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Quality assessment of the Fez city's surface waters using physicochemical and microbiological parameters

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Abstract

This retrospective study aimed to examine the region's surface water quality using physicochemical and microbiological properties of several surface waters in Fez, Morocco. Samples were collected from 33 distinct sites between June 2017 and August 2017 by Environmental Health Technicians using appropriate vials, which were stored and transported in a cooler at the Regional Diagnostic Laboratory Epidemiological and Environmental Hygiene Fez (RDLEEHF) and analyzed in accordance with prevailing standards. The pH ranged from 6.93 to 8.33, the temperature ranged from 8 to 10 °C, the electrical conductivity was between 578 and 1765 µS/cm, and the turbidity ranged from 0.25 to 5.15 NTU. All these values are consistent with the Moroccan standard, with the exception of turbidity. Sulfate concentrations were between 7.28 and 55.39 mg/L, nitrite 0.01-0.13 mg/L, and nitrate 0.02-5.72 mg/L. These values comply with the Moroccan standard and those of WHO. Orthophosphate was absent in all samples analyzed, and chloride levels were between 50 and 400 mgl/L. Most of the samples complied with the Moroccan standard for this type of water, with the exception of Oued Jawhara and Oued Sebou Boulaguone. For the microbiology analysis, our research showed that seven out of the thirty-three samples recorded more than >5000 CFU which is above the Moroccan standard of total coliform colonies. Ten samples recorded more fecal coliform than the Moroccan standard (< 20000), which shows that the samples were contaminated by fecal origin. The intestinal enterococci found in the samples showed that seven out of the thirty-three samples did not comply with the Moroccan standard.

Keywords: Water quality; Microbiological quality; Physicochemical quality; Public health.

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1. Introduction

Clean and safe water is a vital natural resource for sustaining life and promoting a healthy economy. Freshwater supply is a significant global challenge, with nearly one-third of the world's drinking water sourced from surface resources, including rivers, dams, lakes, and canals (Jonnalagadda & Mhere, 2001). These water sources are also ideal for disposing of household and industrial waste (Das & Acharya, 2003). The primary danger to sustainable water supply in Fez is the pollution of accessible water resources (Faouzi et al., 2023). Many diseases in the world today are caused by drinking polluted water, and approximately four billion cases of diarrhea were reported in 2000 in developing countries (Johansson et al., 2009; World Health Organization (WHO), 2000). More than three million people, mostly children, die annually from water-related diseases (WHO, 2000). Diarrhea is estimated to cause 1.5 million child deaths per year, mostly among children under five living in developing countries (Johansson et al., 2009). Morocco, like other Mediterranean countries, suffers climate change in a large part of its territory, which leads to the impoverishment of water resources exploited as drinking water and for irrigation (Rassam et al., 2014). Numerous populations in Morocco continue to depend on untreated or inadequately treated water from surface sources like rivers, lakes, and wells for their daily needs; consequently, there is a significant danger of waterborne infections (Moubchir et al., 2024; Rezouki et al., 2024; Abouabdallah et al., 2025). Surface water pollution

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continues to pose a serious problem for humans and their environment (Ougrad et al., 2024). The population growth in the city of Fez, climate change, industrial and agricultural development control, monitoring of surface water quality and groundwater should be of particular interest (Lalami et al., 2010). Various indicator species and pathogens employed to evaluate microbiological contamination of water encompass total coliform count, fecal coliform, fecal streptococci, coliphages, *C. perfringens*, *Salmonella*, and heterotrophic plate counts (Baird et al., 2012; Varol & Davraz, 2015). The limitations of several systems for routine monitoring have consequently resulted in a preference for some over others (WHO, 2017). *E. coli* is a commonly recognized indicator bacterium for potable water; despite criticism from certain experts, it remains extensively employed for the routine surveillance of home water supplies (Dufour, 1977; Odiyo et al., 2005). The United States Environmental Protection Agency (USEPA) has designated enterococci and *E. coli* as the most suitable indicator organisms for recreational water based on a study conducted at beaches in the United States (Schulze, 1986).

This study aims to evaluate the physicochemical and microbiological characteristics of surface waters' quality in Fez city, utilized by local communities for domestic, recreational, and agricultural purposes, in order to assess the extent, nature, and source of pollution impacting these waters and to prevent occurrences of waterborne diseases.

