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# Surface Water Quality – A Physicochemical and Bacteriological Assessment with the SEQ-Water System

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**ABSTRACT**

The city of Taza, situated in Morocco, boasts a significant ecological heritage. However, a concerning practice of discharging untreated wastewater into the nearby Oueds has raised apprehensions about potential threats to public well-being. This research endeavors to discern the locations most adversely affected by pollution and subsequently assess their environmental condition. By conducting an extensive year-long analysis encompassing physicochemical and bacteriological aspects, we gathered a comprehensive dataset for appraising the surface water quality, utilizing the SEQ-WATER system as the evaluation framework. Four distinct sites emerged as particularly impacted: upstream of Oueds Jaouna and Taza, downstream of Oued Larbâa and adjacent to the "Julien" public dump, and at the confluence of Oueds Rhouireg and Dfali. Employing the GIS-SEQ integration, we meticulously gauged the physicochemical and bacteriological attributes of these sites. Our assessment unveiled readings that surpassed the established Moroccan benchmarks for surface water quality. Notably, the water exhibited pronounced turbidity and elevated levels of suspended particles, including nitrites and sulfates. Additionally, a notable organic load and microbial contamination involving fecal coliforms (E. coli) and intestinal enterococci were observed. These findings underscore the critical necessity for the implementation of efficient wastewater treatment measures within Taza, which would substantially safeguard both the populace and the surrounding ecosystem. It is imperative to conduct further in-depth investigations to validate these outcomes and devise comprehensive strategies aimed at mitigating the potential hazards linked with the compromised state of surface water.

**Keywords:** GIS-SEQ; SEQ-Water system; surface water.

## INTRODUCTION

One of the most challenging and persistent issues confronted by most growing countries and their cities is the health impact of urban pollution due to poor fecal and industrial waste management (Ferronato and Torretta 2019). Globally and according to the World Health Organization (WHO), 2.1 billion people, or 30% of the world's population, still do not have access to safe drinking water and 60% do not have safely managed sanitation (WHO 2017). Because of this problem, 1.7 billion episodes of diarrhea occurred in 2010 in children under five years of age in low- and middle-income countries, leading to an estimated 750,000 deaths (Walker et al. 2013). In fact, contrary to popular wisdom, this disease alone kills more children than all three diseases, AIDS, tuberculosis, and malaria, combined (Bartram and Cairncross 2010).

In Morocco, despite the efforts made by the state to eradicate this kind of disease, by ensuring the salubrity of water, setting up sewerage networks for the agglomerations, and reinforcing the legal and regulatory arsenal by the adoption of several laws, in particular, law 23-12 modifying law 28-00 related to the management of waste and law 35-15 modifying law 10-95 related to water, its uses, its protection, its preservation, its treatment, and its recycling. Studies have shown that the consumption of crops irrigated with wastewater may be a contributing factor to the persistence of typhoid fever and viral hepatitis epidemic (Dssouli et al. 2001).

Moreover, the province of Taza is among those at high risk for waterborne diseases (Abbou et al. 2014). The city wastewater is discharged directly into the neighboring wadis without any prior treatment because the city still does not have a wastewater treatment plant. According to the statistics of the public health services, four waterborne diseases are the most common in the city. These are acute gastroenteritis, hepatitis A, collective food poisoning, and typhoid. While cholera has disappeared since 1997 according to the Ministry of Health (Ministère de La Santé, 2014).

The problem, therefore, requires the establishment of a monitoring system of water quality, especially when it is water intended for the irrigation of products consumed directly by citizens. There are several water quality monitoring systems, among them the water quality index (WQI), based on the aggregation functions for analyzing large sets of data on water quality that vary in both space and time to provide a single value, the water quality indicator, which describes the quality of the water body (Uddin et al. 2021). There are also multivariate statistical techniques such as cluster analysis (CA), multidimensional scaling (MDS), and principal component analysis (PCA) that are used to analyze and compare data from physicochemical and bacteriological analyses to better identify possible sources of pollution (Abhijna 2016). A new water quality assessment method based on the harmony degree equation (WQA-HDE) was proposed by (Zuo et al. 2018). It is a composite method that combines the single-factor assessment and the global assessment that can provide a unification of the water quality assessment system and can be used as a reference in other global assessments.

The main objective of this study is to carry out a spatiotemporal monitoring of the physicochemical and bacteriological quality of the wadis crossing the city of Taza after having identified the most polluted sites over a one-year period (from February 2021 to January 2022). Then we evaluated the quality of these waters according to the SEQ-Water system.

## MATERIALS AND METHODS

### Study area

The city of Taza belongs to the northeastern region of Morocco, its climate is classified as a warm summer Mediterranean climate according to the Koppen-Geiger climate classification. The average annual rainfall is 563 mm, and the average annual temperature is 17.9 °C/64.3 °F (Mahmoud et al. 2021).

The topography of the study area is characterized by very steep slopes from the south northward, with a difference in elevation of 230 m between the southern limit of the development perimeter (630 m NGM) and the train station to the southwest (400 m NGM). The terrain has slopes generally higher than 5% and can reach 15 and 20% in places. The water network consists of the Larbâa wadi to the north, El Haddar (or Taza) wadi to the south, and the Dfali, Rhouireg, and Jaouna wadis to the east. The effluents from the South (Oued Taza) and the East (Oued Dfali, Rhouireg, and Jaouna) flow towards Oued Larbâa to the north (Fig. 1).

The city has a combined sewerage system. It covers nearly the entire town and totals a linear of 140 km with 27 km of the primary network, seventeen km of the secondary network, and 96 km of the tertiary network. The rate of connection to the sewerage network is now estimated at 77% (L'agence urbaine de Taza 2014). The system consists of 5 principal collectors (Larbâa, Taza, Rhouireg, Dfali, and Jaouna) who discharge their collections at different points of the wadis crossing the city without prior treatment (Abbou et al. 2014a) (Fig. 1) thus contributing to the environmental degradation of these environments and constitute, therefore, a non-compliance with the laws on Water and the Environment.

### Sampling sites

The selection of the chosen sites for this study is firmly grounded in a comprehensive foundation of previous research, particularly the extensive work conducted by Abbou et al. (2014b). Moreover, a series of thorough field trips were undertaken to conduct a meticulous diagnosis of the study area.

