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Assessment of the Bacteriological and Physicochemical Water Quality of the Inaouene and Larbaa Rivers (Taza, Morocco)

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Abstract: In the region of Taza and Oued Amlil cities, an alarming environmental issue related to wastewater and solid wastes unfolds in the absence of an effective management strategy. Large quantities of wastewater from Taza (5.03 mm^3) and Oued Amlil (4.2 mm^3) in 2022 find their way directly into the river environment. In response to this critical situation, we conducted a bacteriological pollution survey of the waters in the Inaouene River and its tributary, Larbaa stream, to further evaluate potential damage during two distinct periods (July 2022 and January 2023). Our investigation revealed a concerning level of contamination. Mesophilic Flora at 37°C (TAMF), Total Coliforms (TC), Fecal Coliforms (FC), E. coli (E.C), Fecal Streptococci (FS), Sulfite-reducing Clostridium (ASRC), Intestinal Enterococci (IE), Pseudomonas aerugenosa (PA), Staphylococcus aureus (SA), and even Salmonella were found to be at notably high concentrations. This contamination wasn't confined to one location; both the Inaouene River upstream and the Larbaa stream downstream were impacted. Furthermore, bacterial contamination portrays a decreasing gradient from upstream to downstream. The statistical analysis of the physicochemical and bacteriological data uncovered significant temporal variations (p-value < 0.05) for TC, FC, EC, SA, PA, T, TUR, EC, and DO. Conversely, some factors like ASRC, TAMF, FS, IE, and PH showed no statistically significant temporal variations (p-value > 0.05).

Keywords: Inaouene, pollution, spatial and seasonal variations, wastewater.

Introduction

Demographic development and human activities are contributing to the degradation of aquatic environments that receive wastewater from riverside settlements (Connor, 2015). Wastewater contains both organic and inorganic pollutants, as well as biological contaminants such as pathogenic microorganisms (Kostyla et al., 2015). Bacteriological contamination in water is a significant public health concern. Very few cases of waterborne diseases have been recorded in recent years in Morocco (Ministry of Health, 2020). However, due to the drought and lack of wastewater treatment in the Inaouene watershed, it is crucial to monitor and control the water resources quality. These waters are utilized for drinking water production, livestock watering, irrigation, and bathing, which can be a risk to human health. Waterborne diseases are commonly transmitted

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through the fecal-oral route, and individuals can become contaminated by consuming water or food contaminated with fecal matter, as well as by bathing or coming into contact with recreational water (Yongsi, 2018).

The most frequently used bacteriological indicators of water quality are total coliforms (TC), faecal coliforms (FC) and faecal streptococci (FS). They are considered indicators of recent fecal contamination (Attoui et al., 2016). In its middle course, the Inaouene receives domestic and industrial wastewater from Oued Amlil city (4.2 mm^3 in 2022), while discharges from Taza city (5.03 mm^3 in 2022) (Radetta, 2023) are carried by its tributary, the Larbaa stream. This study focusses on the bacteriological and physicochemical quality of the water in the Inaouene and Larbaa watercourses.

Materials and Methods

Study Area

The Inaouene watershed is located between the Middle Atlas and the Pre-Rif. It is characterized by an impermeable marly bedrock, more or less reinforced by sandstone and limestone banks (Vidal, 1977). The climate is semi-arid to sub-humid Mediterranean (ABHS, 2023). Rainfall shows a temporal distribution with a succession of dry and wet years (Tuel et al., 2020). The Inaouene River is known for the Driss I dam (34°07'N-04°40'W), built in 1973, that serves water for irrigation and generates hydroelectric power. The river assumes a pivotal socio-economic role in the region by serving as a vital water source for extensively developed agricultural irrigation along its banks and for livestock watering.

To assess the water bacteriological and physicochemical quality, six sampling stations (O_1, O_2, O_3, O_4, O_5, O_6) were strategically identified along the Inaouene River. Station O_1, situated downstream of the town's landfill site in Larbaa stream, serves as the initial point, with the remaining five stations systematically positioned along the course of the Inaouene River (Figure 1).

Water Sampling and Analysis Methodology

Two water sampling campaigns were carried out during the dry (July 2022) and wet (January 2023) seasons. Water samples were collected in sterile glass bottles and transported in a refrigerated cooler (± 4°C) to the Laboratory of Public Health-Environmental Health