2. Materials and Methods

2.1. Study area and Sampling

Fez is a city in northern internal Morocco. It is the second largest city of Morocco after Casablanca, with a population of 1100000 inhabitants according to the 2014 Moroccan census (Haut Commissariat au Plan (HCP), 2014). Located northeast of Atlas Mountains, Fez is situated at the crossroads of the important cities of all regions. Water samples were collected from different surface waters in Fez city (lake, lagoon, etc.) as shown in figure 1 from June to August 2017, resulting in a total of thirty-three samples (S1-S33), the name of each site is provided in Appendix 1. Each sample was collected in sterile glass Schott bottles by submerging the sample container into the river at approximately 100–300 mm below the surface with an open end facing against the current flow direction (Odiyo et al., 2005). All samples were stored and transported in a cool box kept below 4 °C. All the samples were directed to the Regional Laboratory for Epidemiological Diagnosis and Environmental Health of Fez for analysis.

2.2. Physicochemical analysis

Surface waters were analyzed for pH, electrical conductivity, temperature, turbidity, nitrates, nitrites, sulfates, phosphates and chloride ions. All physico-chemical and microbiological assays were carried out following the protocol outlined by Rodier et al. (2009). Temperature' measurement (T °C) was carried out on site at the time of sampling using a digital thermometer plunged in the sample for three minutes. The pH was measured at 20°C using an ADWA brand AD1000 which was calibrated using buffer solutions at pH of 4 ±0.05, 7 ±0.05, 10 ±0.05. Electrical conductivity was measured using a Conductivity meter (WTW, model 330i) calibrated using a solution of KCl with a 0.01 mol. L^{-1}/1413 µS/cm by completely immersing its probe into the sample (The temperature of the samples must be brought to 25 °C). Turbidity was measured with a Tobcon turbidimeter at 25 °C. Sulfate ions content in the samples were determined by precipitation in hydrochloric medium in a barium sulfate state. The precipitate obtained was stabilized with a solution of Tween 20 or Polyvinylpyrrolidone which is a homogeneous suspension which is measured using spectrometer. The Chloride ions concentration is determined in a neutral medium using Mohr's method. For samples with a pH outside the range of 5 to 9.5, adjustment is made using either a nitric acid or sodium hydroxide solution. Chlorides are then determined in a neutral environment using a standard silver nitrate solution with potassium chromate as an indicator. The endpoint is marked by the appearance of the characteristic red hue of silver chromate. Orthophosphate: In an acidic medium, orthophosphate reacts with ammonium molybdate to form a phosphomolybdic complex, which is then reduced by ascorbic acid, producing a blue color measured spectrophotometrically.

Nitrate and Nitrite*:* The nitrate assay was determined using sodium salicylate, in which nitrates give sodium paranitrosalicylate, producing a yellow color measured using spectrometry. The nitrate assay was determined by Diazotization of 4-amino-benzenesulfonamide in acidic medium and its coupling with N- (1-naphthyl) 1, 2-diamino dichloride ethane which then gives a purple-colored complex that was measured with a spectrophotometer.

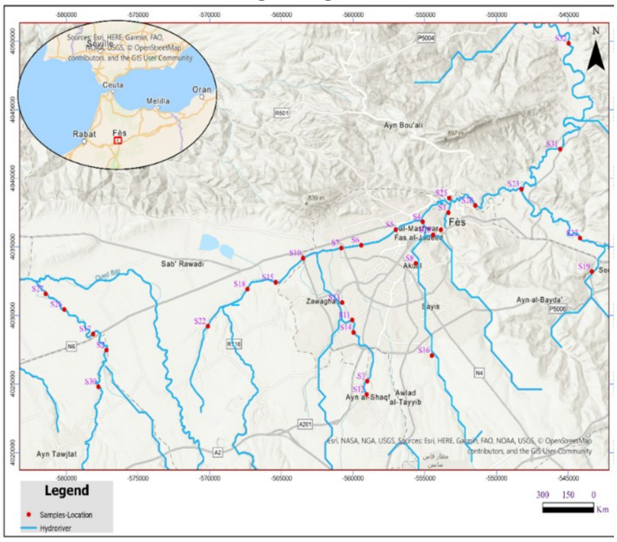

Figure 1. Map of the study area and sampling location.

