7). This confirms that the particle load is mainly influenced by liquid and solid discharges from the riparian urban centres which are proven by several works in Morocco and the Mediterranean region (Guellaf et al., 2021; Laaraj et al., 2020; Makhoukh et al., 2011; Varol et al., 2012). Despite these relatively high TSS loads, the waters of different stations are of good quality according to Moroccan standards.

Furthermore, the degradation of water quality at stations O_1, O_3, and O_6 is related to their organic enrichment and wastewater discharges. This organic enrichment of water in the urban centres downstream is consistent with the results of Laaraj et al. (2020) and Rezouki et al. (2021) in the same site. As a result, the waters in these stations are of very poor quality according to the MSSWQ (SEEE, 2002). However, the increasing gradient of water oxygenation is linked to the self-purification process and the well-oxygenated water inflow from the tributaries. Nevertheless, unlike stations O_1 and O_6, which are both affected by liquid effluents, the remoteness of station O_2 from the wastewater discharge points explains its water's high oxygenation and low organic pollution. The Lahdar tributary water (O_2) also contributes to the dilution of urban organic pollution (station O_1), which explains the improvement of water quality in station O_3 as reported in a similar literature study. This phenomenon is also observed at the confluence of the Bouhlou tributary and the main watercourse (O_7) (Figure 4). Furthermore, the low oxidisable load in stations O_2, O_5, and O_7 demonstrates the biodegradable nature of the discharged wastewater into this river on the one hand and the self-purification capacity of its water on the other. But, when these organic loads are compared to the previous quality status of this river's water (Ben Abou et al., 2018; Naoura, 2011), it is obvious that the Inaouene River's water quality is constantly deteriorating as a result of the anthropic activities which further enhance the organic enrichment of water. While, this organic enrichment level exceeds that of several Moroccan rivers (Barakat et al., 2016; Derfoufi et al., 2019; Makhoukh et al., 2011) that receive raw sewage from riparian settlements and confirms the alarming state of this river's water quality. In addition, these anthropogenic activities on the Inaouene river sides as well influence nitrogenous and phosphorus enrichment of water also observed in several Mediterranean hydrosystems impacted by wastewater discharges (Mabrouki et al., 2016; Perrin et al., 2014; Özbay et al., 2019; Resende et al., 2010; Varol et al., 2012), deteriorating its quality from moderate to poor quality downstream of the wastewater discharge points (SEEE, 2002). Indeed, the highest nitrogenous and phosphorus element concentrations were found at stations downstream of urban centres and drainage water from fertilised agricultural lands (O_1, O_3, and O_6). In addition to liquid discharge inputs, the NO_3^- enrichment in these stations can be linked to agricultural inputs from the leaching of nitrogenous fertiliser applied to soils (Ben Abou et al., 2018). Despite this, the phenomenon

of water self-purification participates in the reduction of this nutrients load, also diluted by the tributary waters in the most oxygenated stations, and explains its spatial decreasing evolution. Furthermore, the comparison of these findings to the river's previous status (Ben Abou et al., 2018; Naoura, 2011) reveals the increasing nutrient enrichment and the water quality deterioration over the last decade.

Moreover, this degrading effect of wastewater effluents, margins, and leachates of the riparian agglomerations on the water quality is confirmed by the OPI index. Indeed, this synthetic index, used for the first time in the Inaouene River, underlines the diluting effects of Inaouene River tributaries and the self-purification phenomenon of water by reducing organic water pollution, which is enhanced by the hydrosystem's oxygen resources. This degrading effect of the riparian settlement's activities on the water quality is also elucidated by the multivariate analysis, which identifies two major samples/station groupings of water typology: one with impaired water quality (O_1, O_3, and O_6) which is related to the various discharge impacts from the urban centres and the agricultural soil leaching, and the other with more improved water quality (O_2, O_4, O_5, and O_7), through the self-purification and the dilution of pollution phenomena.

Conclusion

This evaluation study of the water quality of the Inaouene River, based on an adequate spatial and temporal sampling, reveals that the degradation of water quality is related to the amount of allochthonous organic matter and nutrients received from the diverse anthropogenic activities in the river's watershed. Indeed, the stations downstream of the urban centres have poor water quality and the highest organic matter, nitrogenous, and phosphorus loads. However, the physicochemical quality of the water improves progressively away from the discharge points, as a result of the environment's self-purification ability and the pollution dilution phenomenon. Otherwise, this water quality deteriorates over the years under the combined effects of anthropogenic impacts, and climatic and hydrological irregularities. Thus, the treatment of urban centres and oil mills' liquid effluents, the controlled landfills construction in Taza and Oued Amlil centres, and the agricultural activities rationalisation in this River watershed are essential to stop the degradation of its water quality and preserve aquatic biodiversity fauna, and flora.

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