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Study of The Physico-Chemical and Microbiological Quality of Water from River Innaouene, Taza Province, Morocco

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ABSTRACT

In recent decades, the province of Taza has undergone extensive agricultural modernization, marked by an increase in industrial units such as modern oil mills and olive canneries. At the same time, rapid population growth has exacerbated an important problem, the deterioration of the quality of water resources in limited quantities. This study explored the heart of matter by meticulously sampling physico-chemical and bacteriological parameters at eight strategically chosen sites. Conducted in late July 2021, the survey focused on the surface waters of the Innaouene River, providing a timely and insightful examination of the complex dynamics of water quality in the context of modernization and demographic change. This work focused on the determination of physicochemical and microbiological parameters of water. The results of the analyses show that this river is subject to multiple constraints and reaches its tolerance level on most of its sections. A multivariate statistical approach: principal component analysis (PCA) has shown that water pollution in the Innaouene River is mainly related to untreated wastewater discharges into streams. Water quality is considered bad to very bad. Therefore, ecological and health impacts can occur.

Keywords: microbiological parameters, water resources, water quality, pollution, wastewater, surface water.

INTRODUCTION

Across the world, a multitude of investigations have undeniably demonstrated that invaluable freshwater sources are currently being threatened by the pernicious intrusion of harmful chemicals. Moreover, the specter of eutrophication looms prominently, exerting its influence on innumerable rivers as they contend with an excess of organic material and nutrients. This disconcerting reality emphasizes the pressing necessity for a collective and concerted endeavor to safeguard the lifeblood of our planet – precious freshwater ecosystems (Yang et al., 2021), while projections indicate that the global demand for freshwater will surge by a third by the year 2050, as posited by the Program and Raymond in 2018. The investigations conducted by Wang et al. in 2020 revealed that over 350000 registered chemicals and 70,000 unidentified chemicals have been manufactured and employed in the global marketplace, some of which are deemed hazardous pollutants and can be discharged into aquatic environments, eventually reaching rivers and groundwater. The management of waste disposal remains a global concern, as the process of urbanization expands in numerous developing nations, rendering waste management an issue of public health and environmental significance in urban regions (Ouyang et al., 2022). Many rivers in developing nations face persistent pollution stemming from domestic and industrial discharges (Balali et al., 2020). These nations operate landfills lacking adequate facilities for the collection and treatment of wastewater, and it is estimated that untreated water is released into bodies of water (Sghiouer et al., 2022).

The quality of natural surface water in the Innaouene watershed can result from anthropogenic and natural constraints, as well as the way of water management and saving. Therefore questions arise when one asks how to improve it without degrading it.

The formidable threat of pollution in the environment presents a worrying threat, resulting in a series of adverse effects. The rivers of Morocco, far from being exempt, bear the burden of this environmental threat, struggling with serious health and economic repercussions. Recent research has drawn attention to the critical condition of many rivers in different parts of the country, highlighting the urgency of addressing this urgent issue to protect the well-being of ecosystems and communities (El Hajjami et al., 2021) and (Abba et al., 2021).

Given the socio-economic and demographic development in Morocco, particular interest is given to the protection and sustainable conservation of Moroccan hydrographic systems, and as for the majority of the countries of the world, Morocco does not escape the scourge of pollution. However, anthropogenic activity remains a major cause of the degradation of natural water quality. This work focused on the study of the physicochemical quality and the microbiological contamination of the surface waters of the Innaouene River, the tributary of the Oued Sebou, being one of the least studied rivers.

For this purpose, several physicochemical and microbiological parameters have been measured, the conclusions of which will be investigated as follows:

- A statistical examination using Principal Component Analysis (PCA) in order to establish a correlation between various physicochemical parameters, thus enabling a more comprehensive evaluation of the impact of human activities on water quality.
- A hydro-chemical assessment aimed at classifying the chemicals and identifying the chemical composition of the water, accomplished through a graphical representation of the major cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) as well as the major anions (HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-).
- Additionally, an analysis of the microbial contamination of water has been conducted, focusing on the enumeration of total microorganisms at 37 °C (GT), fecal coliforms (CF), total coliforms (CT), and fecal streptococci (SF).

MATERIALS AND METHODS

Study area

The Innaouene watershed is a small sub-basin of Sebou, it covers an area of 3 320 km^2. It drains surface water towards the Driss 1st dam. The Innaouene River is the most important river in this basin, of which the Larbâa River is one of its main tributaries, which is known for its torrential floods, as shown in Figure 1.

It is bounded to the east by the Middle Moulouya watershed, to the northwest by the Upper Ouergha, and to the southwest by the Upper Sebou (Yafetto et al., 2019).

To enhance the understanding of the water quality in the Innaouene River, a strategically designed sampling network was employed. This network was meticulously chosen to capture a comprehensive snapshot of the spatial variability of the elements under investigation. The water sampling initiative took place during the low water period in July 2021, with a focus on obtaining eight (8) samples. This approach ensures a nuanced and representative dataset, laying the

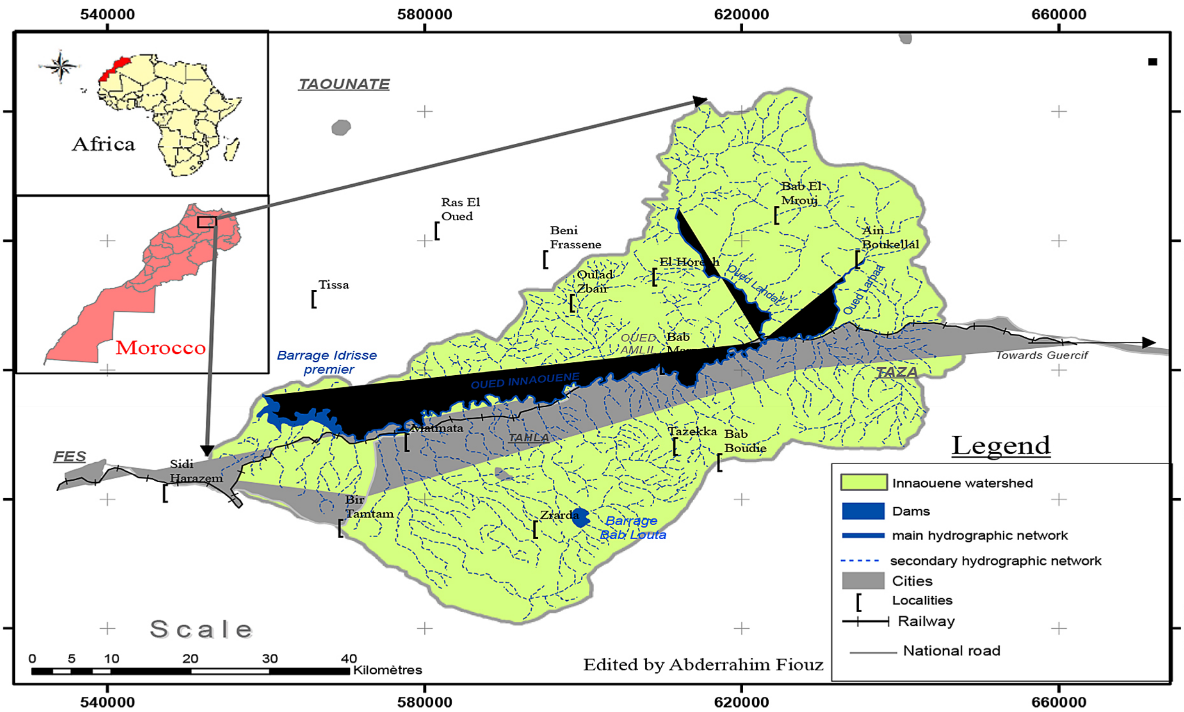

Figure 1. Geographical location of the Innaouene River watershed

foundation for a thorough characterization of the water quality dynamics of the Innaouene River (Figure 2).

It was necessary to have a sufficient number of sampling stations to allow comparisons on a catchment scale. The main criteria selected were the morpho-dynamic and lithological characteristics of the sites as well as the distribution of anthropogenic activities. However, a logistical constraint, namely the accessibility of the sites, also influenced the choice and location of the number of stations.

The sampling stations chosen above all respected the land use in their watershed. In fact, the criteria for choosing the location of the sampling stations were as follows:

- Station S1 is located upstream in an area where the anthropogenic effect is minimal.
- Station S2 is located downstream of three large modern industrial oil mills suspected of discharging their wastewater into the Innaouene River without any prior treatment, and also are all located near a salt mine.
- The S3 station is located near the sewer discharge point of the town of Taza in the absence of a wastewater treatment plant.
- Stations S4 and S5 are located just after the main town center of (Bab Marzouka and Oued Amlil) where anthropogenic action is significant.
- Stations S6 and S7 and S8: Discharges are not significant
- The S8 station located downstream and at the water entrance to the Idriss Premier dam.