2.3. Bacteriological analysis

All samples were analyzed using membrane filtration culture methods in accordance with Moroccan standard 03.7.001. Total coliforms (TC), fecal coliforms (FC) and intestinal enterococci (IE) were enumerated by 0.45 µm membrane filtration method. TC culture was performed on on TTC Tergitol 7 agar medium and incubation at 37°C for 24 hours. FC culture was on TTC Tergitol 7 agar but incubation was done at 44°C for 24 hours. Enumeration of IE was performed by culturing on Slanetz and Bartley (1957) medium after incubation at 37°C for 24 hours (SLANETZ & BARTLEY, 1957).

2.4. Statistical analysis

The statistical analysis of hydrochemistry data was performed using RStudio software (Version 2023.3.0.386) with the following procedures. Descriptive statistics were initially conducted using the "psych" program for all variables, yielding clear insights into data distribution and variability. Additionally, the data undergo Z-score normalization; this process is essential as it centers the variables around zero, facilitating the identification of commonalities based on patterns rather than absolute numbers. Subsequently, Principal Component Analysis (PCA) was conducted for all samples. PCA is chosen as a robust analytical instrument in this study piece because of its capacity to reveal underlying patterns in intricate hydrochemical and bacteriological datasets.

3. Results and discussion

The table 1 summarizes the results of all the parameters studied. The analysis of these results is carried out in sections 3.1 and 3.2. It should be noted that orthophosphate was absent in all samples analyzed, so this parameter will be excluded from the statistical study.

3.1. The physicochemical parameters

As can be seen, the analyzed waters have a very close and acceptable temperature for this type of water, as the temperature was found to be between 8 and 10 °C. The variation in temperature values may result from the significant altitude differences and the unique geographical characteristics of each sampling station. The pH results of the waters studied varied from 6.93 to 8.33. The difference observed between the pH could be explained by the difference in the geological nature of the lands crossed by these waters.

These results correspond to the findings of a study conducted by Akil et al (2014). The geological nature of the lands traversed by these waters may explain the slight difference in pH observed between the surfaces waters studied. The values indicate that the water samples exhibit alkaline properties. High pH levels are typically observed where water interacts with carbonate rocks. The measured pH, was in the range recommended by both the Moroccan standards (2007) and the USEPA Standards (2004).

The EC values of the samples vary between 578 and 1824 µS/cm. These values show that samples are quite rich in minerals and conform to the Moroccan standard, with a maximum of 2700 µS/cm, while the Guidelines for the preparation of drinking water 75/440/CEC recommended a maximum of 180 to 1000 µS/cm. The same range of values was also found by Lalami et al. (2010). The maximum EC values measured at Belagroune Ain kansara, Oued Sebou Boulaguone and Sidi Magdad Hamria, were 1824, 1765 and 1657 µS/cm respectively, which seems to be influenced by the rising ion content associated with the source of water and wastewater. However, EC values were higher than those recorded during the rainy season, likely due to the dilution of dissolved salts caused by the increased water volume, as observed by Lalami et al. (2010). The turbidity values measured during our research vary between 0.25 and 5.15 NTU. According to the Moroccan standard and WHO (2011), the permissible turbidity limit is 5 NTU. The results indicate that all measured turbidity values are within this limit, except Oued Ain Chkef upstream, Oued Ain Chkef downstream and Oued El Jawaher, with values of 5.22, 5.01 and 5.15 NTU respectively. These high values of turbidity are due to the discharging wastewater of the Fez city without any treatment. The concentrations (mg/L) of NO_3^- measured in water samples are between 0.02 and 5.72 mg/L, and the content did not exceed 6 mg /L, which is lower than the limit set by the WHO and the Moroccan standard (50 mg/L).

For these values, we can say that the water is of good quality. The particularly high nitrate concentrations measured in stations could be attributed to excessive nitrogen input from livestock effluents, agricultural runoff, and leaching of soils during the wet period. The nitrite NO_2^- content found in the various samples conformed to the Moroccan standard, which is 0.5 mg/L. The minimum value was 0.01 mg/L, and the maximum value obtained was 0.13 mg/L. These results do not correlate with Lalami et al. (2010) because they found a value of 11.37 mg/L for nitrite in Oued Fez. This might be due to the decrease of waste discharge into surfaces water. The measured sulfate SO_4^{2-} concentrations varied between 7.28 and 55.39 mg/L.