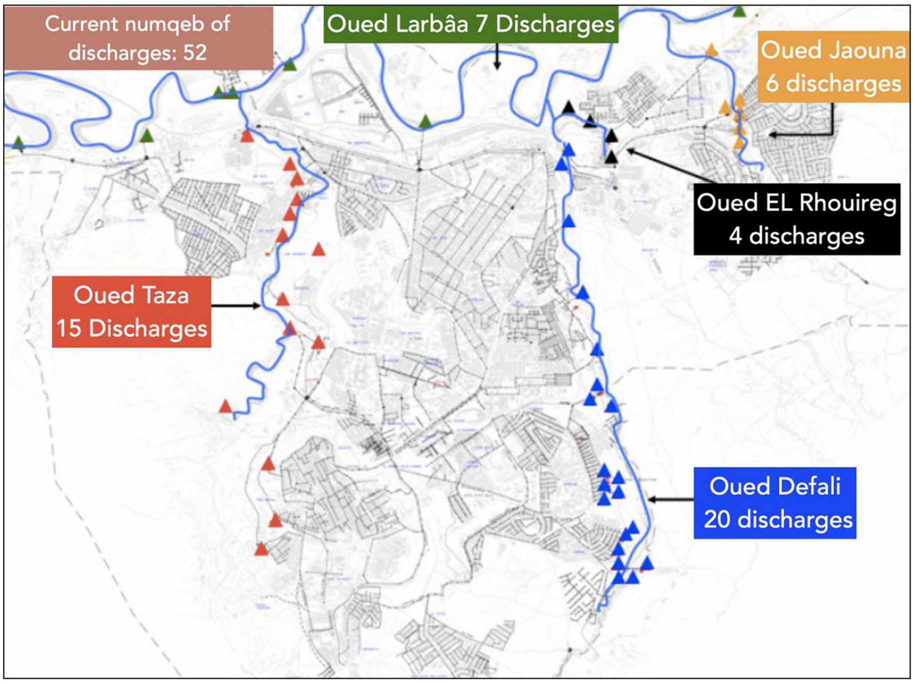


**Fig. 1.** Hydrographic network and wastewater discharge points of the city of Taza (Radeeta, 2018)

A critical aspect driving our site selection is the diverse nature of wastewater, encompassing industrial and municipal sources, coupled with a myriad of anthropogenic activities in close proximity to contaminated waterways. Particularly noteworthy are the multifaceted agricultural practices that contribute significantly to water pollution in the region.

Drawing from this rich background, a systematic approach was adopted to pinpoint the optimal sampling sites. Inspired by the term "Oued" (which translates to "river" in English), we have labeled these sites with the letter "O" to indicate their association with these water bodies (as illustrated in Fig. 2). Specifically, our focus was on the four principal oueds that traverse the city of Taza.

By aligning our sampling sites with the upstream locations of these key oueds, we aim to capture a holistic view of the water quality dynamics and contamination patterns in the area. This strategic choice allows us to assess the initial sources of pollutants and understand how these contaminants propagate downstream, subsequently impacting the surrounding environment.

In summary, the meticulous selection of these four sampling sites, denoted by the letter "O," is underpinned by a robust foundation of existing research, in conjunction with on-site assessments. This approach ensures that the chosen sites provide a comprehensive representation of the intricate interplay between various wastewater sources, anthropogenic activities, and the region's waterways.

- O1: 34,23822° N, 3,98688° W: Located upstream of Oued Jaouna
- O2: 34,23048° N, 3,99922° W: Located at the meeting point of Rhouireg and Dfali oueds
- O3: 34,23476° N, 4,02421° W: Located upstream of Oued Taza
- O4: 34,23371° N, 4,06150° W: Located upstream of the Oued Larbâa downstream of the public dump "Julien"

## Experimental protocol

### *Physicochemical parameters*

We collected manual samples using the instantaneous method at a frequency of once every two months, starting in February 2021 and ending in January 2022. Samples were stored in high-density polyethylene (HDPE) bottles previously cleaned and rinsed with distilled water. At the time of in situ samplings, the vials were rinsed three times with river water before sample collection (Idrissi 2018). Samples were carefully labeled and transported from the sampling site to the laboratory by storing them at four degrees Celsius in a cooler according to AFNOR-approved standards (EN ISO 5667-14:2016) and edited by Rodier (Rodier et al. 2016).

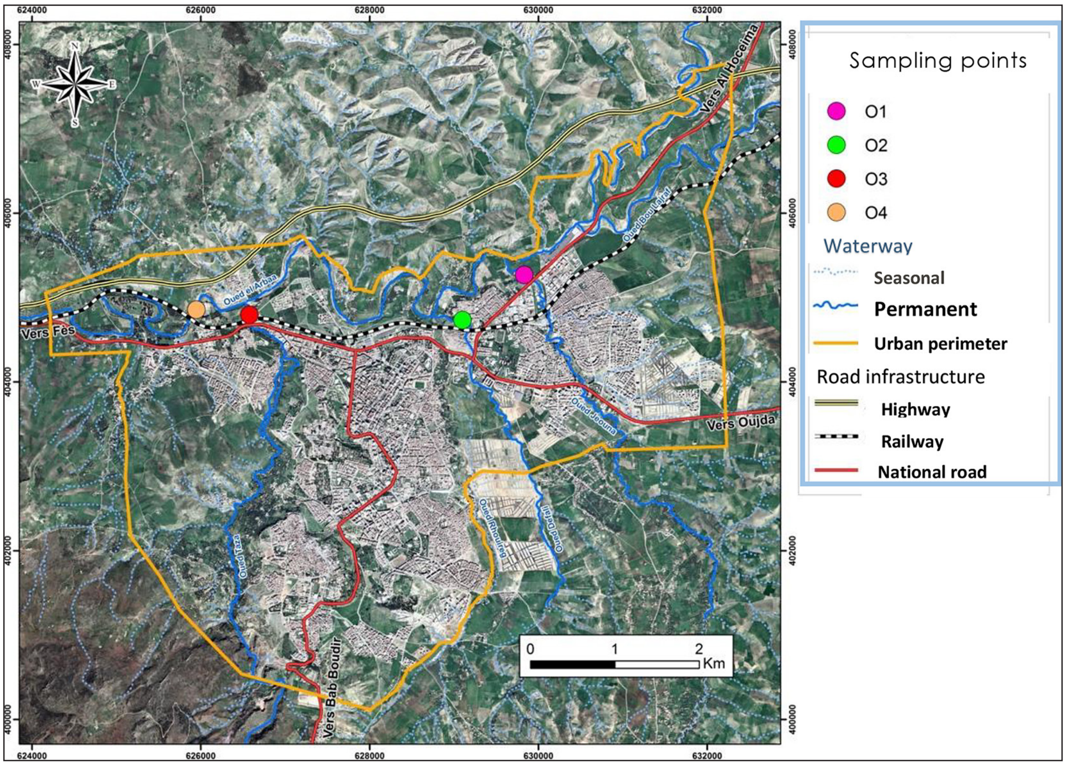


**Fig. 2.** Overview of the study area, location of sampling sites in the rivers crossing the city of Taza

The tests were conducted following the protocols outlined by Rodier (Rodier et al. 2016). In situ measurements of the physicochemical parameters (temperature, pH, dissolved oxygen, and electrical conductivity) were taken using a CONSORT C535 Portable multi-probe, which was calibrated before each campaign. Turbidity was measured using a HACH 2100P turbidimeter, and dissolved oxygen was measured using a HANNA HI98196 oximeter.