In order to conduct this investigation, a series of measurements pertaining to physicochemical and microbiological parameters was conducted. These measurements were performed on a total of 8 samples, encompassing various factors such as Temperature, pH level, Dissolved oxygen content, Turbidity, Conductivity, the chemical oxygen demand (COD), the biological oxygen demand (BOD_5), chlorides Cl^-, Nitrates NO_3^-, nitrites NO_2^-, ammonium ion NH_4^+, sulphates SO_4^{2-}, ortho-phosphates (PO_4^{3-}), calcium ions (Ca^{2+}), magnesium ions (Mg^{2+}), sodium ions (Na^+), potassium ions K^+, bicarbonate ions HCO_3^-, as well as the enumeration of total germs at 37 °C (GT), faecal coliforms (CF), total coliforms (CT), and fecal streptococci (SF).

Five of the physical parameters were measured in the field: temperature, pH, conductivity using a multi-parameter analyzer Type CONSORT, Model C535, turbidity was measured using a turbidimeter Type HACH, Model 2100P, and dissolved oxygen using the Winkler titration method.

The methods used for physicochemical analysis at the laboratory are molecular absorption spectrophotometry for sulfates, nitrates, nitrites, ammonium ions, and orthophosphates, volumetry for bicarbonates, chlorides, calcium and magnesium, and flame spectrophotometry for sodium and potassium. BOD_5 is determined by an OXITOP, DCO is analyzed by acid oxidation with excess potassium dichromate (at 148 °C) of oxidizable materials under test conditions in the presence of silver sulfate as a catalyst and mercury sulfate and suspended solids (using a 0.45 µm membrane).

The water samples were taken in 1 liter polyethylene bottles and transported in the cooler as well as stored at a temperature of 4 °C according to the procedures dictated by (Yafetto et al., 2019).

The study of the microbiological contamination of the water focused on the direct colony count after concentration by membrane filtration of Total Germs at 37 °C (TG), Faecal Coliforms (FC), Total Coliforms (TC), and Faecal Streptococci (FS) by the direct bacterial colony count method.

Since the density of microorganisms' indicative of pollution varies greatly during the same day and from one day to another, it was preferred to carry out the sampling during the intensive period of water use and at the same time in the morning in order to avoid the disinfecting action of the sun's ultraviolet rays.

Physicochemical analyses

Ionic balance: Before processing and interpreting the analyses of the water samples taken at the eight selected stations, the reliability of the results had to be analyzed. The method used is the Ionic Balance (IB). It should be remembered that in theory, natural water is electrically neutral. Therefore, the sum (in chemical equivalents) of the cations should be equal to that of the anions (in chemical equivalents). In reality, this equality is rarely achieved. In general, the difference is attributed to uncertainties, the presence of some unassayed ions, or analytical errors. Therefore, a certain margin of imbalance between anions and cations is allowed. This is expressed as a relative deviation by the formula:

$$Ionique\ balance(IB) = \\ = \frac{\sum(\text{cations}) - \sum(anions)}{\sum(\text{cations}) + \sum(anions)} \times 100 \quad (1)$$

The calculation of the ion balance generally allows the reliability of the results of chemical analyses to be verified. However, the uncertainties in the results, which vary according to the analytical techniques, can explain the sometimes

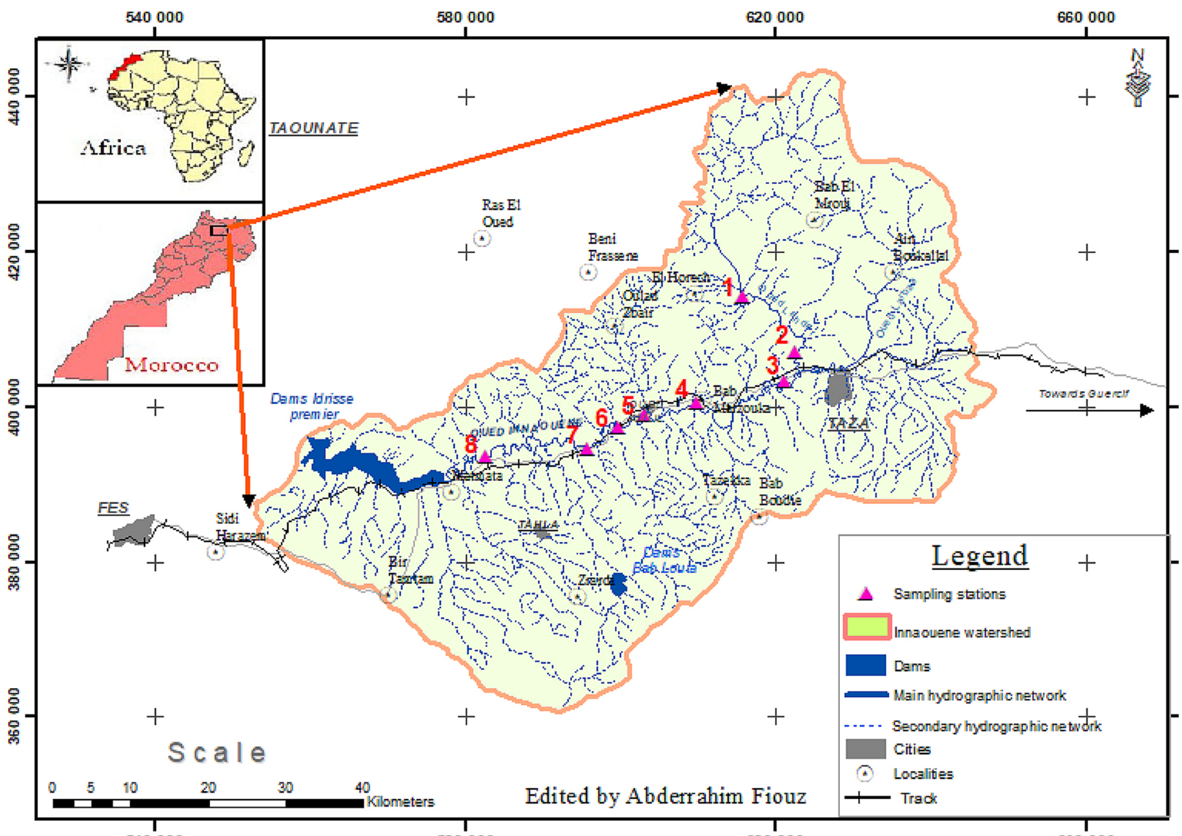

Figure 2. Location of sampled stations in the Innaouene River watershed

high errors in ionic balances, due to the possible presence of organic anions not taken into account in the calculations. In general, chemical analyses are considered:

Excellent if (BI) is less than 5%, acceptable if (5% < (BI) < 10%), and doubtful if (BI) greater is than 10%.

RESULTS

With regard to the surface water data treated in this study, the treatment was carried out for the 8 points distributed along the Innaouene River basin. The results obtained are all of good quality.

Water temperature is an ecological factor with important ecological repercussions (Robinne et al., 2020). In the waters of the stations studied, this parameter has values between 22 °C (S1) and 27.50 °C (S8) as shown in Figure 3. The spatial variations of the water observed between the sampling sites can be explained either by a situation close to the points of discharge of liquid wastewater effluents (the case of S3) resulting in an increase in temperature or by the situation downstream of the resurgence of water sources of mountainous origin which originate in the middle Atlas karstic reservoir, as is the case of S4, S5, and S6, which results in a decrease in temperature. This drop in temperature is explained by the storage of water in the cold seasons and its flow during the year.

Turbidity is the reduction in transparency of a liquid due to the presence of undissolved matter. The measurement of turbidity is very useful for the control of treatment, but does not give any indication of the suspended particles that cause it. The measurement is made by comparing the scattered and transmitted light in the water sample and by a standard range. It can be caused by either decomposed organic particles or inorganic particles. Interpreting the obtained results, the high values above 50 NTU (S1, S2, S3, S6, S7, and S8) recorded may be related to the nature of the highly erosive soils consisting of clay, and pelites (a finely detrital, clayey, water-pasty rock (Råman Vinnå et al., 2017)), and the rugged terrain where the soils are affected by runoff, they are very high compared to the normal range of turbidity given by (Yuan et al., 2017), while the values recorded in sites S4 and S5 represent the

Table 1. Quality of the chemical analyses carried out

Stations	S1	S2	S3	S4	S5	S6	S7	S8
X	615840.70	622909.32	621196.95	609868.65	603061.00	599618.17	595703.54	582620.61
Y	414267.39	404537.81	403279.14	400672.46	398950.64	397362.22	394677.10	393565.96
Ionic balance	3%	3%	1%	3%	4%	2%	3%	4%

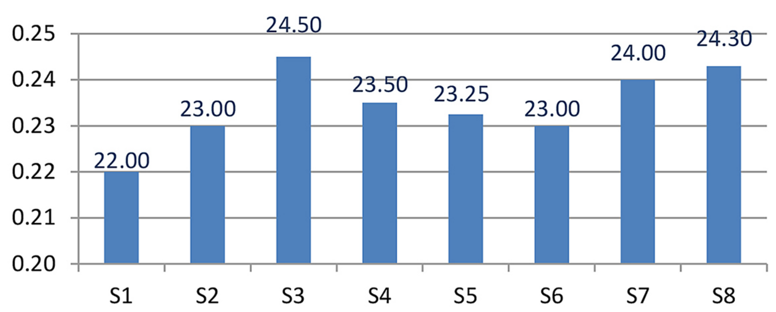

Figure 3. Spatial variation of temperature values

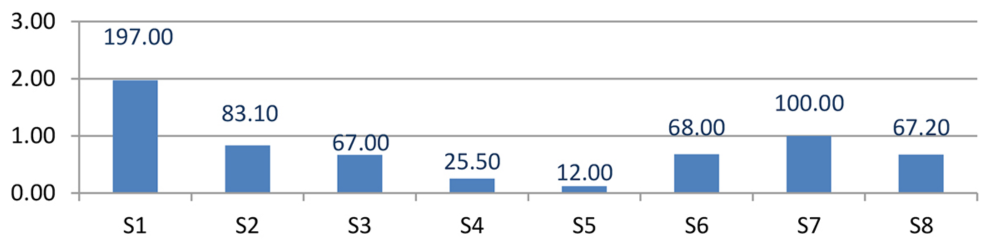

Figure 4. Spatial variation of turbidity values

values that according to Rodier et al. (2009) and in the absence of a Moroccan standard are within the normal turbidity range of surface waters as shown in Figure 4.