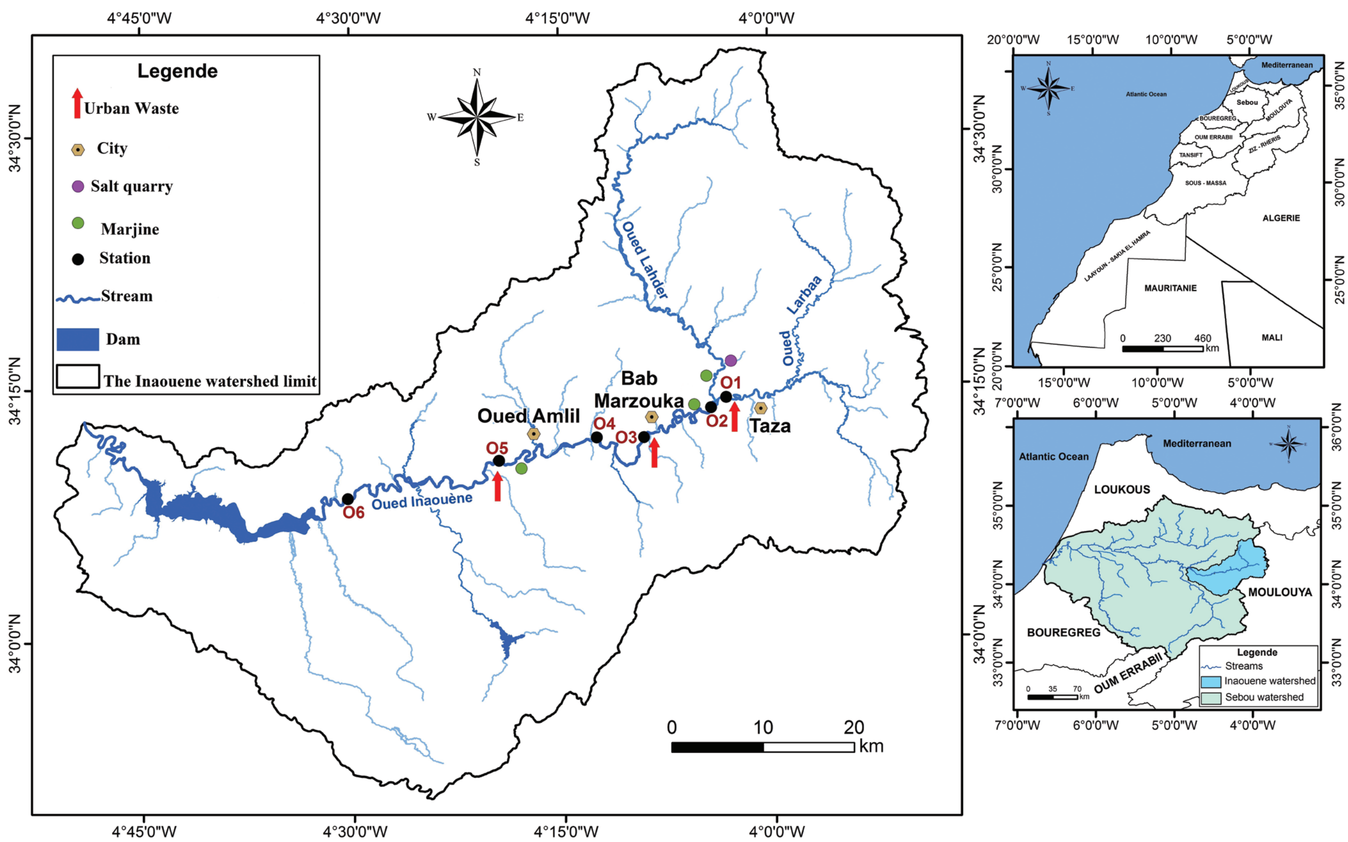

Table 2: Variable values and seasonal variation significance from the Kruskal-Wali's test

(TAZA Health and Social Protection Delegation) for bacteriological analysis. This analysis focussed on Total Aerobic Mesophilic Flora (TAMF), Total Coliforms (TC), Fecal Coliforms (FC), E. coli (EC), Fecal Streptococci (FS), Sulfite-reducing Clostridium (ASRC), Intestinal Enterococci (IE), *Pseudomonas aerugenosa* (PA), *Staphylococcus aureus* (SA) and *Salmonella* spp., as determined by the Moroccan standards (SEEE, 2007) (Table 1). Three samples were simultaneously filtered for analysis. Beforehand, each sample was serially diluted from 10^{-1} to 10^{-6} with sterile distilled water twice. Typical colonies were counted directly after incubation.

In order to assess the water physicochemical quality, we conducted in situ analysis of five parameters: temperature (T), electrical conductivity (EC), and pH using a multi-parameter analyzer Type CONSORT - Model C535, turbidity (Tur) using a turbidimeter Type

Table 1: Analysis methods for bacteriological indicators

Germs	*Culture medium and biochemical tests*	*Temperature and incubation time*	*Reference*
Total Coliforms (TC)	Lactose TTC agar with tergitol 7 (LAT)	36± 1 °C / 24h	NM ISO 9308-1 RI (ranking index) 03.7.003 (2007)
	Oxidase test	--------------	
Faecal Coliforms (FC)	Lactose TTC agar with tergitol 7 (LAT) Oxidase test	44 ± 1 °C / 24h	NM ISO 9308-1 RI 03.7.003 (2007)
Escherichia coli (E.C)	Lactose TTC Agar with Tergitol7 (LAT)	36± 1 °C / 24h	NM ISO 9308-1 RI 03.7.003 (2007)
	Oxidase test	---------------	
	Indole test	44± 1 °C/ 24h	
Faecal Streptococci (FS)	Slanetz and Bartley Agar (SBA)	37± 1 °C/ 48 h	NM ISO 7899- 2 RI 03.7.006 (2007)
Intestinal Enterococci (IE)	Slanetz and Bartley Agar Bile EsculineAzide agar (BEA)	37± 1 °C/48 h 44°C ± 0.5 °C / 2h	NM ISO 7899- 2 RI 03.7.006 (2007)
Anaerobic Sulfite-Reducing Clostridium (ASRC)	Sulfite –Polymexin-Sulfadiazine (SPS)	75± 5 °C/15 min 37°C/ 24 - 48h	NM ISO 6461-2 RI 3.7.004 (2007)
Total Aerobic Mesophilic Flora (TAMF)	Yeast Extract Agar (YEA)	36°± 1 °C/ 24 - 48 h	NM ISO 6222 RI 3.7.005 (2007)
Staphylococcus aureus (SA)	Baird-Parker Agar (BPA)	37°C± 1 °C/ 24 h -48h	NM 03.7.036 (2012)
	Gram staining , Catalase test	---------------	
	Coagulase test	37± 1 °C / 4h-24h	
Pseudomonas aeruginosa (PA)	Cetrimide Agar (CA)	42°C± 1 °C/ 48 h	NM ISO 16266 RI 03.7.035 (2012)
	Gram staining ,Oxidase test ,	---------------	
	API 20NE	37± 1 °C / 24h	
Salmonella spp.	Buffered Peptone Water (BPW)	37± 1 °C / 24h	NM ISO 19250 RI 03.7.050 (2012)
	Rappaport-Vassiliadis Soy Broth (RVS)	42 ± 1 °C / 24h	
	Hektoen Enteric Agar (HEA)	37± 1 °C / 24h	
	Gram staining,Oxidase test ,	---------------	
	Urea test	37± 1 °C / 24h	
	API 20E	37± 1 °C / 24h	