The physicochemical analyses on the following parameters; Biological Oxygen Demand $BOD_5$, Chemical Oxygen Demand COD, Kjeldahl Nitrogen NTK, orthophosphates $PO_4^{3-}$, ammonium $NH_4^+$, nitrates $NO_3^-$, nitrite $NO_2^-$, and sulfates $SO_4^{2-}$, NTK, $BOD_5$, Pt, are performed according to the standards set by AFNOR (2016) carried by Rodier. Mineral elements such as iron Fe, cadmium Cd, chromium Cr, aluminum Al, arsenic As, and lead Pb were analyzed by inductively coupled plasma spectrometry (ICP)

### *Bacteriological parameters*

The fecal contamination indicator bacteria FC, Escherichia coli (EC), and Intestinal Enterococcus (IE) were counted using the Most Probable Number (MPN) multiple tube fermentation method, which is a quantitative method used to estimate the concentration of bacteria in a water sample. It involves inoculating a series of tubes with different volumes of the water sample and incubating the tubes under conditions that allow the bacteria to grow. The presence or absence of bacterial growth in each tube is then determined, and the results are used to estimate the concentration of bacteria in the original water sample (Bari and Yeasmin 2022).

The Mac Crady statistical tables are a set of tables that are used in conjunction with the MPN method to interpret the results of the bacterial growth tests. The tables contain probabilities that correspond to different combinations of positive and negative results in the test tubes, and these probabilities are used to calculate the most probable number of bacteria present in the water sample (Tillett 1987).

Together, the MPN method and the Mac Crady statistical tables provide a reliable and accurate way to estimate the concentration of bacteria in a water sample and to determine the level of fecal contamination in the sample. Water samples for bacteriological analysis were collected using a protocol that involved using borosilicate glass bottles that were pre-cleaned with distilled water, cleaned, rinsed, and sterilized in an autoclave at 120°C and pressurized at 120 $kg/cm^2$ for 30 minutes. These water samples were analyzed according to the Moroccan standard NM 03-7-003, with modifications.

After storing the water samples in an appropriate 500 mL bottle, they are labeled and stored in a cooler at a temperature maintained between 0 and 4°C. They are then transferred to the laboratory with a sample sheet indicating all the required data, mainly the sampling site, the date, as well as the sanitary conditions at the sampling sites.

## RESULTS AND DISCUSSION

### Physicochemical parameters

Physicochemical and bacteriological results are shown in Figure 3, with the standards indicated in red for each sampling site. We will discuss all the results according to the surface water quality Moroccan standards (NMQES) NM 03-7-003 modified. In the discussion, we considered the water quality assessment according to the SEQ-Water system (Table 2).

### Parameters measured in situ

Temperature, a major parameter in any ecological study, significantly affects the stability of other physicochemical and biological parameters in natural environments (Patil et al. 2012). It can infect dissolved oxygen consumption and $H_2S$ release in aquatic environments and consequently affect the distribution of aquatic species and their diversity (Bi et al. 2022). In the study area, we noticed that the water temperature follows the annual climatic variation indicating the absence of any thermal pollution with low variation among sites (Fig. 3a). We recorded a minimum value (13 °C) during winter in the Larbâa wadi (O4). The temperature varied between 17 and 21 during the fall and spring seasons in the four sites. While the value and maximum are between 24 and 26 °C during the summer, especially at Oued Jaouna (O1). This temperature is favorable for the proliferation of bacteria, parasites, mosquito larvae, and other microbial germs. The confirmed values (< 30°C) classify these waters in the good quality range.

The pH of water affects most chemical and biological mechanisms in water. It can also be influenced by acid precipitation, biological activity, and some industrial discharges (Nisrine Idrissi 2018) (Fig. 3b). The pH values ranged from neutral to a little alkaline. In addition, we did not notice any significant variation in the pH values of the water at the study sites. With a minimum of 7.01 at point O4 in Autumn because of its high organic matter content and a maximum of 7.95 at point O2 in Summer. The pH values obtained are acceptable and meet Moroccan guidelines on the classification of surface waters.

Electrical conductivity is a strong indicator of the ionic charge of the water, the higher it is, the more minerals the water contains (Chu et al. 2018). In the sites selected for the study (Fig. 3c), the conductivity was very high at points O1, O2, and O4 with a maximum value reaching 5710 $s.cm^{-1}$ at point O1 during month 02/2021. While the low value is recorded at point O3 (5710 $s.cm^{-1}$) during the month of 04/2021. According to the Moroccan classification of surface waters, the values obtained (< 2700 $s.cm^{-1}$) position these waters in the range of good quality.

Turbidity is the measure of water clarity. All turbidity values obtained (Fig. 3d) exceeded the NMQES set at 5 NTU with a maximum on the order of 397 NTU recorded at point O1 during month 10/2021 and a minimum on the order of 15 NTU at both points O3 and O4 during month 04/2021, which classifies these waters in the very low-quality range.

Dissolved oxygen is one of the most sensitive parameters to pollution since dissolved oxygen levels that are too high or too low can harm aquatic life and affect water quality. The dissolved oxygen values obtained (Fig. 3e) decreased below the one mg/L minimum limit accepted by the NMQES during the summer periods at points O1, O2, and O4, which places these waters in the poor-quality range in terms of dissolved $O_2$. This drop in dissolved O2 concentration can be explained by the proliferation of microorganisms following the high biodegradable organic load, especially at point O4 characterized by a high $BOD_5$ (Fig. 8) located downstream of the uncontrolled public landfill (the Julien landfill) (Abbou et al. 2014a). The increase in dissolved oxygen concentration during the winter and spring periods is due to the decrease in temperature because the lower the temperature more biological activity decreases are O2 consumption also decreases (Edberg et al. 2000).