The pH of water is used to highlight the chemical species present in a sample. It measures the concentration of H^+ ions in water and thus reflects the balance between acids and bases on a logarithmic scale from 0 to 14. Its values do not show significant variations and tend to be slightly basic with a minimum of 6.81 and a maximum of 7.68 as shown in Figure 5.

The pH values of the water at sites S1 to S8 are in line with Moroccan surface water quality standards, which qualify these waters as good quality (Chai et al., 2020). According to these standards, the general limit values for liquid discharges from sewers into surface waters vary between 5.5 and 9.5. Therefore, wastewater has no impact on the water quality of the Innaouene River.

The biochemical oxygen demand (BOD_5) is the amount of oxygen (expressed in mg/L) required by decomposing microorganisms to degrade and mineralize the organic matter present in one liter of polluted water within 5 days. The higher the BOD_5, the higher the amount of organic matter present in the sample.

However, BOD_5 can help to assess the purification process and is an important tool for monitoring water quality (Zhao et al., 2015).

Chemical oxygen demand (COD) is the amount of oxygen required for the chemical degradation of organic compounds in water using a strong oxidant. It is a measure of the total organic matter content, including that which is not degradable by bacteria. It is therefore an important parameter for characterizing the overall pollution of water by organic compounds.

The COD/BOD_5 ratio gives an indication of the origin of the organic pollution, so the waters of the 8 stations analyzed may be difficult to biodegrade, indicating pollution mainly of urban waste origin (Sanae et al., 2023) as shown in Table 2.

Considering Table 2, it can be seen that the two parameters COD and BOD_5 are at their highest at station S3 (BOD_5 = 364 mg/l and COD = 992 mg/L) where the liquid wastewater discharges are the highest.

According to the surface water classification grid (Mfonka et al., 2021), the water of all stations can be classified as 'very poor'.

In Table 2, it can be seen that the two parameters COD and BOD_5 are at their highest electrical conductivity of water refers to the ability of water to conduct an electrical current and is usually expressed in µs/cm. It is determined by the content of dissolved substances, ionic charge, ionization capacity, mobility, and temperature of the water (Derwich et al., 2011). It can be used as an indicator of pollution in environmental studies, to show significant inputs of salts of natural (watershed) and/or anthropogenic origin.

The surface waters of the Innaouene River are moderately mineralized for the samples from S3 to S8 with values between 1700 µs/cm and 1250 µs/cm as shown in Figure 7, on the other hand, a more important mineralization is noted for samples S1 (3590 µs/cm) and S2 (4650 µs/cm) and this is justified by the dissolution of the Triassic saliferous rocks of the eastern prerif nappe constituted by salt and gypsum deposits crossed by the water course.

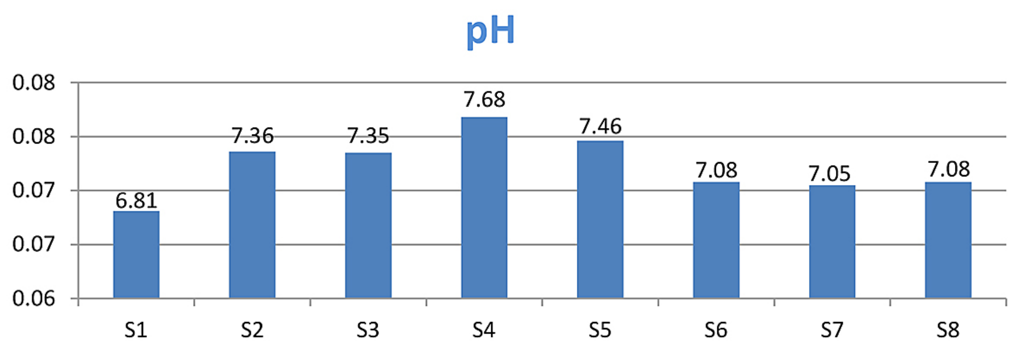

Figure 5. Spatial variation of hydrogen potential (pH)

Table 2. Quality of the chemical analyses carried out

Stations	S1	S2	S3	S4	S5	S6	S7	S8
DCO/BOD5	1.97	2.10	2.72	2.36	2.34	2.16	2.84	2.75

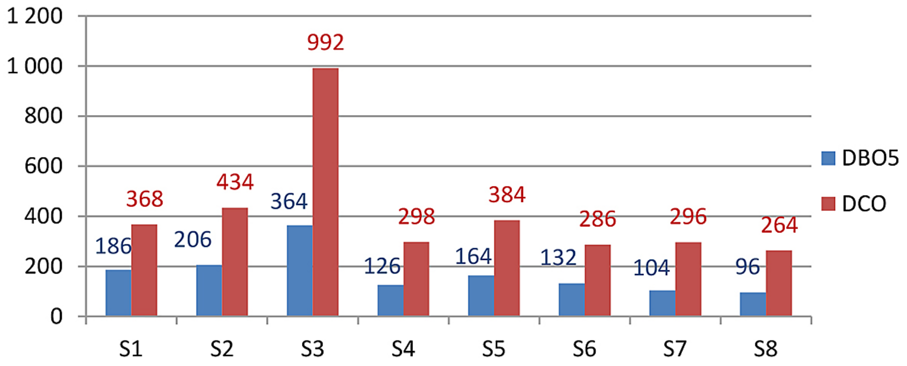

Figure 6. Spatial variation of biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD)

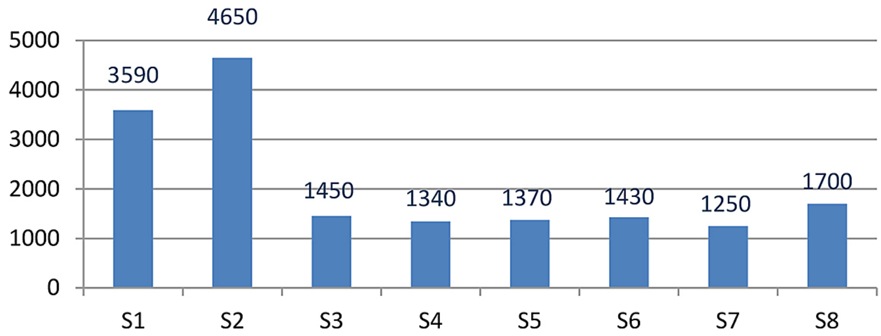

Figure 7. Spatial variation of conductivity values

In surface waters, the abundance of chloride ions (Cl^-) depends on the chemical composition of the bedrock, the climate, and the proximity to the sea, as it can be an indicator of pollution (Makhoukh et al., 2011a), their existence in water can indicate anthropogenic contamination (Yang et al., 2021) due to their presence in urine as well as in cleaning products.

In the waters of the Innaouene River, this content reaches high values as is the case of S2 (2378.50 mg/L) and S1 (1434.20 mg/L) linked mainly to the nature of the saliferous soils crossed, as shown in Figure 8, while for the rest of the section (S3 to S8), these values vary little and are situated between 553.80 mg/L and 369.20 mg/L which can be qualified according to Moroccan standards in the medium quality class (Mfonka et al., 2021).

The sulfate ion (SO_4^{2-}) is a chemical compound that occurs naturally in almost all natural waters in highly variable concentrations (most commonly in contact with gypsum or other common minerals) (Atteia et al., 1998). Sulfates in natural waters have essentially two origins:

- Geochemical and atmospheric (Faiz et al., 2021).
- As a result of the bacterial activity (chlorothiobacteria, rhodothiobacteria, etc.). This activity can oxidize toxic hydrogen sulfide (H_2S) to sulfate (Attien et al., 2022).

