Assessment of the effect of drought and anthropogenic liquid pollution on the physico-chemical quality of the waters of Oued Inaouene using the Water Quality Index (Taza, Morocco)

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Abstract. The Inaouene river, a tributary of the Oued Sebou, is subject to the effects of drought in the Mediterranean climate and pollution from raw wastewater. Assessment of water quality in this hydrosystem using the water quality index (WQI) calculated from 19 physico-chemical parameters (pH, T°, EC, DO, MES, $NH4^+$, NTK, NO_3^-,SO_4^{--}, PO_4^{--} ,PT, COD, BOD_5, Cl^-, Cr, Zn, Pb, Cu and Fe) over 3 hydrological cycles (May 2019 to June 2022) showed that upstream, water quality remains very poor, with no significant inter-annual variations, except for stations located on Oued Lahdar (WQI=35.11) and those downstream of Inaouène (WQI=43.71), where quality is good during the 2nd hydrological cycle. During the 1st and 3rd hydrological cycles, water quality deteriorated in the Inaouene (WQI>100), reflecting water quality unfit for consumption. Overall, the WQI values recorded are very high during the 3rd dry hydrological cycle. Moreover, the WQI varied significantly between the 3 cycles ($p = 0.0006$).

Keywords: Oued Inaouene, water, physico-chemistry, WQI, pollution, drought.

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1. Introduction

In Morocco, the challenge of water is one of the main environmental problems, due on the one hand to the consequences of water pollution and the lack of adequate waste management, and on the other hand to the natural pressures exerted on resources: drought, geological and geomorphological conditions favouring water erosion [1]. At the same time, we are witnessing a significant increase in water demand and the annual volume of wastewater produced. This is due to the growth of the urban population, the increase in drinking water consumption and the significant use of water by the industrial sector and pumping for agricultural purposes.

The city of Taza is one of Morocco's fastest-growing urban areas, producing large volumes of wastewater which poses a threat to the aquatic environment of Oued Inouaene which is already subject to a significant water deficit. At the same time, the communes along Oued Inaouene also contribute to the pollution of this receiving environment through the direct discharge of wastewater. Indeed, domestic discharges from the town of Taza are 5760948 m^3/year 2019, 6000475.2 m^3/year 2020, 5683079.2 m^3/year 2021 and 5031830.4m^3/year 2022[2], and discharges from the town of Oued Amlil into Oued Inaouène are 409434 m3/year 2022[3]. Monitoring and monitoring the water quality of this hydrosystem is essential to ensure its sustainability and good sustainable management [4]. The physico-chemical characteristics of the water of Oued Larbaa and Inaouene have been the subject of several studies [5, 6, 7], none of which has used the water quality index (WQI). This method initially proposed by [8,9] is a simple method used as part of the analysis of general water quality using a group of parameters [10, 11]. This index was used by Talhaoui at Oued Moulouya [12] and Mimouni [13] to assess the water quality of Oued Tensift. The aim of this study is to determine the surface water quality of Oued Inaouene and its tributaries Larbaa and Lahdar by calculating the WQI, in order to highlight the interannual and spatial evolution from upstream to downstream of the water quality regime along the Inaouene over 3 hydrological cycles.

2. Materials and methods

2.1 Study area and sampling stations

The study area covers the part of the Inaouene watershed upstream of the Idriss1st dam. It covers an area of 2720 Km^2 and a perimeter of 268 Km, located between parallel (33.84N ; 34.58N) and meridian (3.78W ; 4.91W) lines. Oued Inaouene is a main tributary of Sebou, (Fig. 1), formed by the junction of Oued Larbaa and Lahdar. The Inaouène watershed has a semi-arid Mediterranean climate with a 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. During low-water periods, high atmospheric temperatures can cause significant evaporation, resulting in the beds of the Inaouène's tributaries sometimes drying up prematurely. Low-water periods are severe enough; the average flows recorded at the Bab Merzouka station for the years 2019/2020, 2020/2021 and 2021/2022 are 1.75, 0.83 and 0.45 m^3.s-1 respectively [14]. The study area is bordered by two mountain ranges: the Rif, to the north, whose southern front extends a region of marly, clayey hills. To the south, the Middle Atlas is a tiered plateau dominated by folded chains. The Inaouene watershed is characterized by a marly substratum more or less reinforced by limestone and sandstone banks [15]. To carry out this study, seven stations were selected from May 2019 to June 2022. To determine the impact of liquid pollution, we chose station O_1 on Oued Larbaa, which receives wastewater discharges and leachates from the Taza city landfill, and station OH downstream of Lahdar. In order to monitor the evolution of pollution in the watercourse, we chose stations O_2 to O_6, which follow each other from upstream to downstream, according to the longitudinal profile of the watercourse (figure 1).