The sulfate concentrations measured at all locations comply with the permissible limits set by WHO and the Moroccan Standard (2007) and thus less than 250 mg/L. The minimum value was obtained in Jnane Sbil while the high values were determined in Belagroune Ain kansara. Elevated sulfate levels may be attributed to the decomposition of organic matter in the soil, leaching from fertilizers, and human activities, including the presence of sulfuric salts in domestic wastewater (Bahar & Yamamuro, 2008; Varol & Davraz, 2015).

Chloride concentrations ranged from 50 mg/L at Oued Ain Chkef to 400 mg/L at Jawhara. Most values were within the Moroccan surface water standard (2007) of 350 mg/L, except for those at Oued Jawhara and Oued Sebou Boulaguone, which reached 400 mg/L. Elevated chloride levels in water may result from contamination by municipal wastewater, leaching of saline residues from the soil, and/or human activities. This is particularly evident during the dry period when untreated urban sewage is directly discharged into the river, with minimal dilution effect.

3.2. Microbiological analysis

The TC test is the currently recommended method for assessing the presence or absence of coliform bacteria in water. They are not necessarily pathogenic, but their presence suggests the potential existence of harmful microorganisms. Figure 2 presents the results in the studied area. When total coliforms are detected, a FC test is necessary. Their presence indicates contamination with intestinal bacteria, suggesting the possible presence of pathogens.

Table 1. Descriptive statistics of physicochemical characteristics in samples.

	vars	n	mean	sd	median	min	max	se
T (°C)	1	33	9	0.866	9	8	11	0.150
pH	2	33	7.749	0.290	7.75	6.93	8.33	0.050
Turbidity (NTU)	3	33	1.916	1.496	1.45	0.23	5.22	0.260
EC (µS/cm)	4	33	1019.727	280.450	933	578	1824	48.820
Cl (mg/L)	5	33	151.515	81.590	120	50	400	14.203
SO_4 (mg/L)	6	33	28.594	10.392	26.57	7.28	55.39	1.809
NO_2 (mg/L)	7	33	0.068	0.058	0.06	0.01	0.31	0.010
NO_3 (mg/L)	8	33	1.597	1.499	1.4	0.02	5.72	0.260
FC (CFU)	9	33	65969.7	171301.9	4000	0	650000	29819.83
TC (CFU)	10	33	96000	193519.1	12000	0	700000	33687.34
IE (CFU)	11	33	31424.24	73879.56	3000	0	270000	12860.78

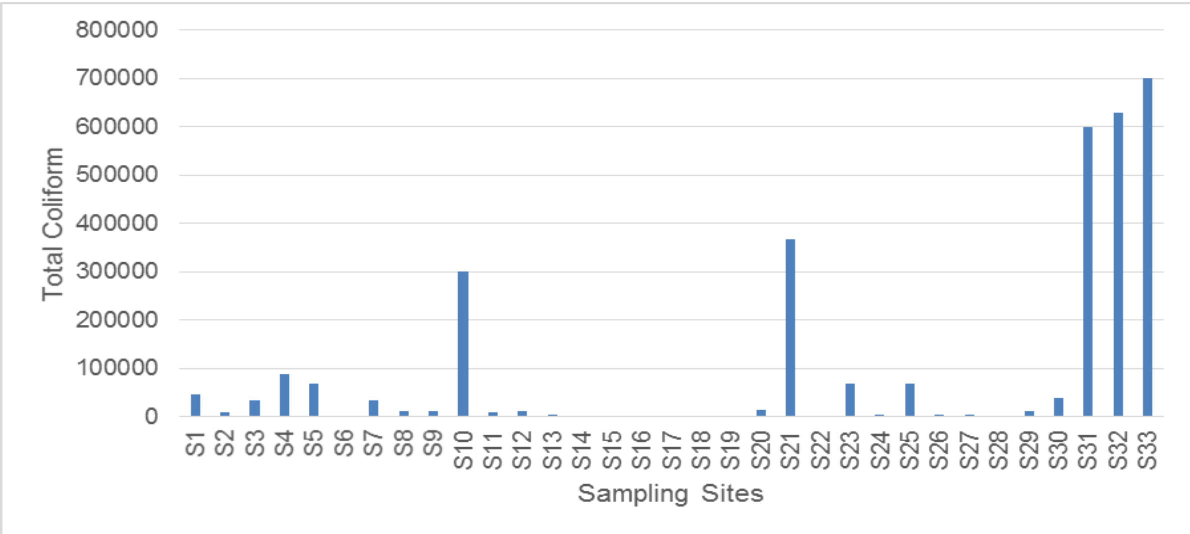

Figure 2. Number of total coliform present in each sample.