HACH-Model 2100P, and dissolved oxygen (DO) using an oximeter WTW Oxi 3310 (1/100). All instruments used in the measurements were calibrated before each sampling campaign.

Data processing

To enhance the interpretation of the data, a descriptive statistical study was conducted on the results obtained from bacteriological and physicochemical analyses. The seasonal difference within the bacteriological and physicochemical data were assessed using the Kruskal–Walli's test (Walpole, 2022), in conjunction with Dunn's test and the application of Bonferroni's correction for multiple comparisons.

A Principal Component Analysis (PCA) with a Varimax rotation was performed on a log-transformed matrix (log x+1) of 14 parameters (T, pH, EC, Tur, DO, TC, FC, FS, IE, E.C, TAMF, ASRC, PA, and SA) and 12 samples to identify relationships between bacteriological and physicochemical variables and the spatiotemporal variations of water quality along the Inaouene River. The Varimax rotation was applied to maximize the variances sum of the squared correlations between variables and factors. This rotation facilitates interpreting the results and identifying possible relationships between variables that determine water quality. The statistical analyses were conducted using XLSTAT software, version 2018 (Addinsoft, 2018).

Results and Discussion

Bacteriological and Physicochemical Quality

The physicochemical evaluation of the Inaouene River water quality revealed fluctuations in water temperature ranging from 3 (O_4) and 4.5 °C (O_2) in January 2023, and from 27.5 (O_3, O_4, O_5) to 28°C (O_1, O_6) in July 2022. The observed temperature variations display a significant correlation with air temperature dynamics and water depth across the study sites. This relationship suggests that fluctuations in air temperature directly influence water temperature, and that the depth of the water plays a critical role in moderating these temperature changes. This interplay between air temperature, water depth, and temperature variation is crucial for understanding the thermal dynamics within these aquatic ecosystems (Harvey et al., 2011). The elevated water temperatures observed during the dry period in July 2023 may facilitate self-purification processes and increase the sedimentation rate of suspended matter (Moumouni, 2005). Spatially, a discernible pattern emerges, in which water temperature decreases progressively along the longitudinal profile, due to exchanges with the air and the substrate. However, a marginal increase is observed at stations O_1, O_2, and O_5, which receive wastewater from urban centers. The application of Kruskal-Wallis and Dunn's tests revealed statistically significant temporal variations in water temperature (p-value < 0.05) and disparities among sampling stations.

The pH values exhibit variability across different stations (Table 2) ranging from 7.22 to 7.77. In July, the extreme values range from 7.12, measured downstream (O_6), to 7.45, recorded at station O_5. Statistical analysis indicates that the spatial differences in water pH are not statistically significant (p-value > 0.05). However, the subtle spatial variation observed in water pH at stations O_1, O_2, and O_5 could be linked to the nature of the substrate that the waters traverse. Decomposition processes, particularly those involving organic matter from animals, can release various compounds that affect water temperature and chemistry. Human activities, such as industrial discharges and agricultural runoff, also contribute to these variations. Furthermore, the geochemical characteristics of the substrate, such as the presence of carbonate minerals, can impart a basic (alkaline) quality to the water, influencing its overall pH levels (Ben Abou, 2014). Importantly, these water pH values fall within the range of 5 to 9 that allow normal development of flora and fauna (Blinda, 2007).

The electrical conductivity (EC) of water exhibits sustained elevation (Table 2) ranging from 2134.28 $\mu S.cm^{-1}$ (O_6) and 3190.34 $\mu S.cm^{-1}$ (O_1). Notably, spatial heterogeneity in this parameter is observed among distinct sampling stations (p-value < 0.05). The high values of water EC at the upstream stations (O_1 and O_2) and the station O_5, positioned immediately downstream of the discharge point, are indicative of pronounced water mineralization. This heightened mineralization is attributed primarily to the decomposition of organic matter derived from agricultural and domestic sources. The breakdown of organic materials from these sources releases minerals and nutrients into the water, increasing its mineral content. Agricultural runoff often contains fertilizers and other organic compounds, while domestic wastewater can include a variety of organic materials from household activities. These inputs lead to increased mineralization as the organic matter decomposes, releasing various dissolved minerals and ions into the water (Barakat et al., 2016).