The highest value recorded in station S2, as shown in Figure 9, originates from gypsum contained in evaporites located NW of the city of Taza. The other sulfate contents in the study area

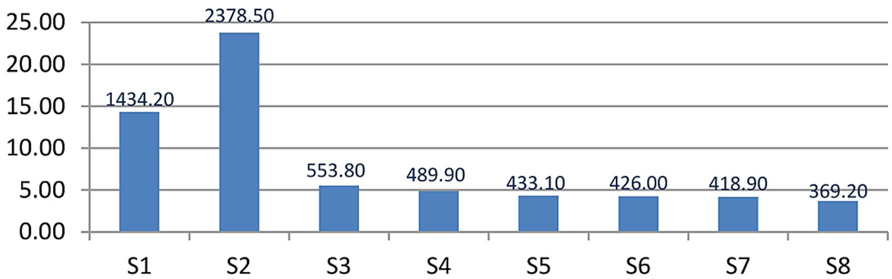

Figure 8. Spatial variation of chloride ion values (Cl^-)

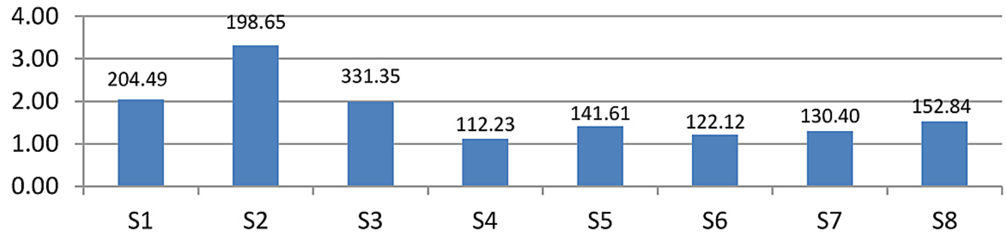

Figure 9. Spatial variation of sulfate values

range from 112.23 mg/L to 204.49 mg/L due to dilution along the course River.

Naturally occurring and soluble in the soil, nitrates enter the soil and groundwater and flow into watercourses. However, they are also synthetically added by fertilizers (Rachiq et al., 2021) and are one of the factors in the degradation of water quality. Nitrate is usually produced by the decomposition of organic matter through bacterial oxidation of nitrite and is thus the ultimate product of nitrification.

In the studied station, nitrate levels range from a minimum value of 21.79 mg/L recorded at the station (S1) to a maximum value at the station (S3) of 70 mg/L, as shown in Figure 10. The nitrate contamination seems to be linked to the wastewater input of the city of Taza (S3) and also to the leaching of the soils crossed by the Innaouene River. Nevertheless, these values identify these waters in the poor to a very poor class set according to Moroccan standards (Naoura et al., 2015).

Nitrite is either the result of incomplete oxidation of ammonia or the reduction of nitrate (NO_2^-) under the influence of denitrifying action. Water containing nitrite is to be considered suspect.

Nitrite is considered to be an intermediate ion between nitrate and ammoniacal nitrogen, which explains the low quantities found in the aquatic environment. The results of the conducted study show that nitrite levels are between 0.61 mg/L (S4) and 1.21 mg/L (S3), as shown in Figure 11. These levels seem to be high since the WHO recommends a limit value of 50 mg/L for water intended for human consumption, and specifies that the nitrite concentration must also be taken into account in such a way that the sum of the ratios of the concentrations (of nitrate and nitrite) in relation to their respective guide values must be less than 1 (Nguyen et al., 2019).

Ammonium is the product of the final reduction of nitrogenous organic substances and inorganic matter in water and soil. It also comes from the excretion of living organisms and from the reduction and biodegradation of waste, not

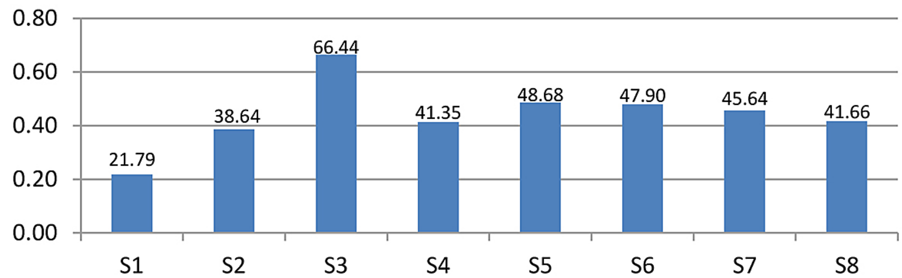

Figure 10. Spatial variation of nitrate values

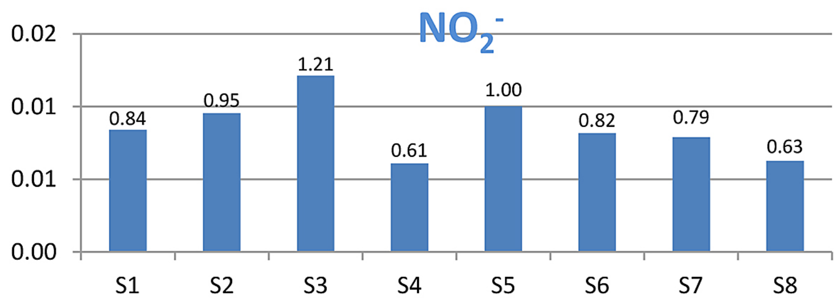

Figure 11. Spatial variation of nitrite values

forgetting inputs from domestic, industrial, and agricultural sources. This element exists in small proportions below 0.1 mg/L of ammoniacal nitrogen in natural waters. In surface waters, it comes from nitrogenous organic matter and from gas exchanges between water and the atmosphere (Vieux et al., 2020). It is therefore a good indicator of pollution of watercourses by effluents.

Ammonium ion concentrations vary along the watercourse, being highest at site S3 (1.23 mg/L) and lowest at S1 (0.47 mg/L), as shown in Figure 12, which allows classifying the quality of this element as medium (Makhoukh et al., 2011).

Dissolved oxygen is very important, because it conditions the state of several mineral salts, the degradation of organic matter, and the life of aquatic animals (Derwich et al., 2011). As one of the most important indicators of the degree of water pollution, dissolved oxygen measures the concentration of dissolved oxygen in water expressed in mg/l or in the percentage of saturation.

The concentrations obtained at the level of the waters of the various stations studied present notable variations, as shown in Figure 13, they vary from 1.64 mg/L (in S3) and 8.80 mg/L downstream (S8), which testifies to the excellent quality of this parameter in the downstream stations of the Innaouene River (S7 and S8) and the poor quality in upstream stations such as (S1, S2, and S3) (Makhoukh et al., 2011b).

The physicochemical results of the analyzed water samples from the different sites have been listed according to the quality classes, as shown in the Figure 14, with the conventional colors (Naoura et al., 2015).

The evaluation of the percentages of the quality classes, at the level of the different sampled sites, as shown in Figure 15, was carried out in order to conclude the trends. This enabled us to draw up a map of the state of the physicochemical quality of the water in the section of the Innaouene River, the subject of this study.

The map of the physicochemical quality of the surface water in the study area shows a very marked anthropogenic impact, particularly near the urban centers. Thus, near the city of Taza, the quality of the tributary Larbae River (site S3) is very poor, following an accumulation of solid and liquid pollutants. This quality can improve after the confluence with the Lahdar River, which causes the dilution of water. The improvement of the physicochemical quality of the water of the Inaouène River continues but remains very poor.

The data obtained was subjected to hydrochemical analysis, and Diagram software was used for the chemical classification of the waters,