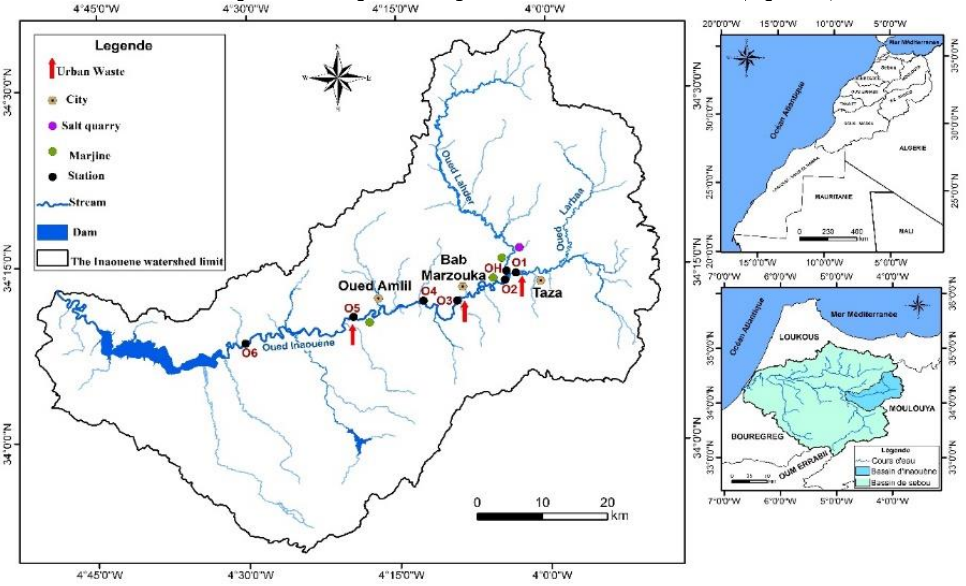

Fig. 1. study area and location of sampling sites.

2.2 Physical-chemical analysis Methods

During this study, water samples were collected in polyethylene bottles and transported to the laboratory in a cool box at low temperature (+4°C). The physico-chemical study of the water involved the determination of 19 parameters: temperature (°C), pH, conductivity (EC) and dissolved oxygen (DO) were measured in the field using a multi-parameter CONSORT Model C535 Type, while the other parameters (Tab 1) were analyzed in the laboratory using the techniques and methods cited by Rodier [16], and in accordance with Afnor standards [17]. Metal elements Cr, Pb, Zn, Cu and Fe were analyzed by inductively coupled plasma atomic emission spectrophotometer (ICP-AES).

Table 1. Analysis methods for physico-chemical parameters.

Parameter	Unit	Method	Norme
Total Suspended Solids (TSS)	mg/l	Filtration method on GFC filter (0.45 µm)	NF EN 872
Kjeldhal nitrogen (NTK)	mg/l	Sulfuric acid mineralization, distillation at Buchi Distillation Unit B324	NF EN 25663
Ammonium (NH_4^+)	mg/l	Indophenol blue method	NF T 90-015
Nitrates (NO_3^-)	mg/l	Sodium salycilate method	NF T 90-012
Sulfates (SO_4^{2-})	mg/l	Nephelometric method	NF T 90-040
Total phosphorus (Tp)		Determination after oxidation with peroxidislufate	NF T 90-012
Orthophosphates (PO_4^{3-})	mg/l	Ammonium molybdate method	NF T 90-023
Biochemical Oxygen Demand (BOD_5)	mg O2/l	Oxitop manometric method	-
Chemical OxygenDemand (COD)	mg O2/l	Oxidation with potassium dichromate at 180°C	NF T 90-101
Chloride (Cl^-)	mg /l	Mohr's volumetric method	NF T 90-014

2.3 Water Quality Index (WQI)

19 parameters (pH, T°, CE, TSS, DO, NH_4^+, NO_3^-, NTK, TP, SO_4^{--}, PO_4^{--}, BOD_5, COD, Cl^-, Cr, Pb, Zn , Cu and Fe) were chosen to calculate the WQI. This index is a water quality classification technique based on the comparison of water quality parameters with international or Moroccan national standards [18]. The WQI summarizes large quantities of data in simple terms (Excellent, Good, Poor, etc.). In this study, the WQI index is applied to estimate the influence of drought and liquid discharges on the basis of several parameters. It is calculated using the weighted arithmetic index method [9, 20, 21], Five quality classes can be identified according to the values of the water quality index (Tab.2).

Table 2. Classification and possible use of water according to the WQI [19, 21, 23].