The dissolved oxygen (DO) concentration in water demonstrates a significant increasing gradient along the Inaouene River, ranging from 1.3 mg $O_2.L^{-1}$at

Table 2: Variable values and seasonal variation significance from the Kruskal-Wali's test

		ASRC (UFC/100 ml)	*TAMF (UFC/100 ml)*	*TC (UFC/100 ml)*	*FC (UFC/ 100 ml)*	*E.C (UFC/100 ml)*	*FS (UFC/100 ml)*	*IE (UFC/100 ml)*	*SA (UFC/100 ml)*	*PA (UFC/100 ml)*	*T (° C)*	*PH*	*TUR (NTU)*	*EC (µS. cm^{-1})*	*OD (mg $O_2.L^{-1}$)*
O1	July 2022	6.710^{4}	4.3510^{6}	7.710^{5}	6.410^{5}	2.610^{4}	3.810^{4}	4.310^{4}	6.310^{4}	7.610^{4}	28	7.33	13.34	3190.4	0.5
	January 2023	6.3104	3.3110^{6}	710^{4}	3.410^{4}	1.210^{4}	3.210^{4}	310^{4}	2.110^{4}	2.210^{4}	4.4	7.22	33.12	1200.3	2.1
O2	July 2022	6.6104	4.310^{6}	7.510^{5}	6.310^{5}	2.510^{4}	3.810^{4}	410^{4}	5.410^{4}	7.610^{4}	28	7.3	15.11	3104.6	0.5
	January 2023	610^{4}	3.310^{6}	6.810^{4}	3.210^{4}	1.110^{4}	3.210^{4}	2.910^{4}	210^{4}	210^{4}	4.5	7.28	27.5	1130.5	2.5
O3	July 2022	$4.6.10^{4}$	310^{6}	6.410^{5}	1.4610^{5}	2.610^{4}	2.910^{4}	3.710^{4}	4.710^{4}	3.910^{4}	27.5	7.43	19.34	30001	0.67
	January 2023	310^{4}	1.810^{6}	5.210^{4}	2.310^{4}	610^{3}	1.610^{4}	610^{3}	1.410^{4}	5.810^{3}	3.5	7.35	25.3	1123.3	2.76
O4	July 2022	2.310^{4}	2.810^{6}	3.810^{5}	1.5910^{5}	1.610^{4}	1.710^{4}	7.110^{3}	1.810^{4}	1.910^{4}	27.5	7.13	45.56	2675.5	0.89
	January 2023	$2\ 10^{4}$	4.110^{5}	3.1310^{4}	1.210^{4}	2.810^{3}	210^{3}	510^{2}	810^{3}	10^{3}	3	7.45	67.3	810.2	3.02
O5	July 2022	4.310^{4}	410^{6}	6.710^{5}	4.810^{5}	2.110^{4}	2.410^{4}	9.510^{3}	2.710^{4}	7.810^{4}	27.5	7.45	20.76	2777.2	0.63
	January 2023	310^{4}	3.610^{6}	4.710^{4}	3.110^{4}	110^{4}	710^{3}	410^{3}	1.910^{4}	10^{4}	3	7.54	47.33	1200.2	2.22
O6	July 2022	2.810^{4}	3.310^{6}	1.910^{5}	4.110^{4}	110^{4}	1.110^{4}	4.310^{2}	10^{4}	410^{4}	28	7.12	33.12	2134.3	1.3
	January 2023	0.710^{4}	1.410^{5}	8.910^{3}	6.510^{3}	2.210^{3}	5.310^{2}	210^{2}	10^{3}	7.210^{3}	4.5	7.77	50.23	660.7	3.45
p-value*		0.249	0.142	0.009	0.009	0.0212	0.117	0.174	0.047	0.016	0.007	0.142	0.045	0.009	0.009

*Kruskal-Walis p-value less than 0.05 is statistically significant.

upstream station O_1 to 2.38 mg $O_2.L^{-1}$ at downstream station O_6. This observed pattern reflects the intrinsic self-purification capacity of the Inaouene River waters (Sghiouer et al., 2023). Nevertheless, the stations downstream the wastewater discharge points (O_1, O_2 and O_5), exhibit the lowest levels of oxygenation, a phenomenon attributed to the influence of localized anthropogenic impacts. Over time, a significative decline in oxygenation is evident during dry periods by critical values ranging from 0.4 to 1.5 mg. L^{-1}. This decline is attributable to the decreased solubility of oxygen, a consequence of elevated temperatures (Truesdale et al., 1955). The wet period in January 2023 registers the highest levels of water oxygenation, a phenomenon attributed to the combined effects of precipitation and enhanced oxygen exchanges with the atmosphere. Increased rainfall contributes to greater water turbulence and mixing, which facilitates the dissolution of oxygen from the atmosphere into the water. Additionally, the influx of fresh rainwater can introduce more dissolved oxygen, further elevating oxygen levels in the water. This combination of factors during the wet period leads to optimal conditions for high water oxygenation.

The turbidity levels in the water exhibit a significant spatial variation (p-value <0.05). Particularly, the highest turbidity values were observed downstream, notably the station O_4 (Table 2). This pronounced turbidity at station O_4 is likely attributable to the presence of a fluvial sand quarry. Temporally, there is a significant seasonal variation in water turbidity, with an observed increase during the wet period (January) and a decrease during the dry period (July) (p-value < 0.05). The elevated turbidity during the wet period can be attributed to the agricultural land leaching along both banks of the Inaouene River. Runoff from agricultural fields introduces soil particles, nutrients, and other sediments into the river, increasing its turbidity. Additionally, the suspension of bottom particles, influenced by alterations in flow dynamics due to increased rainfall and water flow, contributes to the heightened turbidity during this period. The combined effect of surface runoff and disturbed sediments results in the noticeable increase in water turbidity during the wet period (Paaijmans et al., 2008).

In general, the determined values for temperature T, pH, EC, and DO consistently fall within the permissible limits outlined in the irrigation standard across all monitoring sites. A comparison of the temperature data with the Moroccan water quality grid (SEEE, 2002), designates the surface water quality at all stations as excellent during the winter period and as average during the dry period. Concurrently, pH results for all sites, when compared with the Moroccan surface water quality grid, signify that the evaluated water quality ranges from average to excellent. Furthermore, an examination of EC data in relation to the Moroccan surface water quality grid (SEEE, 2002) discloses that water quality in the summer months is characterized as mediocre to very mediocre. In contrast, the values recorded during winter for sites O_1 to O_5 and O_6 are categorized as good and very good quality, respectively.