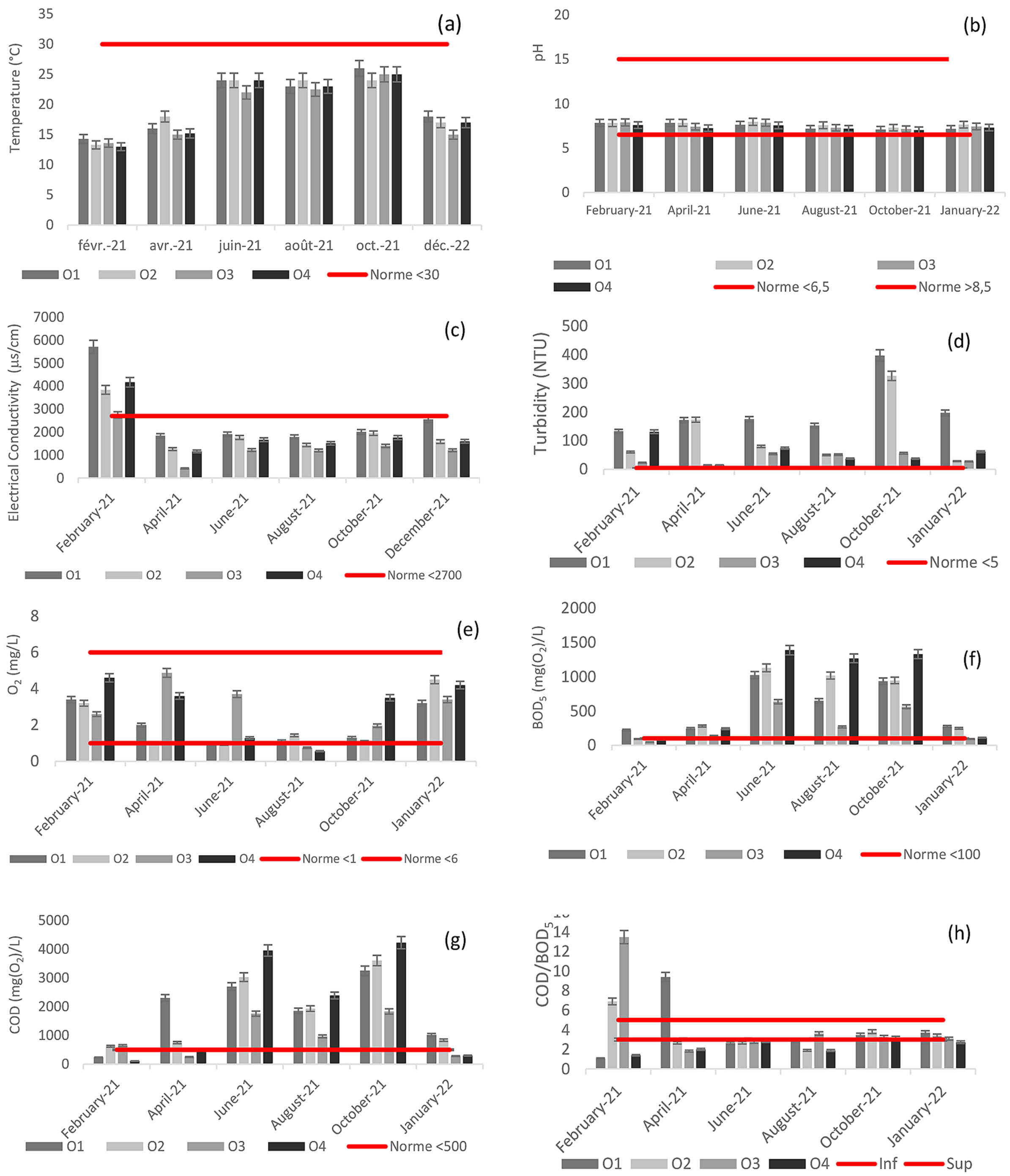


**Fig. 3.** Variation of the physicochemical parameters in the Oueds crossing the city of Taza during the monitoring period; parameters measured in situ: (a) temperature (°C); (b) pH; (c) electrical conductivity EC (µS/cm), (d) turbidity (NTU); (e) dissolved $O_2$ (mg/L); Parameters measured in laboratory: (f) biological oxygen demand $BOD_5$ (mg($O_2$)/L), (g) COD chemical oxygen demand (mg($O_2$)/L), (h) COD/$BOD_5$

## Parameters measured in laboratory

The $BOD_5$ is the amount of dissolved oxygen that is needed to oxidize the easily degradable organic matter by aerobic micro-organisms within a 5 day period (Mekawi et al. 2023). The high values of the $DBO_5$ are far exceeding the NMQES with a sharp increase at points O1, O2 and O4 were recorded during months 06, 08, and 10/2021 (Fig. 3f), which positions these waters in the very poor-quality range in terms of $BOD_5$. These results can be explained by the concentration of organic matter, from urban and industrial liquid discharges, due to the decrease in rainfall during the summer period.