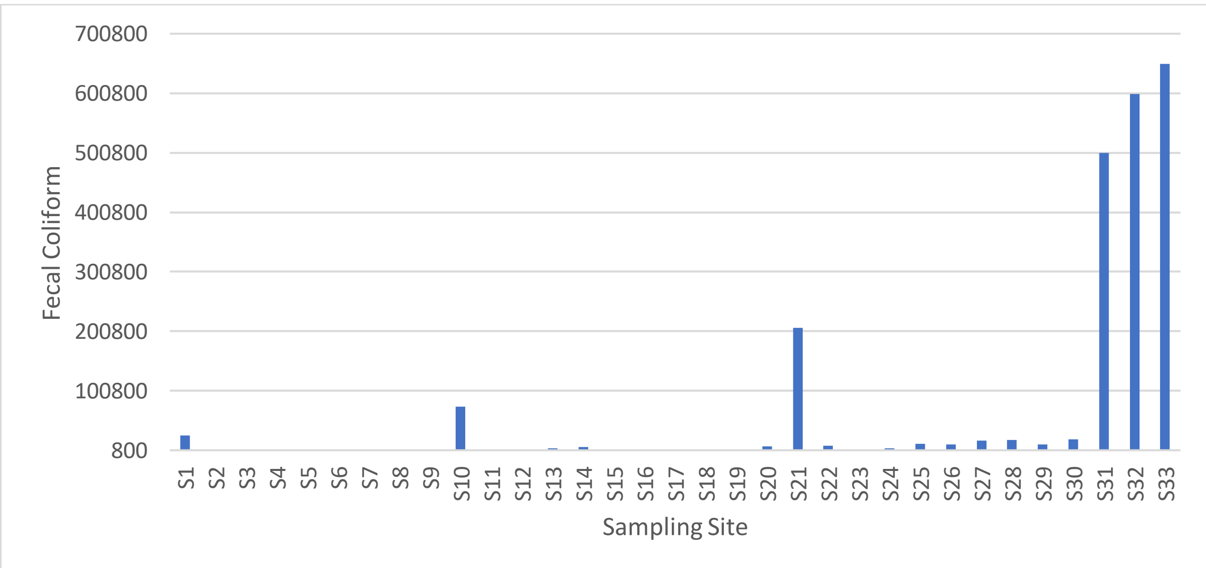

Figure 3. Number of fecal coliform present in each sample.

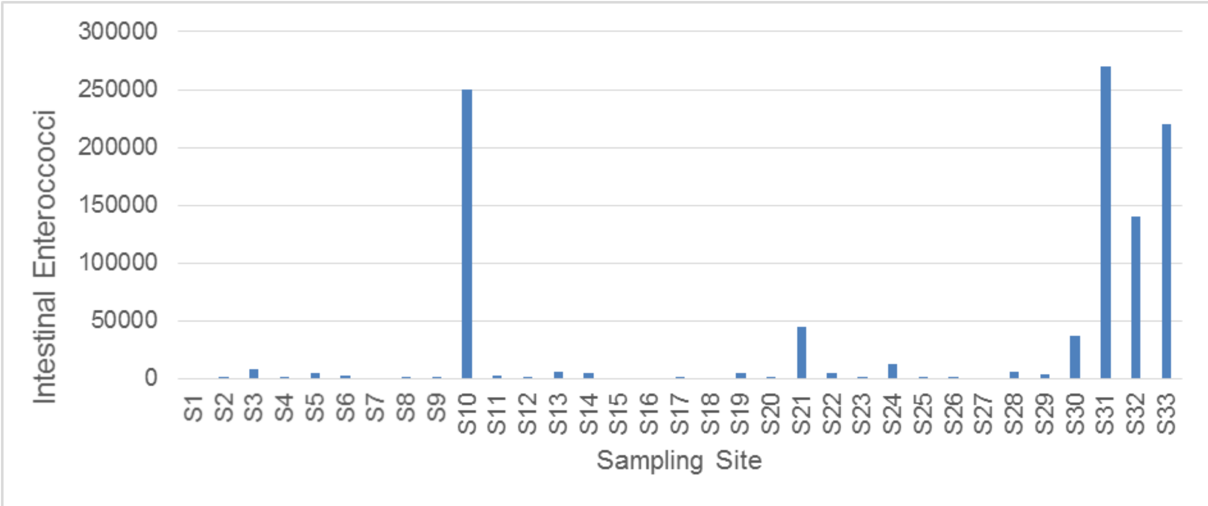

Figure 4. The number of intestinal enterococci present in each sample.