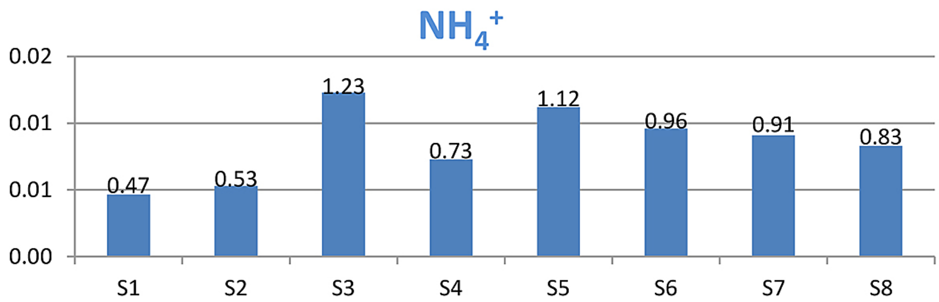

Figure 12. Spatial variation of ammonium ion values

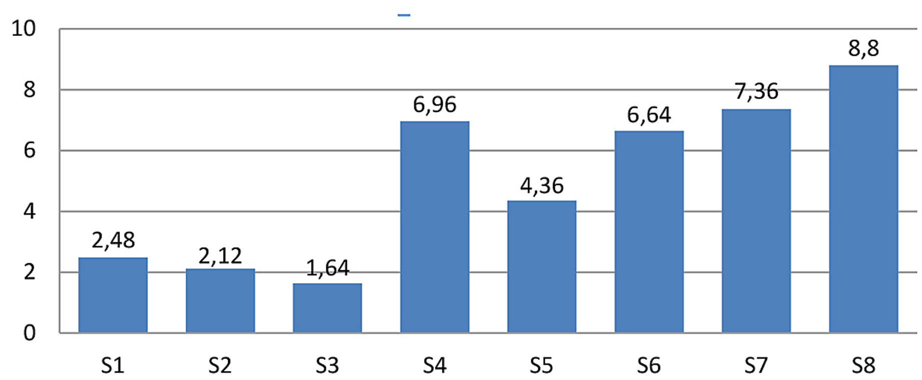

Figure 13. Variation in dissolved oxygen levels

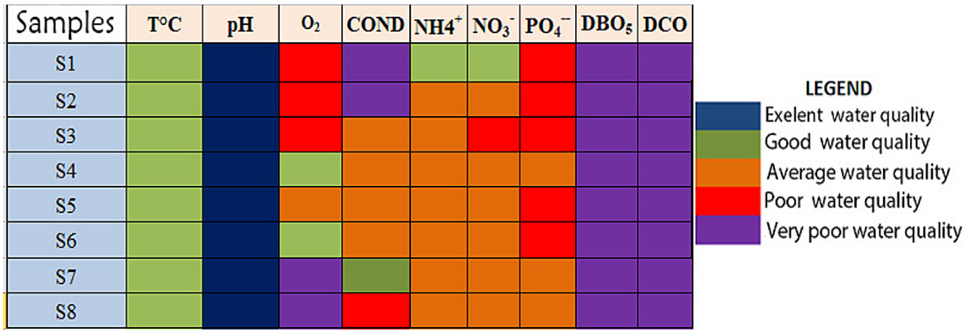

Figure 14. Quality classes of physicochemical results of water samples analyzed

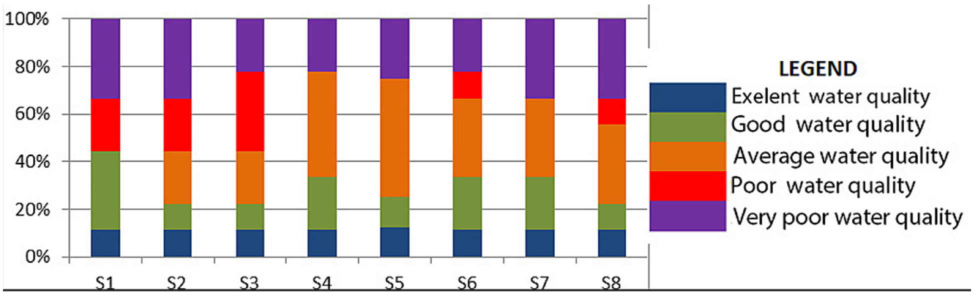

Figure 15. Percentages of quality classes of sampling sites

based on a graphical distribution of major cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and major anions (HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-) in Piper's triangular diagram and Schöeller-Berkaloff's diagram, which will allow for easy comparison and even classification of these waters.

The Piper diagram depicted in Figure 16 is used to represent the chemical facies of a set of water samples. It is made up of two triangles representing the cationic and anionic facies and a diamond corresponding to a synthesis of the overall facies. The Piper diagram also allows:

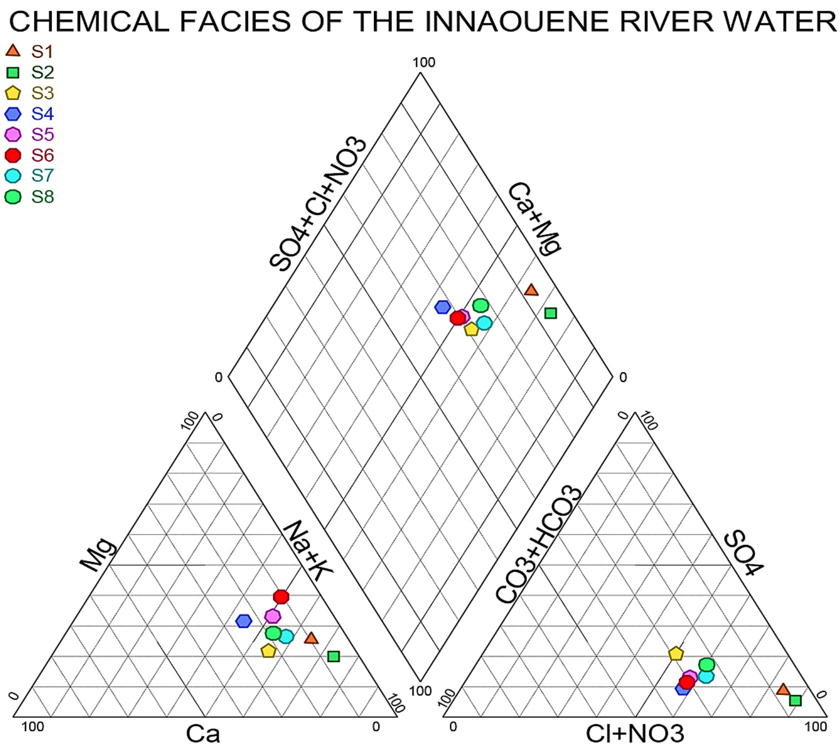

Figure 16. Piper diagram

- To illustrate the chemical evolution of water as well as mixtures of waters of different mineralization.
- To determine of the geological nature from chemical analyses, to have a relationship between the chemist of the water and the lithological nature of the crossed rocks (Noel Keumean et al., 2022).

The projection of several samples at the same time to:

- Follow their evolution in time and space, compare them, determine of the notion of mixing, and follow the physicochemical properties during their spatiotemporal evolution.

The Schoeller-Berkalov diagram (Figure 17) is used to represent the chemical facies of several waters. Each sample is represented by a broken line. The concentration of each chemical element is represented by a vertical line in a logarithmic scale. The broken line is formed by connecting all the points representing the different chemical elements.

The analysis of the waters of Oued Innaouene showed that the chemical facies is chlorinated sodic and sulfated potassic or sodium for all the samples analyzed. This facies is influenced by the salty water brought by the Oued Innaouene and its tributaries. It is also the result of the leaching of Triassic soils of the eastern pre-Rif nappe consisting of salt and gypsum deposits.

Regarding the principal component analysis is a multidimensional statistical method used to synthesize information to compare systems. PCA makes it possible to explain the chemical similarities between different water sources and/or different mineralized acquisition poles, and the variables that control these mechanisms. In fact, it is a technique that can take into account a large number of variables and samples.

This method is widely used to interpret hydro-chemical data (Noel Keumean et al., 2022) and (Yuan et al., 2017). In this study, the statistical analysis was performed on 8 samples and 22 variables using XLSTAT software.

This multidimensional data analysis is a factorial and linear method that deals with numerical characters (in this case, the results of physicochemical and microbiological analyses). This makes it possible to highlight the chemical similarities between the different waters and/or the different points of acquisition of the mineralization. During this work, a statistical analysis (PCA) was carried out on reduced centered variables using the XLSTAT software. The data relate to all the analyses relating to the eight (8) surface

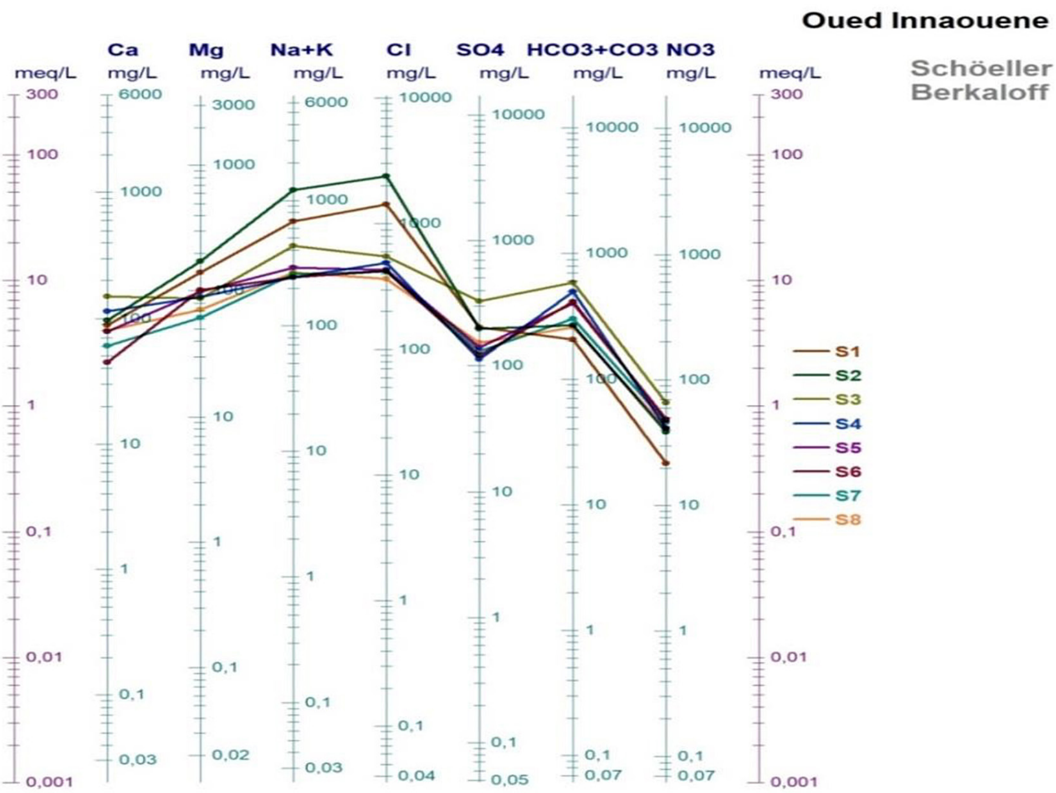

Figure 17. Schoeller-Berkalov diagram

water stations of the Innaouene River. The 22 variables dealt with, relate to the following physicochemical and microbiological parameters: (water T°C, pH, dissolved O_2, HCO_3^-, Cl^-, NO_2^-, NO_3^-, PO_4^{3-}, SO_4^{2-}, Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, BOD_5, COD, Cond, Turb , total germs at 37 °C (GT), faecal coliforms (CF), total coliforms (CT), and streptococci). The use of principal component analysis (PCA) for the global study of surface waters allows differentiation on their chemical and microbiological particularities, a determination of their overall variations factors along the main axes and especially a characterization of the different poles of acquisition of mineralization. The correlation coefficients between the different elements are reported in (Table 3).