WQI class	Water type	possible use of water
0 - 25	Excellent quality	Drinking water, irrigation and industry
>25- 50	Good quality	Drinking water, irrigation and industry
>50- 75	Poor quality	Irrigation and industry
>75 - 100	Very poor quality	Irrigation
>100	Unsuitable for consumption	Appropriate treatment required before use

2.4 Statistical analysis

For a better interpretation of the data and in order to identify the effect of drought on the measured parameters, the WQI values were calculated for the various stations over the 3 hydrological cycles. The results were statistically analyzed using XLSTAT 2018. The methods used for the descriptive analysis are non-parametric tests following the Kruskal-Walis test procedure simultaneously with Dunn's test applying the Binferroni correction.

3. Results and discussion

Monitoring the water quality of the Inaouene River over tree hydrological cycles has enabled us to identify the contribution of drought combined with human activities to the degradation of water resource quality in this river's watershed.

Water temperatures in the Inaouene River range between (17.8±5.2 (O_6) and 20.5±4.9°C (O_1). An increase in the average temperatures was noted during the third hydrological cycle for all studied stations, which could be related to the atmospheric temperature's increase during the drought period. The Inaouene River water is neutral to slightly alkaline. Water pH varies between 7.54±0.08 (O_4) and 7.79±0.1 in (O_H) during the studied period. The EC (1163±285-3757.6 µS/cm), sulphate (102.56±16.4 and 297.9±37.1mg/l), and chloride (157,74±111-826,33±427) parameters show relatively high mineralization downstream of wastewater discharge points and during the 3rd hydrological cycle. This mineralization decreases during the wet period (second hydrological cycle). Water oxygenation decreases downstream of liquid discharge points and during the dry period (third hydrological cycle). The degree of oxygenation closely follows changes in the organic (BOD5= 15,8±5,1 - 467,15±57,7 mg/l) and oxidable (COD=37,37±6,1-784,99±59 mg/l) load of the water. This load increases downstream of urban and sub-urban centres, as well as during third hydrological cycle. The particulate load of water (TSS= 30±00-146,20±77,2 mg/l) shows a temporal gradient, increasing during the wet year (2nd hydrological cycle) and decreasing in the dry year (3rd hydrological cycle). spatially, this load shows a decreasing trend away from liquid discharge points.Similarly, The Inaouene River' water revealed an enrichissement in nutrients (NH_4^+= 0,26±0,03-3,45±0,7 mg/l), NTK (2,96±0,5-29,35±3,1 mg/l); NO_3^- (16,8±3,4-91,8±21,34 mg/l); PO_4^{3-}(0,06±0,02-2,38±0,6 mg/l; TP(0,07±0,06-2,71±0,5 mg/l) downstream of urban and sub-urban agglomerations and during periods of drought (third hydrological cycle).

For trace metal elements (TMEs), the waters of Wadi Inaouene show an increase in Zn(0,03±0,002 - 0,22±0,001 mg/l) , Fe (0,66±0-2,5±0,2 mg/l), Pb (26±0,01-38,4±0,001 mg/l), Cu (0,01±0,004-0,53±0,01 mg/l) and Cr (20±0,01-27,5±1,3 mg/l) levels during the dry period at all the stations studied.

Kruskal-Wallis and Dunn's tests show significant interannual variation ($p<0.05$) for T (Pvalue=0.0021), EC (Pvalue =0.003), BOD_5 (Pvalue =0.009), COD (Pvalue =0.0019), NH_4^+ (Pvalue =0.0019), NO_3^- (Pvalue =0.0039), DO (Pvalue =0.0028), PO_4^{3-} (P-Value =0.0013), PT (P-Value =0.0033), SO42- (P-Value =0.008), NTK (P-Value =0.0027), Cl- (P-Value =0.0006), Cr (P-Value =0, 022), Pb (Pvalue =0.0077), Zn (Pvalue =0.0066), Cu (Pvalue =0.0077), Fe (Pvalue =0.009), and not significant($p>0.05$) for PH (Pvalue =0.41).

On the one hand, these parameters recorded the highest averages during the third hydrological cycle, suggesting the effect of the drought, the drying up of tributaries (Oued Lahdar, Oued Lakhal, etc.) and the reduction in flow, which favors the phenomenon of evaporation, with peaks at the stations downstream of wastewater discharge points from the Taza (O_1, O_2) and Oued Amlil (O_5) cities. On the other hand, the second hydrological cycle shows lower averages of several pollution parameters at all stations (i.e., EC, DO, MES, $NH4^+$, NTK, NO_3^- ,SO_4^{2-}, PO_4^{2-} ,PT, COD, BOD_5, Cl^-), heralding an improvement of water quality. This decrease can be explained by the rainfall rise during this period (Pa>532mm in 2020) [15], which favored the phenomenon of pollution dilution. In general, low DO values and high COD, BOD_5, NH_4^+, NO_3^{2-} and PO_4^{2-} concentrations indicate contamination by anthropogenic discharges. Values trend to increase at stations receiving discharges from urban centers (O1, O_2, and O_5). According to the results, the basin shows a clear inter-annual variation (P value<0.05) due to the rainfall and river flow variations from one year to other. In dry years, the flow decreases, while effluent flows remain high and, consequently, pollution levels increase.