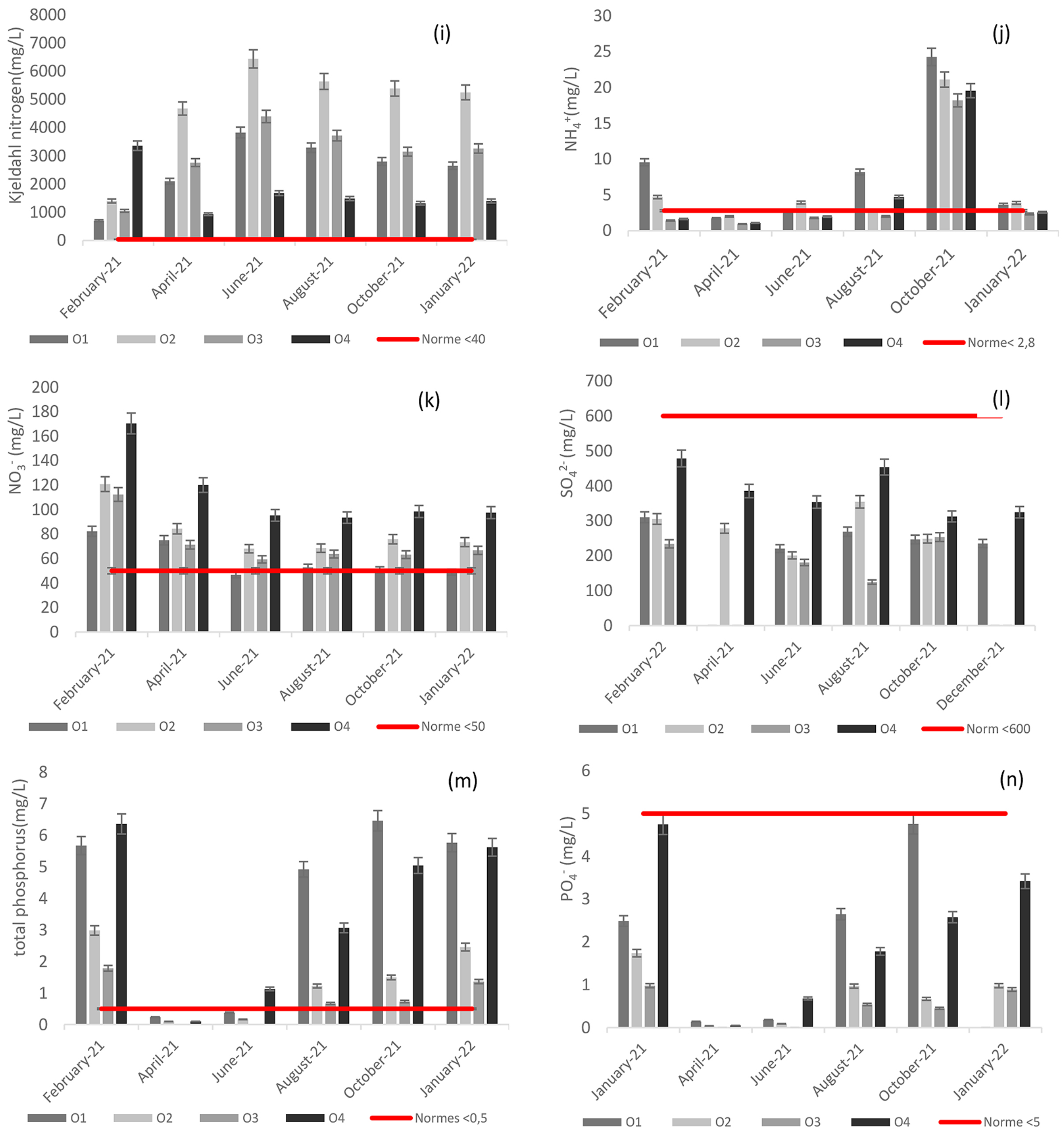


**Fig. 3.** Variation of the physicochemical parameters in the Oueds crossing the city of Taza during the monitoring period; parameters measured in situ: (i) Kjeldahl nitrogen NTK (mg/L), (j) ammonium $NH_4^+$(mg/L); (k) nitrates $NO_3^-$ (mg/L); (l) sulphates $SO_4^{2-}$ (mg/L); (m) total phosphorus TP (mg/L); (n) orthophosphates $PO_4^-$ (mg/L)

As for COD is the required oxygen amount, equivalent to the amount of dichromate, that is consumed in complete chemical decomposition of organic pollutants in water (Mekawi et al. 2023). The values exceeded the NMQES during months 06, 08/2021, and 10/2022 at all four sampling points as well as during month 04/2021 at point O1 (Fig. 3g). A decline in COD was noticed at the other points during the winter and fall period. According to the SEQ-EAU water quality assessment system, the surface waters of the four oueds are qualified as very poor quality in terms of COD.

However, even if the values of $BOD_5$ and COD exceed the limit standards for discharges to surface waters, the COD/$BOD_5$ ratio (Fig. 3h) shows that the organic matter in these wadis is biodegradable (the ratio is less than 3) or moderately biodegradable (the ratio is included between 3 and 5) (Grossule et al. 2022). It became non-biodegradable during the winter period at points O1 and O3. This coincided with the period of crushing of olives which releases wastewater rich in polyphenols that are difficult to biodegrade (Mahmoud et al. 2021).

For the different forms of nitrogen, the analyses show an increase far exceeding the Moroccan standards of surface water quality (NMQES). We also notice a high concentration of Kjeldahl nitrogen characterizing these waters as very poor-quality for points O1 and O2 and poor for points O3 and O4 (Fig. 3i). As for Ammonium, it was moderately high during the study period that increased significantly during the month of 10/2021 at all 4 points (Fig. 3j). The concentrations of nitrates also exceed the NMQES, especially for point O4 (Fig. 3k). The waters of the Oueds studied are of poor quality in terms of ammonium and nitrate content. However, Nitrogen (N) is an essential element for plant growth and is often one of the limiting factors in agriculture. It is found in various forms in wastewater, including ammonium, nitrate, and organic nitrogen. These forms of nitrogen can be recovered and used as fertilizers for agricultural crops, improving crop yields and soil fertility(Fang et al. 2023).

The sulfate concentration (Fig. 3l) in the 4 points studied does not exceed 600 mg/L which is the limit value for sulfate according to the NMQES. With a maximum (478.48 mg/L) at point O4 during month 02/2022 and a minimum (124.6 mg/L) recorded at point O3 during month 08/2021.

Concerning phosphate elements, we noted an increase in the concentration of total phosphorus which exceeded by far the norms fixed at 0,5 mg/L and this at all 4 points but notably at points O1 and O4 (Fig. 3m). However, we recorded that the orthophosphate concentration is moderately low (Fig. 3n), which means that most of the phosphorus is organic in nature.

## Bacteriological results

The results obtained from our data collection reveal that the designated sampling sites, namely O1, O2, O3, and O4, exhibited notable elevations in the concentration levels of fecal coliforms, Escherichia coli (as depicted in Fig. 4a), and intestinal enterococci (as illustrated in Fig. 4b). The proliferation of these microorganisms within the oueds is attributed to the unregulated discharge of untreated wastewater into these water bodies, lacking proper treatment measures. This assertion finds validation through the CF/SF ratio, surpassing 1, thereby corroborating the human origin of the fecal matter (Abba et al. 2021).

In accordance with the classification established by Moroccan standards, the values recorded place the water quality of these sites within the category of the global bacteriological quality average for points O1, O2, and O4. At point O3, the water quality is deemed "good," exhibiting a minimum presence of fecal coliforms (Escherichia coli) and intestinal enterococci. Furthermore, it is noteworthy that the concentration of fecal coliforms exceeds the Moroccan threshold for water intended for irrigation, which is set at 1000 CF/100 mL, observed at points O1 and O2 during both the summer and winter seasons, and consistently at point O4 across all periods. These findings align with the outcomes of previous research conducted by (Bougarne et al. 2019).