Nevertheless, comparison of the DO data with the Moroccan surface water quality grid (SEEE, 2002) reveals that the waters assessed during the dry period are classified as mediocre (O_6) and very mediocre (O_1 to O_5) quality. Conversely, during the wet season, the DO values categorize the water quality at sites O_1, O_2, O_3 and O_5 as mediocre, while O_4 and O_6 are classified as average quality.

This discernible seasonal variation in physicochemical water quality underscores the dynamic nature of the aquatic ecosystem and highlights the need for comprehensive monitoring and management strategies to ensure the maintenance of water quality standards.

Table 2 presents bacteriological data. The most substantial bacteriological contamination was noted during dry period at the station O_1 (Larbaa stream), O_2 (Inaouene River upstream) and O_5 (Oued Amlil city downstream). The contamination levels follow the subsequent order: TAMF>TC>FC>ASRC >FS. *Salmonella* testing yielded positive results at both stations O_1 and O_2, and negative at all other monitoring stations.

Spatially, the investigation revealed the highest levels of bacteriological contamination in monitoring stations situated immediately downstream of the discharge point, specifically within the Inaouene watershed upstream (O_1, O_2) and downstream of Oued Amlil city (O_5). Several studies consistently underscore the detrimental impact of direct wastewater discharge into watercourses without prior treatment, leading to compromised water quality characterized by elevated levels of total coliforms, fecal coliforms, and fecal streptococci. Untreated wastewater introduces a high load of pathogens and nutrients into water bodies, promoting the proliferation of these bacteria. This contamination not only degrades the water quality but also poses significant health risks to humans and wildlife. Proper wastewater treatment is essential to mitigate these impacts and maintain the ecological and sanitary quality of watercourses (Bou Saab et al., 2007). Notably, downstream of the confluence points of the Lakhal and Inaouene rivers (O_4) and the Bouhlou and Inaouene rivers (O_6), a discernible reduction in bacterial content occurs, particularly during the wet period (January, 2023). This observed decline underscores the influential role of tributaries in mitigating bacteriological pollution through dilution. In conjunction with the tributary-induced pollution dilution, self-purification processes contribute to the reduction of bacteriological contamination (Ben Abou, 2014; Laaraj et al., 2022; Sghiouer et al., 2023).

However, despite these mitigating factors, the bacterial load at stations O_3, O_4 and O_6 remains relatively high. This persistence may be attributed to the presence of organic matter and soil bacteria, possibly exacerbated by the application of manure on riparian farmland. Statistical analysis, employing the Kruskal-Walli's test, demonstrates significant spatial variations in TC, FC, EC, SA and PA with a p-value < 0.05 (Table 2). Furthermore, pairwise comparisons using Dunn's test indicate statistical difference between the monitoring periods. In contrast, temporal variations in ASRC, TAMF, FS and IE charges are statistically insignificant (p-value > 0.05) (Table 2), as evidenced by pairwise comparisons using Dunn's test, indicating no discernible differences between the monitoring periods. The observed constancy bacterial load across both seasons is likely associated to temperature elevation during the dry period (July), which fosters optimal conditions for bacterial proliferation and multiplication. Concurrently, in the winter season, the primary causative factor for heightened bacterial contamination in water is inferred to be soil mobilization through leaching induced by runoff water (Bou Saab et al., 2007).

Comparative analysis of the microbial concentrations against the World Health Organization's recommended limit value of 10^3 colony-forming units per 100 milliliters (CFU/100 ml) for water designated for irrigation, as stipulated by the SEEE (2007), indicates the unsuitability of the assessed water for crop irrigation. Conversely, comparison of the bacteriological data and the Moroccan surface water quality grid values (SEEE, 2002) reveals that all surveyed stations exhibited poor water quality during July 2023. According to these standards, the bacteriological quality assessment designates the Larbaa tributary (O_1), upstream of the Inaouene River (O_2), O_3, and the locale downstream of the discharges from Oued Amlil city (O_5) as exhibiting a classification of very poor quality during both sampling periods. This deterioration in water quality is indicative of the adverse impacts from domestic and industrial wastewater discharges. In the wet period (January), the coliform (FC) load classifies the water quality at stations O_4 and O_6 as moderate, while total coliform (TC) load categorizes the stations O_4, O_5, and O_6 as exhibiting moderate quality. Notably, the specific *fecal streptococci* (FS) load determines a moderate water quality status for stations O_4 and O_5, but designates the station O_6 as maintaining good water quality.

A comparison of FC and FS loads across diverse monitoring stations and throughout the study periods reveals a consistent pattern wherein FS load consistently remains low compared to FC load. This observed phenomenon is attributed to the reduction in FS contamination, facilitated by the influence of abiotic factors within the natural environment. Abiotic factors such as sunlight, temperature, pH, and sedimentation can significantly impact the survival and persistence of *fecal streptococci* (FS) in water bodies. These environmental conditions often lead to a more rapid decline in FS populations compared to fecal coliforms (FC), resulting in lower FS loads consistently observed across the study sites. These findings are concordant with Hunter et al. (1999) works, which independently corroborate the trend of declined FS loads relative to FC loads, underscoring the role of abiotic factors in the attenuation of FS contamination.