The eigenvalues of the correlation matrix measure the percentage of variance explained by

Table 3. Correlation matrix between the variables on all the studied stations of the Innaouene river waters

Variables	T°C	pH	O_2	HCO_3^-	Cl^-	NO_2^-	NO_3^-	PO4--	SO4--	Na+	NH4+	K+	Mg^{2+}	Ca++	DBO5	DCO	COND	TURB	CT	CF	GT	SF
T°C	1																					
pH	0.168	1																				
O2	0.776	-0.042	1																			
HCO3-	0.231	0.654	-0.025	1																		
Cl-	-0.755	-0.089	-0.636	-0.537	1																	
NO2-	-0.333	0.094	-0.812	0.321	0.218	1																
NO3-	0.333	0.427	-0.089	0.831	-0.458	0.575	1															
PO4--	-0.516	0.048	-0.828	0.436	0.120	0.881	0.470	1														
SO4--	-0.525	-0.051	-0.756	0.300	0.263	0.783	0.456	0.850	1													
Na+	-0.726	-0.069	-0.673	-0.484	0.991	0.309	-0.353	0.177	0.350	1												
NH4+	0.574	0.288	0.088	0.737	-0.711	0.471	0.894	0.372	0.231	-0.625	1											
K+	-0.087	0.454	-0.410	0.802	-0.232	0.627	0.798	0.720	0.764	-0.142	0.624	1										
Mg++	-0.741	-0.050	-0.687	-0.446	0.933	0.258	-0.473	0.216	0.208	0.909	-0.651	-0.251	1									
Ca++	-0.442	0.476	-0.562	0.546	0.155	0.464	0.408	0.636	0.761	0.208	0.142	0.855	0.101	1								
DBO5	-0.526	0.170	-0.828	0.473	0.242	0.874	0.555	0.936	0.947	0.323	0.329	0.819	0.258	0.785	1							
DCO	-0.357	0.204	-0.682	0.586	0.053	0.838	0.702	0.888	0.936	0.148	0.488	0.912	0.030	0.798	0.970	1						
COND	-0.740	-0.227	-0.588	-0.638	0.981	0.141	-0.566	0.075	0.242	0.964	-0.774	-0.308	0.926	0.095	0.178	-0.017	1					
TURB	-0.660	-0.826	-0.318	-0.660	0.446	-0.005	-0.590	0.161	0.254	0.402	-0.597	-0.328	0.382	-0.102	0.070	-0.035	0.549	1				
CT	-0.394	0.190	-0.714	0.571	0.078	0.846	0.671	0.911	0.942	0.169	0.461	0.898	0.070	0.798	0.981	0.998	0.012	-0.007	1			
CF	0.073	0.391	-0.539	0.413	-0.096	0.772	0.517	0.651	0.440	-0.023	0.610	0.576	0.028	0.392	0.583	0.578	-0.153	-0.387	0.584	1		
GT	-0.447	0.159	-0.749	0.517	0.147	0.848	0.625	0.910	0.960	0.236	0.400	0.872	0.131	0.801	0.989	0.994	0.084	0.044	0.997	0.559	1	
SF	-0.551	0.252	-0.820	0.300	0.515	0.814	0.475	0.732	0.863	0.603	0.142	0.670	0.449	0.721	0.905	0.855	0.421	0.016	0.858	0.459	0.883	1

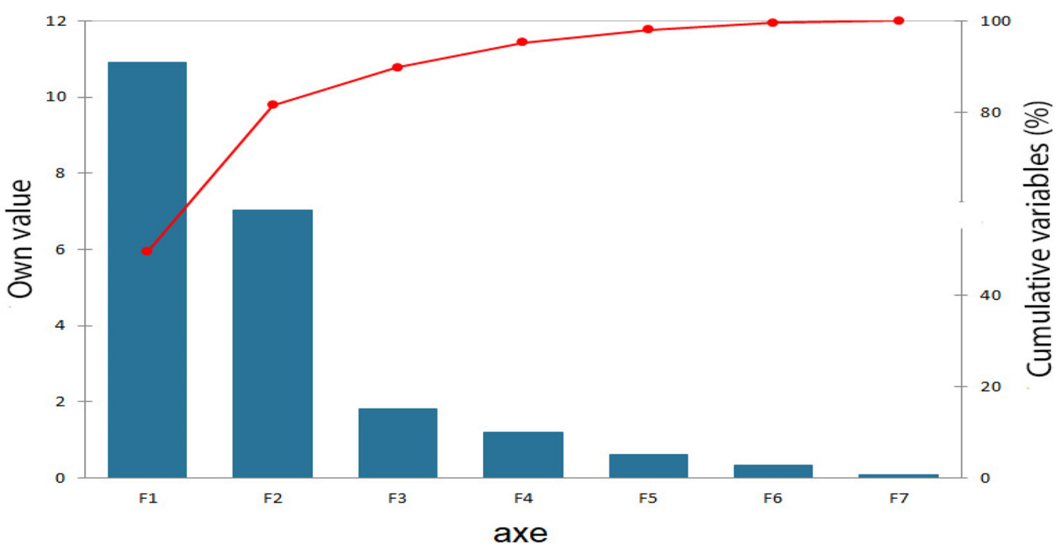

Figure 18. Histogram of eigenvalues

Table 4. Eigenvalues

Parameter	F1	F2	F3	F4	F5	F6	F7
Eigenvalue	10.901	7.035	1.828	1.195	0.605	0.340	0.096
Variability (%)	49.552	31.976	8.307	5.434	2.751	1.545	0.435
Cumulative %	49.552	81.528	89.835	95.269	98.020	99.565	100.000

each factorial (Table 3). The histogram of the eigenvalues (Figure 18) shows that the first factorial plane, made up of the F1 and F2 axes, represents 81.528% of the total inertia (Table 4). This is sufficient to reflect the bulk of the inertia.

The analysis of this matrix shows a good positive correlation between:

- Cl^-, Mg^{2+}, Na^+ and Turbidity.
- SO_4^{2-}, NO_2^-, NO_3^-, BOD5, COND, Ca^{2+}, SF, GT, and CT.

And a good but negative correlation between: Dissolved oxygen O_2 and all the parameters (SO_4^{2-}, NO_2^-, PO_4^{3-}, BOD5, COD, SF, GT, and Ca^{2+}).

The analysis of the variables (Figure 19) shows that:

- The factor F1 expresses 49.55% of the total inertia of the cloud, it is well represented by: (SO_4^{2-}, NO_2^-, PO_4^{3-}, BOD5, COD, Ca^{2+}, SF, GT, and CT), this is the pole of pollution.
- The F2 factor expresses 31.98% of the total inertia of the cloud, it is well represented by (Cl^-, Mg^{2+}, Na^+ and Turbidity) and it is the mineralization pole.

The graphs from the factor analysis (Figure 20) show three water varieties:

- Variety of water (Group1): The F2 axis expresses 31.98% of the variance and highlights a significant positive correlation between the variables: COND, Cl^-, Mg^{2+}, Na^+ and turbidity. The association of these parameters presented by the samples S1 and S2 can be explained by the phenomenon of erosion and dissolution of the evaporitic sediments of the region.
- Variety of water (Group2): The F1 axis expresses 49.55% of the variance and highlights a positive correlation between the variables: SO_4^{2-}, BOD5, COD, NO_2^-, PO_4^{3-}, Ca^{2+} and K^+, and the microbiological parameters: GT,

Table 5. Contribution of variables and their squared cosines

Parameter	Contributions of variables		Squared cosines of the variables	
	F1	F2	F1	F2
T°C	1.798	8.892	0.196	0.625
pH	0.687	2.234	0.075	0.157
O_2	5.821	4.025	0.635	0.283
HCO^-	2.623	7.551	0.286	0.531
Cl^-	0.335	12.124	0.037	0.853
NO_2^-	7.200	0.032	0.785	0.002
NO_3^-	3.585	6.832	0.391	0.481
PO_4^{3-}	7.693	0.038	0.839	0.003
SO_4^{2-}	7.753	0.405	0.845	0.028
Na^+	0.714	11.075	0.078	0.779
NH_4^+	1.504	10.181	0.164	0.716
K^+	6.841	2,540	0.746	0.179
Mg^{2+}	0.363	10.954	0.040	0.771
CA^{2+}	5.949	0.003	0.648	0.000
BOD_5	9,000	0.108	0.981	0.008
DCO	8.775	0.179	0.957	0.013
COND	0.114	13.214	0.012	0.930
TURB	0.020	7.411	0.002	0.521
CT	8.879	0.086	0.968	0.006
CF	3.903	1.069	0.426	0.075
GT	8.909	0.000	0.971	0.000
SF	7.535	1.046	0.821	0.074