This test is used to determine whether the contamination originates from human or animal waste. This test commonly assesses whether a septic tank contaminates a local groundwater well. The results are shown in Figure 3. For FC the results show that five out of the 33 samples (Pond Zouagha, Oued Sebou Boulaguone, oued Fez aval, oued jawaher aval, Belagroune Ain kansara, Oued Sebou Ain Kansara, Sidi Magdad Hamria) do not comply with the Moroccan standards for surface water quality (2007). They recorded more than 50000 TC colonies (Figure 2). These results correlate with Lalami et al.(2010) because they also found a similar range of values. Ten samples (Oued jawhara, Pond Zouagha, Oued Sebou Boulaguone, oued Fez marjane, oued Fez aval, oued jawaher aval, oued nja, Belagroune Ain kansara, Oued Sebou Ain Kansara, Sidi Magdad Hamria) recorded more FC than the Moroccan standard (< 20000).

Figure 3 shows that 50% of samples were contaminated by fecal origin. Other samples complied with the Moroccan standards for water surface quality. The presence and intensity of microbial activities, particularly FC bacteria is influenced by the physicochemical parameters of surface water quality (Davies et al., 1995). The figure 4 shows the intestinal enterococci (IE) found in the samples, it shows that seven out of the thirty-three samples (Pond Zouagha, Oued Sebou Boulaguone, Oued jawaher aval, oued nja, Belagroune Ain kansara, Oued Sebou Ain Kansara, Sidi Magdad Hamria) do not comply with the Moroccan standard (< 10000). These results show that the samples were not recently contaminated since intestinal enterococci resist longer than *E. coli* bacteria.

3.3. Statistical analysis.

According to the PCA, represented in figures 5 and 6, the variables were correlated to two principal components, which accounted for 57.69% of the total variance. Which means that 57.69% of the stations cloud total variability is explained by the plane. The dimension 1 opposes stations such as 33, 31, 32 and 21 to stations such as 4, 12 and 3. The group in which the stations 33, 31, 32 and 21 stand is sharing high values for the variables TC, EC, FC, IE, Cl and SO_4 (sorted from the strongest), as shown in figure 6. The group in which the stations 4, 12 and 3 stand is sharing high values for the variable Turbidity, and low values for the variables SO_4, T, EC, TC, FC and IE, as shown in figure 6. Note that the variables FC, TC, IE, EC are strongly correlated with this dimension (correlation of 0.95, 0.94, 0.92 and 0.82 respectively). The correlation of each variable is provided in Appendix 2. This variable could therefore summarize itself the dimension 1. The dimension 2 opposes stations such as 23, 9 and 22 as shown in figure 5 to stations such as 4, 12 and 3.

The group in which the stations 23, 9 and 22 stand is sharing high values for the variables T and NO_2, as shown in figure 6; and low values for the variable pH. The group, in which the stations 4, 12 and 3 stand, is sharing high values for the variable Turbidity, and low values for the variables SO_4, T, EC, TC, FC and IE (variables are sorted from the weakest), as shown in figure 6. In figure 7, the PCA allowed us to make a classification of stations (sampling sites), revealing six main clusters