Contrasting our findings with those reported by Ben Abou (2014) within the same environmental context suggests that the bacteriological quality of the water has experienced a discernible deterioration over the years. In relation to other water bodies, the bacteriological contamination levels observed in the Inaouene River are relatively lower than those found by Hayzoun et al. (2014) in the Sebou and Fez Rivers. However, this contamination is comparatively higher than the levels reported by Idrissi et al. (2018) in the Fez and Sebou Rivers subsequent to the implementation of wastewater treatment plant of Fez city.

Bacteriological and Physicochemical Variables

Interrelationship

Examination of the interrelationships among diverse pollution indicators reveals a positive correlation between fecal contamination indicator bacteria and turbidity. These results are congruent with the findings of N'diaye et al. (2011) and can be attributed to the occurrence of suspended particles in water, including silt, clay, organic and inorganic matter, plankton, and microorganisms. These particulates serve as protective niches, sheltering bacteria and viruses from disinfection processes, as elucidated by Hudson (1962). Conversely, this fecal contamination indicator bacteria shows negative correlations with EC (Table 3). This last parameter offers insights into overall mineralization and provides a measure of salinity levels. Bennani et al. (2012) underscore that salinity is a significant stress factor for fecal pollution bacteria in saline environments. Furthermore, the fecal contamination indicator bacteria present also a negative correlation with water oxygenation (i.e., DO) (Table 3). This suggests that insufficient oxygen levels in the water may foster increased germ growth and multiplication (Couvert et al., 2019).

The application of Principal Component Analysis (PCA) on physicochemical and bacteriological dataset reveals that the D1 and D2 axes provide 92.71% of the ocumulative information (Figure 2). The spatial disposition of the monitored stations on the PCA plot axes, for the two seasonal periods, is indicative of their respective water quality status. Specifically, the stations O_1, O_2, O_3 and O_5 reveal elevated fecal contamination levels and concurrently show declined oxygenation rate of water compared to the stations O_4 and O_6 across both studied periods. In the wet period (January 2023), all stations are positioned on the negative segment of the D1 axis. Conversely, during the dry period (July 2022), these stations migrate to the positive portion of the D1 axis, denoting a discernible degradation in water quality during the drought conditions. This deterioration is notably manifested by a rise in fecal