Overall assessment of the quality of the studied waters By GIS-SEQ coupling

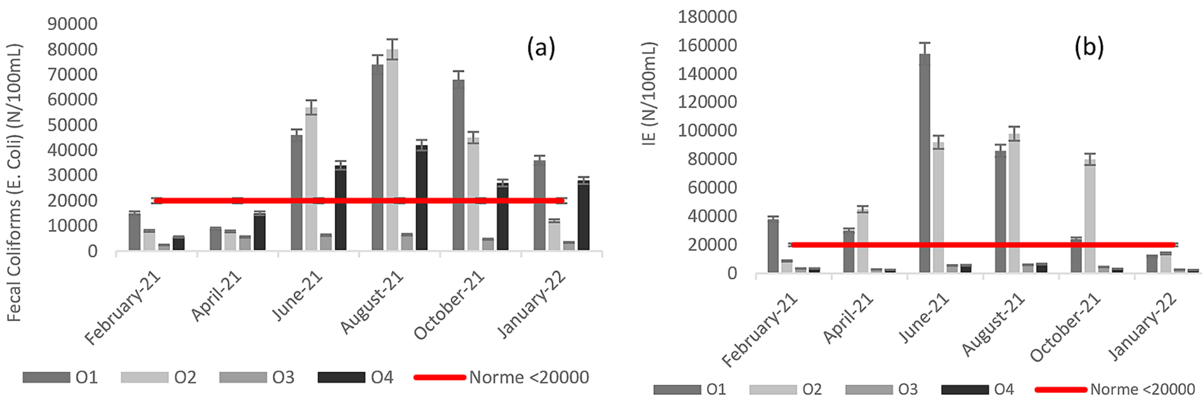


**Fig. 4.** Variation of the bacteriological concentration in the Oueds crossing the city of Taza (a) Fecal Coliforms (E. Coli); (b) Intestinal Enterococcus IE (N/100 mL)

## Taint index and weighting

The SEQ-Water specifies whether the water quality is excellent, good, bad, or very bad (Table 1) (Ismaïl et al. 2015).

The colors used to obtain the surface water quality are given in the table 1 with 5 quality classes fluctuating between 0 and 100, thus specifying by color whether the water is of excellent, good, fair, poor, or very poor quality.

This allowed us to have the Global Quality Weighted Index (GQWI) developed by the Directorate of Water Resources and Planning (DWRP) in Morocco (Ministère de l'Equipement et de l'Eau 2008). The GQWI is determined based on the values of the different parameters included in the index and their relative importance for water quality. These parameters are weighted based on their importance, and a final value is calculated based on these weights (Keumean et al. 2022).

The GQWI can be used to assess the quality of water at different points in time and to compare the quality of water in different watersheds. It can also be used to identify water quality problems and put in place measures to improve water quality. Finally, the GQWI can be used to raise public awareness about water quality issues and influence water management decisions (Idrissi et al. 2018; Elmadani et al. 2019)

## Physicochemical, bacteriological, and metallic quality

Table 2 presents the weighting indices and the alterations of the physicochemical, bacteriological, and metallic results. Thus, ten alterations have been defined: The parameters measured and analyzed are T°, pH, Dissolved Oxygen (DO), Electric conductivity (EC), Turbidity, COD, $NH_4^+$, $NO_3^-$, NTK, DBO5, Pt, $SO_4^{2-}$, CF, As, Cr, Fe, Pb, Cd.

The weathering count classifies the temperature as good at points O1 and O2 and excellent at points O3 and O4.

The weighted index for each alteration IPA is calculated by averaging the values of the weighted indices of the different parameters characterizing the said alteration. For alterations that are evaluated by a single parameter, their weathering index remains the same as the weighting index (Ministère de l'Equipement et de l'Eau 2008):

$$IP_{pa} = Ii + [(Ui - Ii)/(Ul - Ll)] * (Ul - Pa) \quad (1)$$

Acidification and mineralization classify these waters as medium quality. The organic and oxidizable matter as well as phosphate matter and nitrates classify the waters of all the points in poor to mediocre quality due to the increase in the content of organic matter responsible for the consumption of oxygen; probably originating from the great population density in these areas and their high daily activities, domestic, agricultural, and industrial. We also recorded that these alterations classify the waters related to points O1 and O2 as very poor physicochemical quality while those taken from points O3 and O4 are of poor quality (Fig. 5). The presence of some trace metal elements (TMEs) such as Chromium and Arsenic even at low concentrations in surface waters could have direct impacts on the environment and human health (Snoj et al. 2019). These two elements are also present at points O1 and O2 located at the level of wadis Jaouna and the mouth of wadis Rhouireg and Dfali (Fig. 6). These wadis cross the industrial zones that discharge their wastewater into these wadis without treatment. Concerning the alteration of fecal coliforms, it confirms the average quality of all points except point O3 which is of good quality (Fig. 7).

## Impact of the quality of surface water in the city of taza on health

According to the regional mission of the Ministry of Health, between 2016 and 2019, Taza Governorate recorded a worrying number of waterborne diseases. There were 729 cases of acute gastroenteritis (AGE), 182 cases of typhoid fever (CFP), and 149 cases of hepatitis A (Fig. 8). However, it is important to note that these reported cases may not reflect the true extent of the

**Table 1.** Water quality classes according to alteration indices

| QUALITY CATEGORY | EXCELLENT | | GOOD | | MEDIUM | | BAD | | VERA BAD | |
|---|---|---|---|---|---|---|---|---|---|---|
| INDEX | 100 | 80 | 80 | 60 | 60 | 40 | 40 | 20 | 20 | 0 |