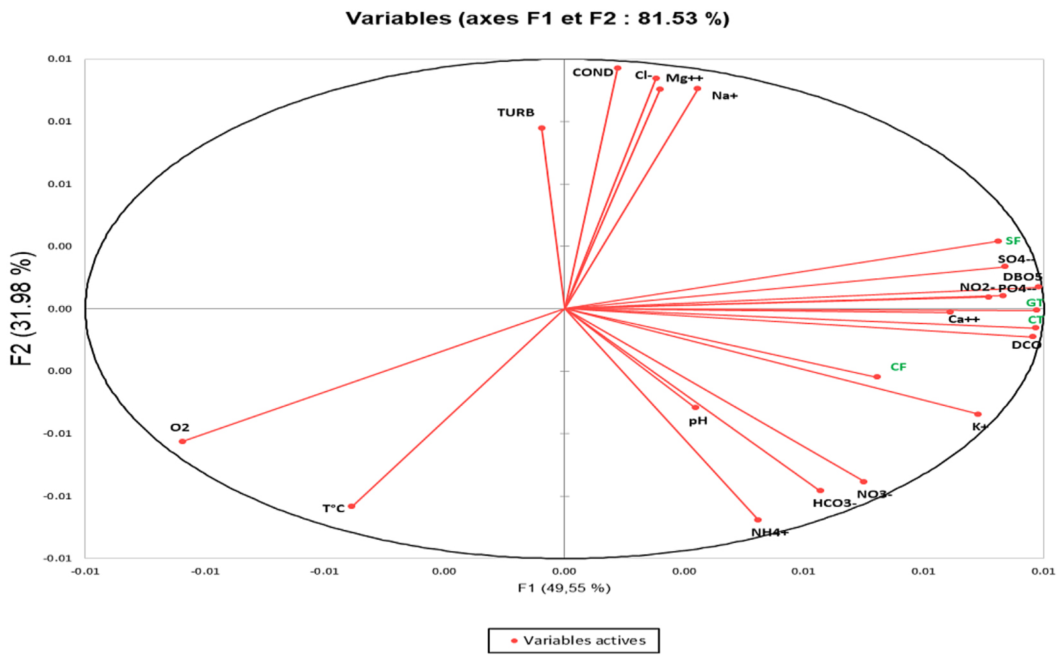

Figure 19. Projection of variables on the first factorial plane

CT, CF, and SF. The association of these parameters presented by the sample S3 can be explained by the significant contribution of a liquid polluting load from the tributary Larbaa River which plays the role of collectors of wastewater which is in very large part channeled and discharged into the watercourse punctually at the exit of the town of Taza (Zhao et al., 2015).

- Variety of water (Group 3): There is also a third group (Group 3) made up of: dissolved O_2 and water T°C, negatively correlated with (Group 2), in fact the polluting organic load of (group 2) favors excessive oxygen consumption, and as the river advances towards stations S4, S5, S6, S7, and S8 it becomes enriched in O_2.

The existence of bacteria in surface waters is a normal phenomenon and is a key aspect of the decomposition of organic matter and the recycling of nutrients essential to the maintenance of aquatic organisms and the food chain. However,

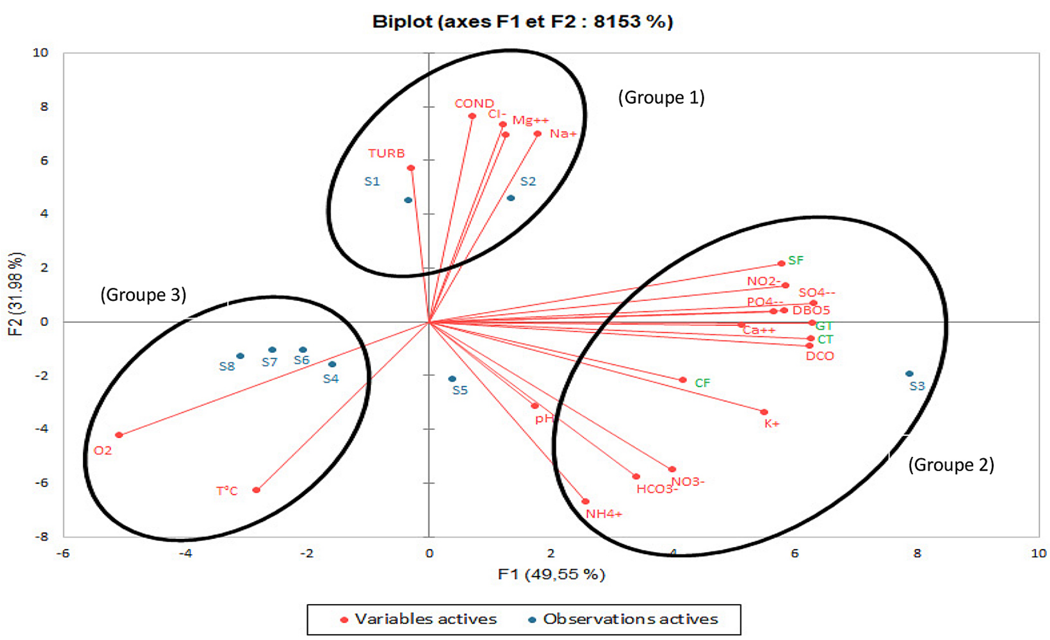

Figure 20. Projection of active variables and observations onto the first factorial plane

when the environment receives animal or human waste, the number and type of bacteria present can make the water unsuitable for certain activities. These bacteria, called faecal coliforms, come from the digestive tract of mammals and are good indicators of the potential presence of pathogenic organisms that can cause health problems (gastro-enteritis, dermatitis, etc.). Discharge of untreated domestic wastewater, sewer overflows in rainy weather, and manure spreading are the main sources of bacteriological contamination.

The principal component analysis (PCA) of all the data obtained on the waters of the Innaouene river, taken during the conducted sampling campaign on the eight sites, shows that the first axis explaining 49.55% of the variance, is marked above all by a coexistence of 4 microbiological parameters in abundance (Total germs (GT), faecal coliforms (CF), total coliforms (CT), and faecal streptococci (SF) with ions (NO_2^-, PO_4^{3-}, SO_4^{2-}, and NH_4^+), this is due to the mineralization of the organic matter present in the soil and in the water of the rivers which is carried out by micro-organisms according to 3 main stages in the degradation nitrogenous waste (Figure 21):

- Ammonization – first step in the transformation of organic nitrogen (living matter, organic waste) into ammoniacal nitrogen (ammonium) by mainly aerobic type bacteria (Bacillus, bacterium). This step releases NH_4^+ and CO_2 according to the equation:

$$2N_2 + 3CH_3OH + 3H_2O \Rightarrow 4NH_4^+ + 3CO_2 \quad (2)$$

In soils where the PH is high, ammonium is transformed into gaseous ammonia following the reaction:

$$NH_4^+ + OH^- \Rightarrow NH_3 + H_2O \quad (3)$$

- Nitrosation – consists of the degradation of ammonium and ammonia into nitrite, it is carried out by the group of bacteria of the Nitrosomonas type.

$$NH_4^+ + ½\, O_2 \Rightarrow NO_2^- + H^- + H_2O \quad (4)$$

- Nitratation – consists of the degradation of nitrites into nitrates and is carried out by the group of aerobic bacteria:

$$2NO^{2-} + O_2 \Rightarrow 2NO_3^- \quad (5)$$

A significant positive correlation is observed between the total germs GT and the faecal coliforms CF (0.997) as well as between the four parameters GT, CT, SF, and CF priced two by two, implies that the significant interconnection of the bacteriological variables considered in this study shows that the monitoring of one of them would be sufficient for the monitoring of the bacteriological quality of the whole river.

During this sampling campaign in the summer period, an increase in bacteriological contamination of the water was observed in two different sections S1-S2 and S3-S8:

An increasing gradient from upstream on the Lahdar River which is a tributary of the Innaouene River (Section S1-S2).

A decreasing gradient from upstream to downstream of the Innaouene river (Section S3-S8) with a peak in S2 which represents the discharge point of the Larbaa river loaded by the sewage of the city of Taza as well as liquid and solid waste from the uncontrolled public dump. The level of water contamination then decreases at site S4, which is located near the market-gardening plots that are irrigated by water pumped from nearby.