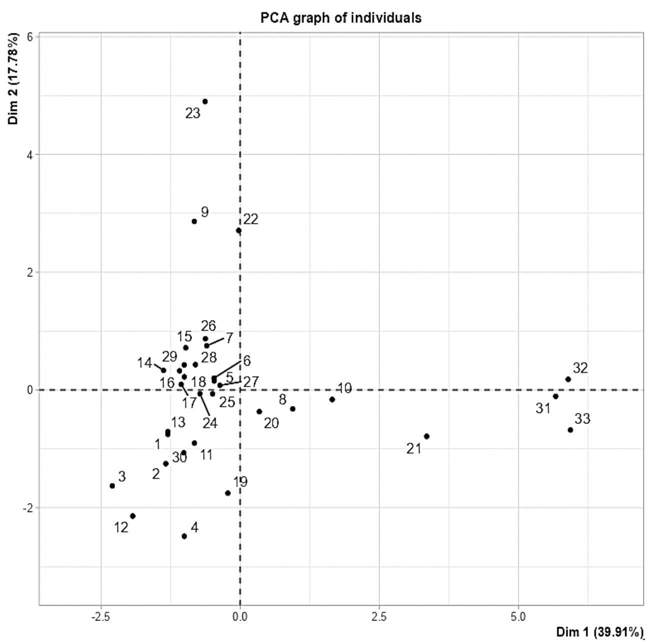

Figure 5. Sampling sites factor map (PCA).

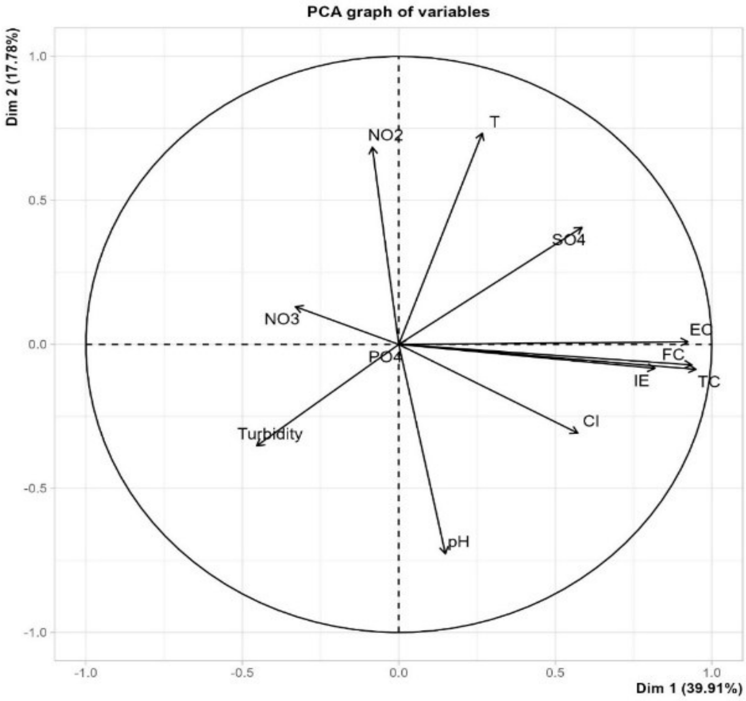

Figure 6. Variables factor map (PCA) the labeled variables are those the best shown on the plane.

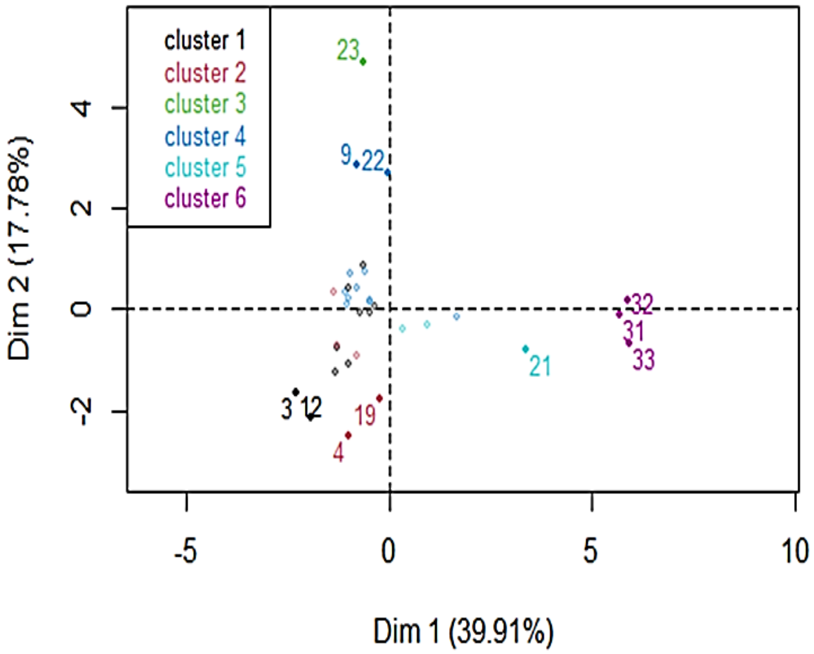

Figure 7. Ascending Hierarchical Classification of the sampling sites.