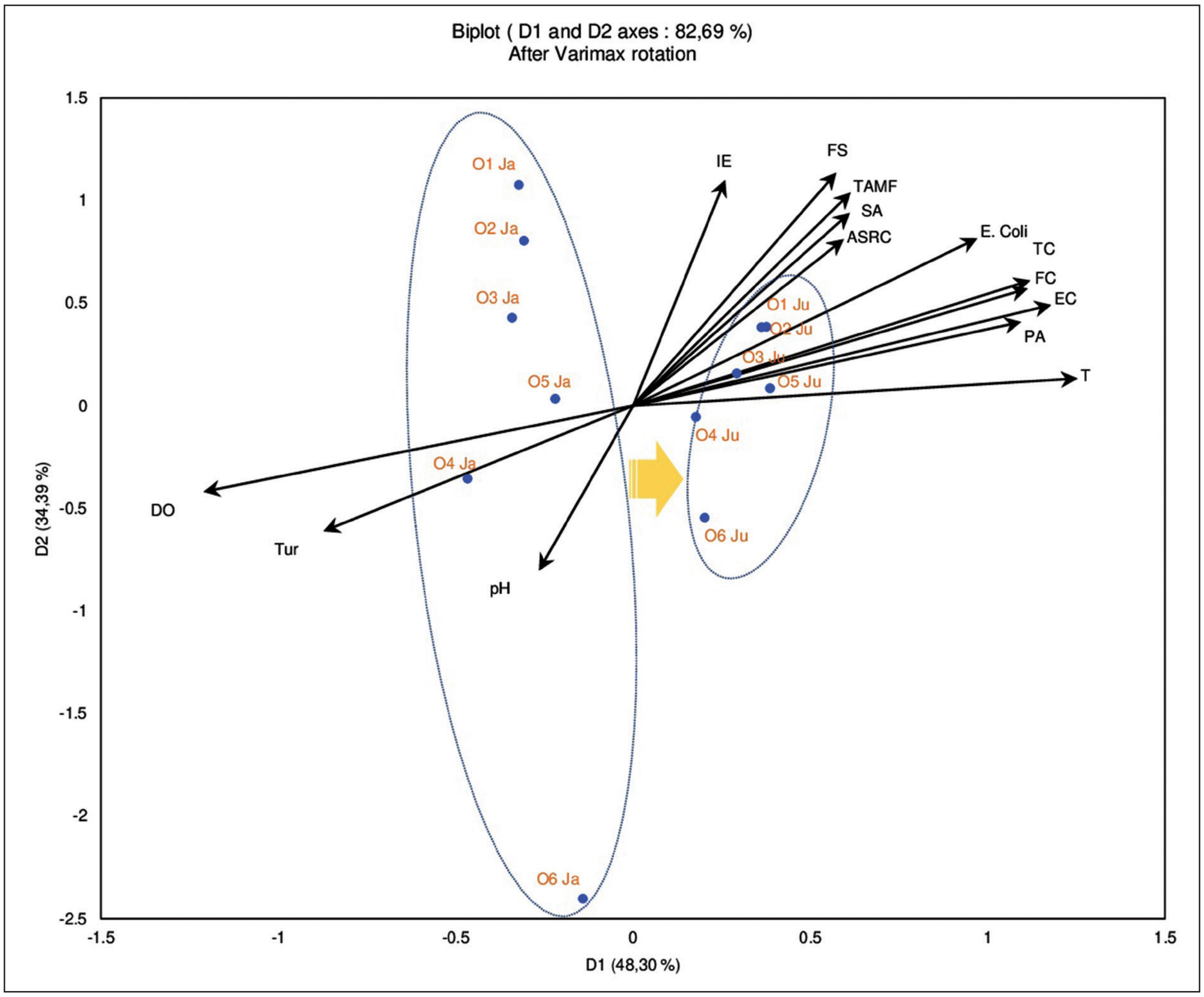

Figure 2: PCA biplot performed on the physicochemical and bacteriological data: Projection of parameters and studied stations on the F1*F2 factorial plane. T: Temperature, EC: Electrical Conductivity, DO: Dissolved Oxygen, Tur: Turbidity, pH, E.C: Escherichia coli, IE: Intestinal Enterococci, TC: Total Coliforms, FS: Faecal Streptococci, IE: Intestinal Enterococci, ASRC: Anaerobic Sulfite-Reducing Clostridium, TAMF: Total Aerobic Mesophilic Flora, SA: Staphylococcus aureus, PA: Pseudomonas aeruginosa; Dots: the stations O_1, O_2, O_3, O_4, O_5, O_6; Ja: January 2020; Ju: July 2023.

Table 3: Correlation matrix between bacteriological and physicochemical variables (Pearson (*n*)) (*Bold: significant correlation at alpha = 0.05*).

Variables	*T*	*PH*	*TU*	*EC*	*DO*	*ASRC*	*TAMF*	*TC*	*FC*	*EC*	*IE*	*FS*	*SA*
pH	-0.4142												
CE	0.9489	-0.4874											
TU	-0.6054	0.2371	-0.7282										
OD	-0.9467	0.3907	-0.9863	0.7313									
ASRC	0.4435	-0.2631	0.5824	-0.6393	-0.6000								
TAMF	0.5495	-0.6565	0.7348	-06319	-0.6723	0.7011							
TC	0.9085	-0.4989	0.9865	-0.7565	-0.9785	0.6688	0.7529						
FC	0.8451	-0.3604	0.9376	-0.7923	-0.9603	0.7077	0.7114	0.9557					
EC	0.7765	-0.4932	0.9154	-0.7807	-0.8990	0.7061	0.8889	0.9266	0.9050				
IE	0.2322	-0.3464	0.4903	-0.6167	-0.4967	0.6065	0.6381	0.5925	0.6167	0.7037			
FS	0.5155	-0.6746	0.7241	-0.7583	-0.6706	0.7228	0.9260	0.7749	0.7341	0.8898	0.8066		
SA	0.5532	-0.5188	0.7538	-0.5606	-0.7249	0.6018	0.7960	0.7928	0.7416	0.7855	0.6932	0.7691	
PA	0.8040	-0.3549	0.8271	-0.8080	-0.8343	0.6394	0.7146	0.8021	0.8199	0.8633	0.3846	0.7049	0.4666

contamination, mineralization, and temperature of the water, concomitant with a reduction in water oxygenation rates.

Conclusion

This study systematically investigated bacteriological and physicochemical attributes of water quality in the Inaouene River, receiving wastewaters and solid waste from riparian agglomerations. The findings revealed a concerning deterioration in the bacteriological quality of water in the Inaouene River. High contamination levels, especially during the dry period, indicate the impact of untreated wastewater discharge. Stations downstream of discharge points exhibit the highest contamination, emphasizing the need for effective wastewater management.

Despite some dilution and self-purification effects from tributaries (Lakhal, Zerg and Bouhlou streams), certain stations maintain relatively high bacterial loads, linked to anthropogenic and agricultural activities. The results of physicochemical and bacteriological analyses of the water indicated that the values of several parameters exceed Moroccan standards, which point out large fecal pollution and generally poor quality, and thus compromise their use in agricultural irrigation.

In summary, urgent interventions are needed to address the sources of contamination, enhance wastewater treatment, and improve water quality monitoring to safeguard the health of ecosystems and communities in the Inaouene River watershed.

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References

ABHS : Agence du Bassin Hydraulique de Sebou (2023). Les ressources en eau dans le bassin du Sebou, Fès.

Addinsoft (2018). XLSTAT statistical and data analysis solution. https://www.xlstat.com

Attoui, B., Toumi, N., Messaoudi, S. and S. Benrabah (2016). Degradation of water quality: The case of plain west of Annaba (northeast Algeria). *Journal of Water and Land Development*, **31(1):** 3.

Barakat, A., El Baghdadi, M., Rais, J., Aghezzaf, B. and M. Slassi (2016). Assessment of spatial and seasonal water quality variation of Oum Er Rbia River (Morocco) using multivariate statistical techniques. *International soil and water conservation research,* **4(4):** 284-292.

Ben Abou, M. (2014). Impact des déchets sur la qualité des ressources hydriques du bassin versant de l'Oued Inaouene et leur valorisation par compostage. Ph.D. Thesis, Sidi Mohammed ben Abdellah University, Fez.

Bennani, M., Amarouch, H., Boukanjer, A., Nadre, H., Lalaoui, M., Allali, M. and N. Cohen (2012). Influence des facteurs environnementaux sur les charges des bactéries fécales dans le littoral méditerranéen du Maroc.

Blinda, M., Bellaouchou, A., Fekhaoui, M., Barcha, S. E. and M. EL Morhit (2013). Evaluation de la contamination métallique des sédiments et des eaux superficielles du littoral Nord-Ouest du Maroc. Bulletin de l'Institut Scientifique, Rabat, **(35) :** 43-49.