In the other sites (A5-A8), a decrease in the bacterial load can be seen, linked to dilution by spring water from the Liassic aquifer of the

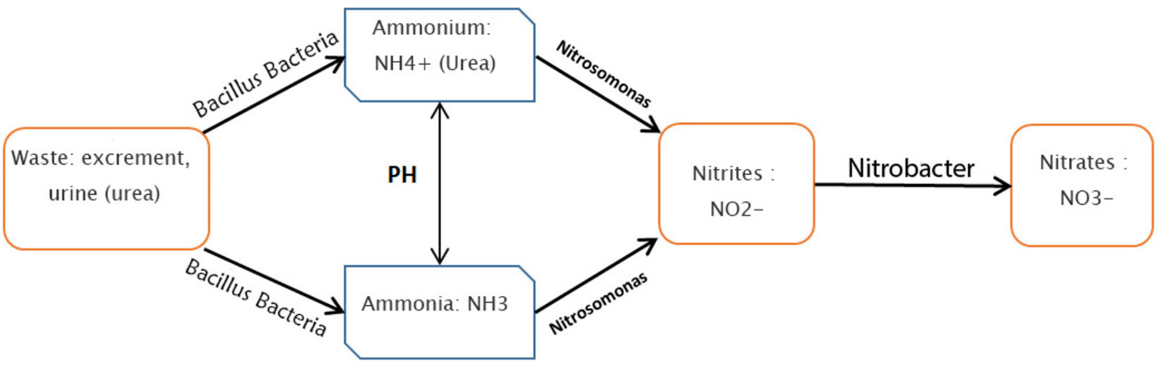

Figure 21. Diagram of the degradation stages of nitrogenous waste

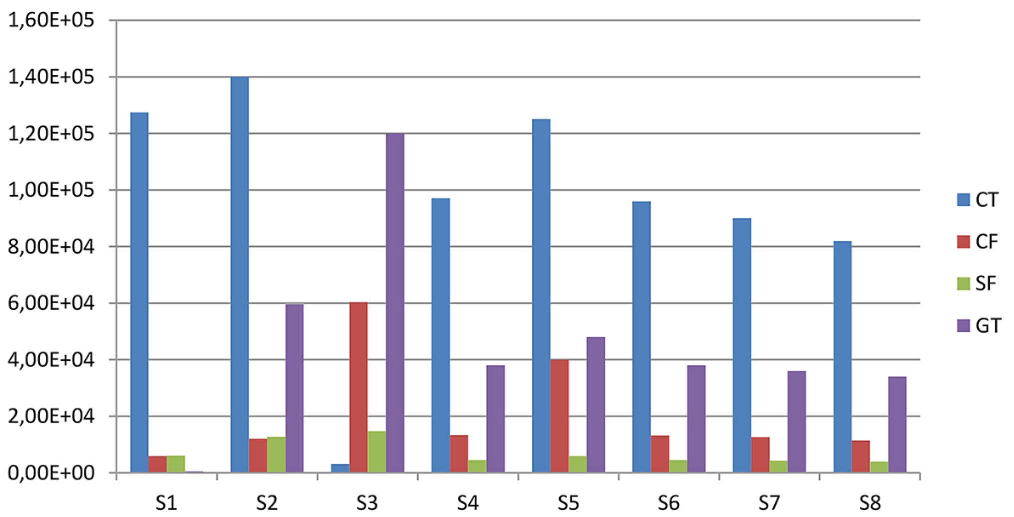

Figure 22. Spatial variation of CT, CF, GT and SF concentrations in the 8 stations

Fez-Taza corridor and from tributary rivers that originate on the northern flank of the Middle Atlas (Berradi et al., 2019) as one moves away from A4, but the bacterial level remains high and decreases slightly as far as the lake of the Idriss I dam as shown in Figure 22.

The origin of faecal pollution is related to the quantitative ratio of faecal coliforms to faecal streptococci (FC/FS).

When:

- CF/SF < 0.7 the pollution is mainly or entirely of animal origin (El Hajjami et al., 2021).
- CF/SF between 0.7 and 1 the pollution is mixed and predominantly animal (Tran et al., 2014).
- CF/SF between 1 and 2 pollution is of uncertain origin.
- CF/SF between 2 and 4 the pollution is mixed and predominantly human (Capps, 2019).
- CF/SF > 4 pollution has an exclusively human source (Wang et al., 2020).

Table 6 represents the ratio of faecal coliforms to faecal streptococci in the sampled sites. On the basis of these results, it can be concluded that the origin of the pollution is:

- Mixed, predominantly animal, for stations S1 and S2: the water in these two stations is less loaded with liquid pollutants from the sewers and is limited to remote rural centers upstream from the Lahdar River, but grazing is predominant.
- Mixed, predominantly human for stations S4, S6, S7, and S8 as the water in these areas is loaded with liquid sewage waste in addition to grazing.

Exclusively human for stations S3 and S5 and this is due to the proximity of the sewage discharge points respectively of the city of Taza and the center of Oued Amlil.

The bacteriological quality of the Innaouene river water was evaluated based on the joint decree of the Minister of Equipment and the Minister in charge of land use planning, urbanism, housing, and the environment n° 1275-02 of 17 October 2002 defining the quality grid of surface water presented in the appendix, and which was published in the official bulletin of 5 December 2002 (Ouyang et al., 2022).

The comparison of the obtained results with the quality grid enabled to represent the quality status of the surface water in the study area Figures 23 and 24. Overall, the analysis of these two Figures allows drawing the following conclusions:

- The bacteriological quality is characterized by spatial variation.
- Bacteriological contamination is essentially linked to the pollution of human origin during this period of the year.
- The quality of the surface water in the study area is very poor at the sites (S3 and S5) which are exposed to definite pollution from sewage, and average to very poor at the other sites.

Table 6. Quantitative ratio R (FC/FS)

Stations	S1	S2	S3	S4	S5	S6	S7	S8
FC/FS	0.98	0.94	4.10	2.92	6.78	2.94	2.95	2.92

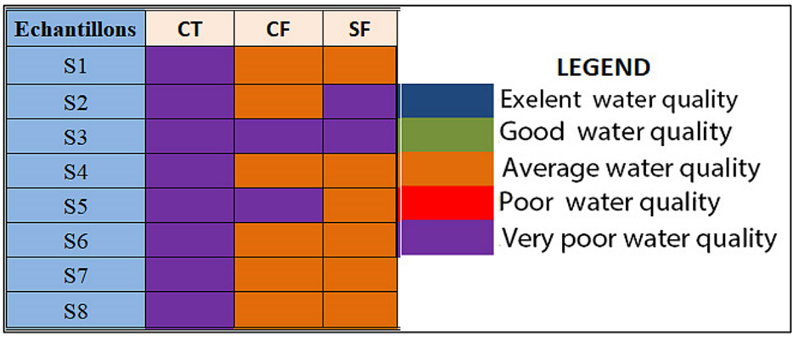

Figure 23. State of the bacteriological quality of the sites

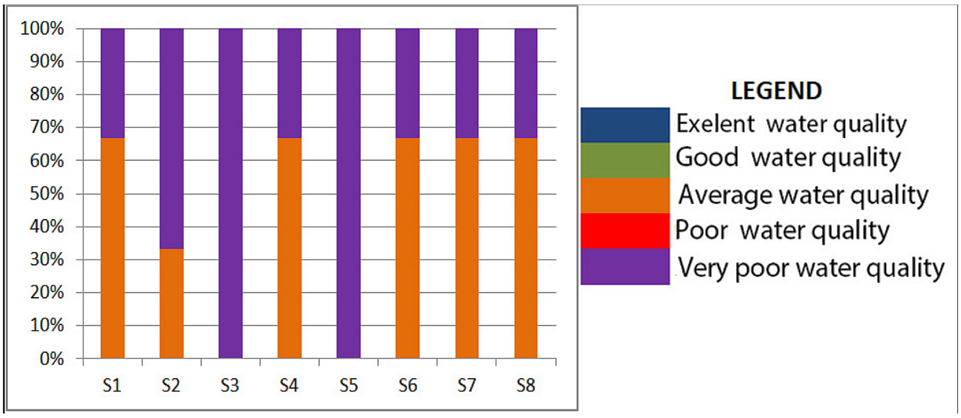

Figure 24. Percentages of bacteriological quality classes according to the sites sampled

CONCLUSIONS

The outcomes of this study have successfully unveiled and assessed the physicochemical and bacteriological quality of the Innaouene River waters. The intricate interplay between the geological formations draining into this watercourse and the impact of anthropic activities, marked by untreated domestic, industrial (primarily margine-related), and agricultural discharges, profoundly influences its water quality. In scrutinizing the physicochemical composition, the conducted analysis reveals elevated levels of pollution indicators across the majority of stations, notably compromising the overall water quality. The microbiological examination further exposes a noteworthy contamination, with heightened counts of total germs at 37 °C (GT), coliforms (CF), coliforms at 37 °C (CT), and faecal streptococci (SF). Remarkably, the geological facies, predominantly soft marl, traversed by the Innaouene River plays a pivotal role in self-purification. This natural phenomenon contributes significantly to improving water quality, transforming it from a state of pronounced degradation (station S3) to a more moderate condition at the entrance of the Idriss I dam (station S8). This positive transformation occurs despite the substantial mineralization and pollution inputs stemming from urban and rural centers along the river's course.

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