**Table 2.** Weighting indices and the alterations of the physicochemical, bacteriological, and metallic results

| Alteration | Sites | O1 | O2 | O3 | O4 |
|---|---|---|---|---|---|
| | Index | 100 80 | 80 60 | 60 40 | 40 20 |
| | Ip & Ia | | | | |
| Temperature | $I\ a_1 = Ip_T$ | 64.18 | 64.04 | 97.39 | 98.55 |
| Acidification | $I\ a_2 = Ip_{pH}$ | 51.62 | 53.42 | 52.50 | 51.11 |
| Organic and oxidizable matter | $Ip_{DO}$ | 39.8 | 29.80 | 21.2 | 20.4 |
| | $Ip_{BOD5}$ | 19.16 | 18.17 | 19.8 | 19.36 |
| | $Ip_{COD}$ | 11.13 | 13.01 | 18.69 | 12.74 |
| | $IP_{NH4+}$ | 20.53 | 25.33 | 31.83 | 29.16 |
| | $I_{a3} = (Ip_{OD} + Ip_{BOD5} + Ip_{COD} + Ip_{NH4^+}) /4$ | 22.66 | 21.58 | 22.88 | 20.42 |
| Phosphorus matter | $I_{a4} = Ip_{PT}$ | 19.80 | 32.80 | 37.92 | 23.60 |
| Nitrogenous matter | $I_{a5} = Ip_{NO3^-}$ | 20.24 | 23.33 | 24.82 | 20.01 |
| | $I_{a6} = Ip_{NTK}$ | 14.49 | 14.97 | 29.68 | 28.04 |
| Sulphates | $Ia7 = Ip_{SO4^{2-}}$ | 39.15 | 36.32 | 59.69 | 22.03 |
| Mineralization | $I_{a8} = Ip_{EC}$ | 40.93 | 50.38 | 59.06 | 50.31 |
| Suspended matter | $I_{a9} = Ip_{Turb}$ | 21.20 | 31.56 | 58.40 | 46.11 |
| Microorganisms | $I_{a10} = Ip_{CF}$/100mL | 59.71 | 58.88 | 61.55 | 59.81 |
| Heavy metals | $Ia_{12} = Ip_{Fe}$ | 79.18 | 79.26 | 79.01 | 79.04 |
| | $Ia_{13} = Ip_{Cd}$ | 79.34 | 79.65 | 79.13 | 78.79 |
| | $Ia_{14} = Ip_{Cr}$ | 59.17 | 58.93 | 79.91 | 79.8 |
| | $Ia_{15} = Ip_{As}$ | 58.6 | 59.77 | 76.15 | 77.58 |
| | $Ia_{16} = Ip_{Pb}$ | 78.41 | 78.97 | 79.08 | 79.81 |
| Overall PC quality | | | | | |
| Overall bacteriological quality | | | | | |
| Overall metal quality | | | | | |