Bou Saab, H., Nassif, N., Antione, G., Samrani, E., Daoud, R., Medawar, S. and N. Ouaïni (2007). Suivi de la qualité bactériologique des eaux de surface (rivière Nahr Ibrahim, Liban), Revue des sciences de l'eau / *Journal of Water Science,* **20(4) :** 341-352.

Connor, R. (2015). Le Rapport mondial des Nations Unies sur la mise en valeur de l'eau 2015 : l'eau pour un monde durable (Vol. 1). Éditions UNESCO.

Couvert, O., Divanac'h, M.L., Lochardet, A., Thuault, D. and V. Huchet (2019). Modelling the effect of oxygen concentration on bacterial growth rates. *Food Microbiology,* **77 :** 21-25.

Harvey, R., Lye L., Khan, A. and R. Paterson (2011). The Influence of Air Temperature on Water Temperature and the Concentration of Dissolved Oxygen in Newfoundland Rivers, *Canadian Water Resources Journal,* **36(2):** 171–192. DOI: 10.4296/cwrj3602849

Hayzoun, H., Ouammou, A., Saidi, O., Khalil, F. and L. Bouayyadi (2014). Evaluation de la qualité bactériologique et chimique du Sebou, Maroc (Assessment of the bacteriological and chemical quality of the Sebou River, Morocco). *Journal of Materials and Environmental Science,* **5(S2):** 2438-2443.

Hudson, H.E. (1962). High- quality water production and viral disease. *J. Am. Water Works Assoc.,* **54:** 1265.

Idrissi, N., Elmadani, F.Z., Ben Abbou, M., Taleb, M., El Rhazi, K., Nejjari, C. and Z. Rais (2018). Assessment of the physicochemical and bacteriological quality of oueds Fez and Sebou downstream of Fez after the launch of the wastewater treatment plant: Impact on health, *Morocco. J. Mater. Environ. Sci,* **9(4) :** 1182-1192.

Kostyla, C., Bain, R., Cronk, R. and J. Bartram (2015). Seasonal variation of fecal contamination in drinking water sources in developing countries: A systematic review. *Science of the Total Environment,* **514:** 333-343.

Laaraj, M., Mesnage, V., Nabih, S., Mliyeh, M.M, Lahmidi, I. and L. Benaabidate (2022). Évaluation des métaux lourds dans les sédiments du bassin versant de l'Inaouène, en amont du 1er barrage d'Idriss, nord du Maroc. *Journal d'ingénierie écologique,* **23(9)**.

Ministry of Health (2020) [The data are provided by the Directorate of Epidemiology and Disease Control] Online, Available from: http://www.sante.gov.ma/Pages/ADM_Centrale/DELM.aspx .

Moumouni Djermakoye, H. (2005). Les eaux résiduelles des tanneries et des teintureries: caractéristiques physico-chimiques, bactériologiques et impact sur les eaux souteraines et les eaux de surface (Doctoral dissertation, Université de Bamako).

N'Diaye, A.D., Sid, M.O., Kankou, A.O. and K.I. Namr (2011). Evaluation des teneurs en coliformes fécaux par couplage avec des paramètres physicochimiques en ACP: cas des effluents de la STEP du périmètre maraicher de Sebkha, Nouakchott. *Cameroon Journal of Experimental Biology,* **7(1):** 35-40.

Paaijmans, K.P., Takken, W., Githeko, A.K. and A.F.G. Jacobs (2008). The effect of water turbidity on the near-surface water temperature of larval habitats of the malaria mosquito Anopheles gambiae. *International Journal of Biometeorology,* **52:** 747-753.

Régie autonome de distribution d'eau et d'électricité de Taza (RADEETA). (2023). Rapport des travaux de réalisation de la conduite d'interception global des eaux usées de la ville de Taza - Tranche 4, 43p.

Secrétariat d'Etat auprès du ministère de l'Energie des Mines, de l'Eau et de l'Environnement (2007) Fiche Sur le nouveau système d'évaluation de la qualité des eaux. Direction de la Recherche et de la Planification de l'Eau. Rabat, Maroc, 5 pp.

Secrétariat d'Etat auprès du Ministère de l'Energie, des Mines, de l'Eau et de l'Environnement, chargé de l'Eau et de l'Environnement (SEEE) (2002). Normes de qualité des eaux et à l'inventaire du degré de pollution des eaux. *Bulletin Officiel,* **5062:** 1501-1563.

Sghiouer, F.E., Nahli, A., Bouka, H. and M. Chlaida (2023). Evaluation of the Effects of Riparian Population Activities on the Physicochemical Quality of Water in a Mediterranean River: The Inaouene River (Taza, North East Morocco). *Asian Journal of Water, Environment and Pollution,* **20(2):** 93-100.

Truesdale, G.A., Downing, A.L., & Lowden, G. F. (1955). The solubility of oxygen in pure water and sea-water. Journal of Applied Chemistry, 5(2), 53-62.

Tuel, A. and E.A. Eltahir (2020). Why is the Mediterranean a climate change hot spot? *Journal of Climate,* **33(14) :** 5829-5843.

Vidal, J.C. (1977). Structure actuelle et évolution depuis le Miocène de la chaîne rifaine (partie Sud de l'arc de Gibraltar). *Bulletin de la Société Géologique de France,* pp. 789-796.

Walpole, L. (2022). Relationship Between Ceo Gender, Hospital Size, and Urban, Rural Location (Doctoral dissertation, Walden University).

Yongsi, H.B.N. (2018). Chapitre 2 Espace et territoires des maladies : Cas des diarrhées infectieuses à Yaoundé (Cameroun). *Santé et territoires en Afrique : inégalités de besoins de santé et d'accès aux soins*, 53.