Cluster 1 is formed by sampling sites 3 and 12, which are characterized by high turbidity values and low T and Cl values.

Cluster 2 is formed by sampling sites 4 and 19. It is characterized by high NO3 and pH values and low SO_4 and NO_2 values.

Cluster 3 is formed by sampling sites such as 23, which are characterized by high values for the variables NO_2, T, and NO_3.

Cluster 4 consists of sampling sites such as 9 and 22, which are characterized by low pH and Turbidity values.

Cluster 5 is formed by sampling sites such as 21, which are characterized by high values for the variable Cl.

Cluster 6 is formed by sampling sites such as 31, 32, and 33. It is characterized by high values for the variables FC, TC, IE, EC, and SO_4.

4. Conclusion

This study assessed the water quality of various surface water sources in Fez city and evaluated their suitability for domestic, recreational, and agricultural use. The physicochemical analysis revealed that while most parameters remained within the permissible limits set by the Moroccan Standard for surface water quality, certain variables at specific sites exceeded the recommended thresholds. In contrast, the microbiological analysis demonstrated a more concerning scenario, with 23% of the samples exceeding the standard for intestinal enterococci, 30% for fecal coliforms, and 15% for total coliforms. These findings highlight significant pollution in some surface water sources, likely attributable to domestic and urban wastewater discharge, agricultural runoff, and natural processes such as soil and rock weathering. The results underscore the potential health hazards associated with the use of these waters, emphasizing the urgent need for effective wastewater treatment and sustainable agricultural practices to mitigate contamination. To address these issues, we recommend comprehensive management of anthropogenic activities across all sites. Continuous monitoring of surface water quality is essential to ensure safe usage for irrigation and drinking purposes. Additionally, implementing appropriate wastewater treatment technologies and constructing treatment facilities for urban and municipal wastewater before discharge into water bodies will significantly reduce contamination risks.

5. Appendix

Appendix 1. Nouns of sampling site and their ID used in the manuscript.

Sampling ID	Sampling site noun
S1	Oued El Jawaher
S2	Oued Nia Ras elma
S3	Oued Ain Chkef
S4	Jnane Sbil
S5	Oued Fez
S6	Oued Fez O. Ourat
S7	Oued Fez Mariane
S8	Oued Jawhara
S9	Oued Fez P. bensuda
S10	Pond Zouagha
S11	Ain Sene
S12	Ain Chkef
S13	Oued Ain Snen
S14	Oeud Ain Chkef
S15	Oued Fez
S16	Oued El Jawaha
S17	Oeud Nia
S18	Oued Ain Allah
S19	Oued Sidi Hrazem
S20	Oeud Sebou Massdoune
S21	Oued Sebou Boulaguone
S22	Oued Fez Amont
S23	Oued Fez Aval
S24	Oued Jawaher Amont
S25	Oued Jawaher Aval
S26	Oued Nia Ras elma
S27	Oued Nia Ain Allah
S28	Oued Fez
S29	Oued El Jawaha
S30	Oued Nia
S31	Oued Sebou Ain Kansara
S32	Belagroune Ain Kansara
S33	Sidi Magdad Hamria

Appendix 2. Link between the variable and the continuous variables (R-square).

Dim1.		**TC**	**FC**	**EC**	**IE**	**SO_4**	**Cl**	**Turbidity**
	correlation	9.50E-01	9.36E-01	9.24E-01	8.19E-01	5.86E-01	5.72E-01	-4.54E-01
	p.value	3.52E-17	1.20E-15	1.71E-14	5.69E-09	3.42E-04	5.07E-04	7.92E-03
Dim2.		**T**	**NO_2**	**SO_4**	**Turbidity**	**pH**		
	correlation	7.33E-01	6.85E-01	4.07E-01	-3.52E-01	-7.27E-01		
	p.value	1.21E-06	1.10E-05	1.89E-02	4.43E-02	1.66E-06		
Dim3.		**NO3**	**pH**	**Cl**	**T**	**Turbidity**		
	correlation	7.42E-01	5.19E-01	4.12E-01	3.45E-01	-4.39E-01		
	p.value	7.85E-07	1.95E-03	1.72E-02	4.92E-02	1.06E-02		

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Data Availability Statement: The datasets presented in this study are available upon reasonable request from the corresponding author.

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