**Note:** *Ii* – lower index; *Ui* – upper index; *Ll* – lower limit; *Ul* – upper limit; *Pa* – parameter analyzed.

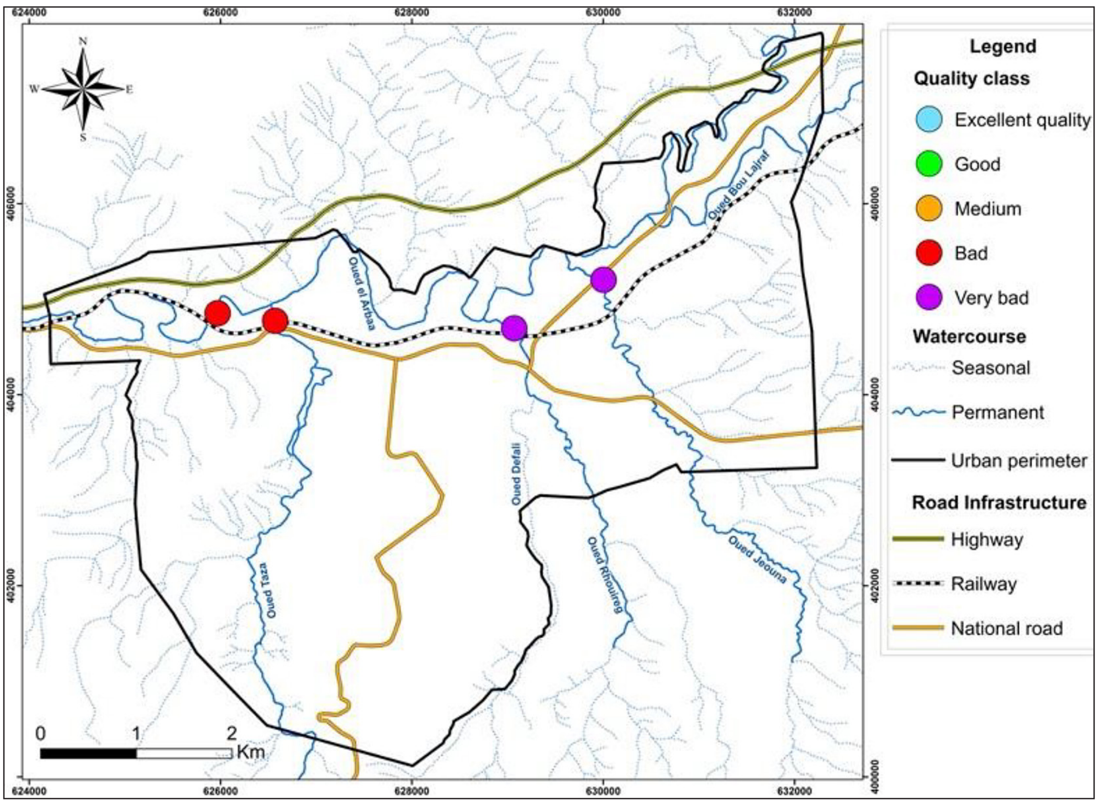


**Fig. 5.** Overall quality classes physico-chemical at the study sites

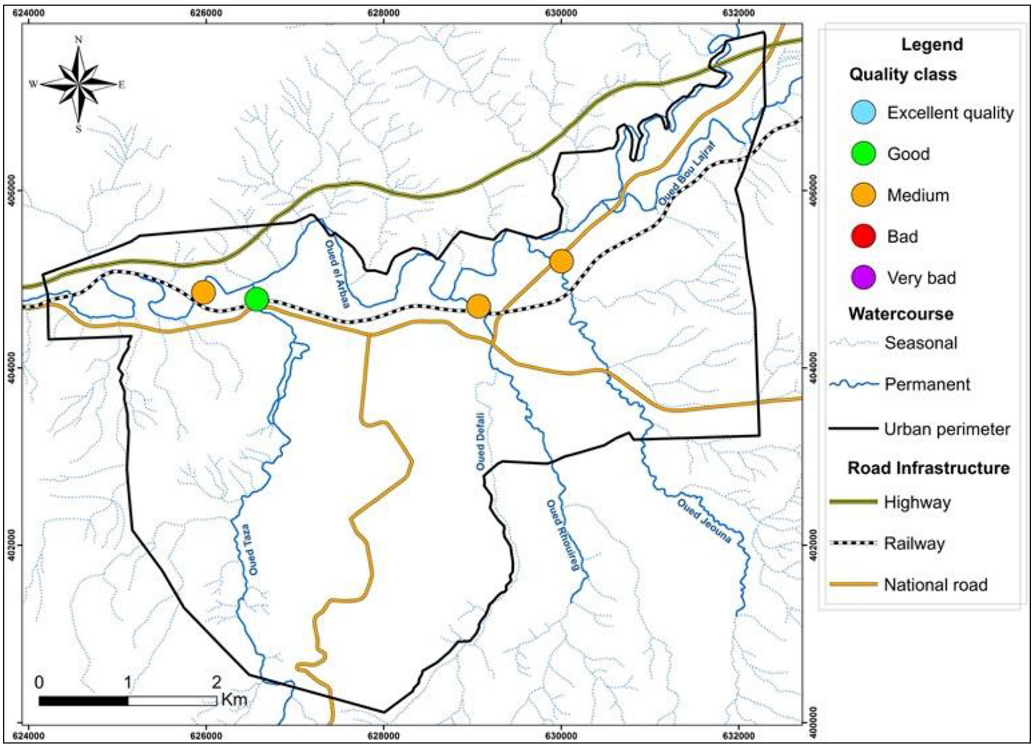


**Fig. 6.** Overall metal quality classes at the study sites

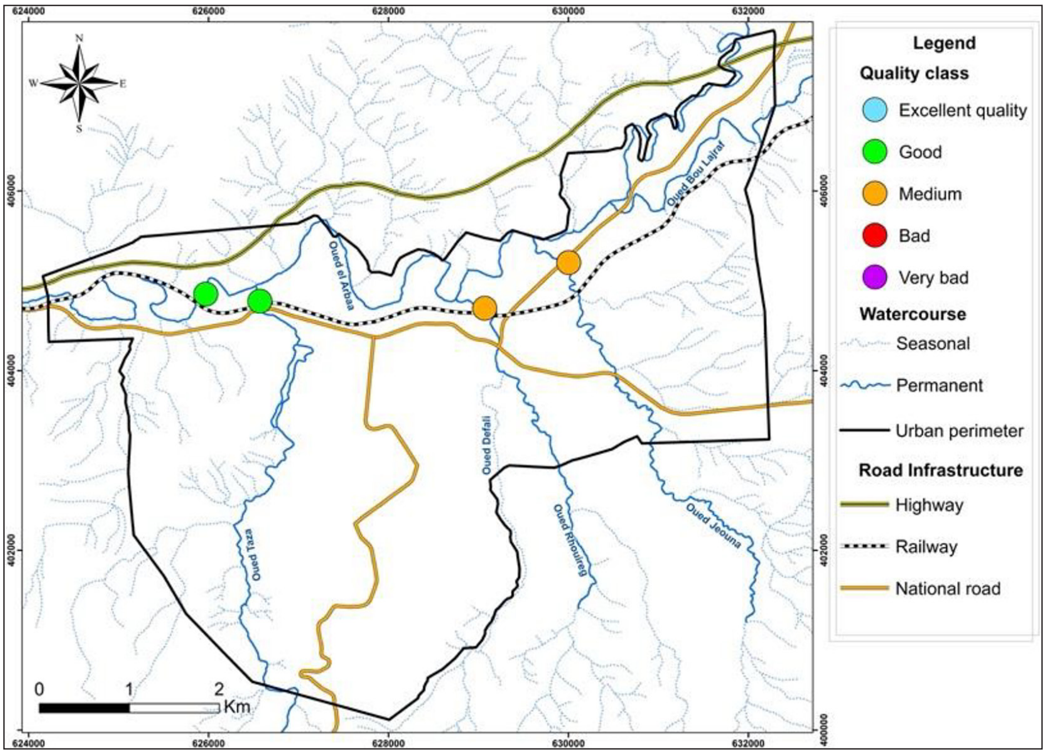


**Fig. 7.** Overall bacteriological quality classes at the study sites

problem as there may be unreported cases. Problems with surface water contamination, possibly caused by inadequate sewage treatment facilities, agricultural activities, and other sources of pollution, may have contributed to the outbreak of these waterborne diseases in Taza. In particular, the use of contaminated surface water to irrigate horticultural produce may be a source of transmission. This highlights the need for effective measures to combat water pollution, improve sanitation

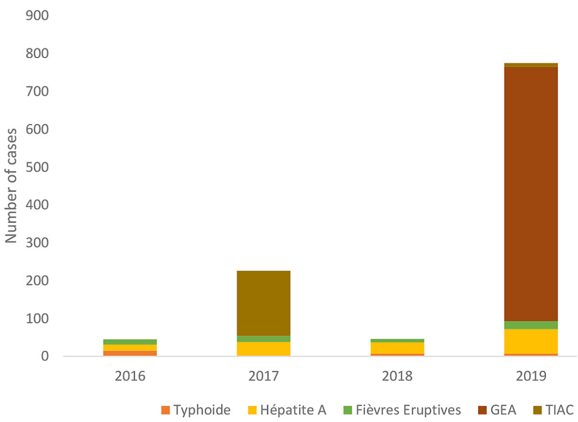


**Fig. 8.** Statistics of waterborne diseases in the province of Taza

infrastructure and promote public health education to prevent and control waterborne diseases in Taza (Abbou et al. 2014a).

## CONCLUSIONS

The results of the space-time monitoring of the physicochemical and bacteriological quality of the water in the Oueds that cross the city of Taza have shown a significant deterioration in water quality. This is largely due to the discharge of untreated wastewater into these waterways, which can have negative impacts on the environment and public health. Water contamination is a serious problem in Taza, as it can lead to outbreaks of waterborne diseases such as typhoid and hepatitis A. This is especially concerning when water from these Oueds is used for irrigation, as it can contaminate crops and potentially be consumed by people. To effectively address the problem of water contamination in the Oueds that cross the city of Taza, it will be necessary to implement a range of strategies: 1) Implementing wastewater treatment: The establishment of a wastewater treatment plant in Taza would be an important step in improving the quality of the water in the Oueds. This would involve the construction of a facility to treat the wastewater that is currently being discharged into the waterways, removing contaminants, and making it safe to be released back into the environment. 2) Managing solid and liquid waste: Proper management of solid and liquid waste is essential to prevent contamination of the Oueds. This could involve the implementation of recycling and composting programs, as well as the establishment of proper waste storage and disposal systems. 3) Implementing water quality monitoring programs: Regular monitoring of the water quality in the Oueds can help to identify potential issues and allow for timely intervention to address any problems that are found. 4) Promoting public education and awareness: It will be important to educate the public about the importance of proper waste management and the potential impacts of water contamination on public health. This could involve the development of educational materials and programs, as well as campaigns to raise awareness about the issue. 5) Working with local organizations and agencies: Collaborating with local organizations and agencies, such as environmental groups and government agencies, can help to bring resources and expertise to bear on the issue of water contamination in Taza. This could involve partnerships to implement waste management and water quality improvement programs or working together to advocate for policy changes or other measures to address the problem.

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