Spatial variation in water quality along the Inaouene River is evident. The Inaouene River upstream (O_1 and O_2) is characterized by very poor water quality. During the first hydrological cycle, the WQI index varies respectively from 84.19 to 72.85. This quality improves and becomes poor during the second hydrological cycle (WQI=59.89 - 54.29) (Tab. 4), and deteriorates again during the third hydrological cycle (WQI>100), making the water unsuitable for consumption at the stations receiving urban wastewater from Taza (O1, O2) and Oued Amlil (O5) cities. The Lahdar stream's station (OH) is characterized by poor water quality during the first hydrological cycle (WQI=55.34), while its water quality is rated as good during the second hydrological cycle. Downstream of the Inaouene (O_6), the WQI records 59.58, 43.71 and 76.08 respectively during the first, second and third hydrological cycles(Tbale.3).

The distance of the station O_H from liquid discharge points explains its low level of pollution, except for the presence of salt and fluvial sand quarries, which contribute to the increase of turbidity and electrical conductivity. The Inaouene river upstream, which includes the stations O_1 and O_2, as well as the station O_5 downstream of the Oued Amlil city, showed poor to unsuitable water quality throughout the study period. The WQI at these stations reach extremely high values. The physicochemical parameters responsible for this deterioration are mainly BOD_5, COD, DO, ammonium and phosphate, and to a lesser extent, nitrate, Cr and Pb. The inter-annual evolution shows a tendency to deterioration during the dry period. This variation is marked in the stations that receive untreated wastewater. The WQI showed a significant spatial variation ($p<0.05$) and varied from 104 to 76.32 in the third hydrological cycle for the station O2 (upstream) and O6 (downstream).

The decreasing upstream-downstream gradient of the pollutant load along the Inaouene River corroborates the results of Bordalo et al. [23], who detected an upstream-downstream improvement in water quality on a Douro transboundary river between Spain and Portugal. On the contrary, Dunca's work [24] on another transboundary river between Romania and

Serbia, and Talhaoui's at the Moulouya River [11], showed that river pollution generally increases from upstream to downstream. In general, the WQI values recorded at our stations are higher than those recorded at the Moulouya River [11], Ourika and Rherhya and lower than those recorded at the Tensift and Issil Rivers [12].

Table 3. WQI index values and water quality class of stations for the tree hydrological cycles (from 2019 to 2022).

	2019-2020		2020-2021		2021-2022	
	WQI	Type of water	WQI	Type of water	WQI	Type of water
OH	55.34	Poor quality	35.11	Good quality		
O1	84.19	Very poor quality	59.89	Poor quality	108.16	Unsuitable for consumption
O2	72.85	Poor quality	54.29	Poor quality	104.91	Unsuitable for consumption
O3	71.76	Poor quality	52.76	Poor quality	94.47	Very poor quality
O4	64.21	Poor quality	44,28	Good quality	87.68	Very poor quality
O5	70.65	Poor quality	50,57	Poor quality	105.97	Unsuitable for consumption
O6	59.58	Poor quality	43,71	Good quality	76.08	Very poor quality

4. Conclusion

This study focused on measuring the overall surface water quality of the Inaouene River and its two tributaries, Larbaa and Lahdars streams. The application of the water quality index (WQI) was very useful for making the right decision and for comparative assessment of water quality over time and space. This index showed significant temporal evolution of the water quality, during the studied period. The water quality deterioration becomes high during the drought period, due to the flow reduction and the drying up of the tributaries the Inaouene River. However, the domestic and industrial effluents flow from the various urban centres (Taza, Oued Amlil, etc.) remain high. It is clear that the dry period has accentuated the processes of the water quality degradation of the surface water in the Inaouene watershed. In addition, the development of agriculture and the high contribution of runoff and soil leaching reinforced this water quality deterioration. Therefore, priority must be given to reducing these sources of pollution in order to protect water resources and improve water quality in the watershed. To achieve this, decision-makers will have to install wastewater treatment plants, controlled landfills and carry out awareness campaigns with farmers for the rational use of fertilizers and pumping, in order to protect the ecosystem and its watershed threatened by the drought effect.

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