Physicochemical Characterization and Evaluation of the Organic Pollution of Domestic and Industrial Wastewater in the City of Fez

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ABSTRACT

Environmental concern implies a degree of basic dynamism aimed at safeguarding ecosystems against any type of pollution and better management of the environment. Wastewater is mainly composed of water and other materials that represent only a small part of wastewater, but can be present in sufficient quantities to endanger public health and the environment, so before discharging wastewater into the natural environment, it is necessary to define its parameters to have information on the composition and qualitative and quantitative characteristics of wastewater and their impacts on the receiving environment. The goal of the conducted work was to determine the degree of wastewater pollution in Fez based on the results of physicochemical analysis of samples collected from various stations in 2021. The temperature varies between 24.6°C and 29.9°C in wet periods and between 26.5°C and 38.3°C in dry periods, the pH is alkaline to neutral with high turbidity levels, especially in wet periods, for dissolved oxygen, the wastewater of the city of Fez is under saturated in oxygen, which accentuates anaerobic fermentation and the release of bad odors, and the average values of the BOD_5 are higher than 100 mg O_2/l considered. These wastewaters are rated as being of very poor quality. COD values are greater than 500 mg of O_2/l, which is considered the limit value for direct rejections. Nitrate concentrations are highest in S1, with a value of 12.83 mg/l in the dry period. The recorded contents of orthophosphates and total phosphorus do not vary significantly. The obtained values are higher than the WHO recommended wastewater discharge standards. At the conclusion of this research, it was discovered that the wastewater in the city of Fez is of poor to very poor quality.

Keywords: water pollution, wastewater, industrial pollution, anthropogenic pollution, water treatment, biodegradation.

INTRODUCTION

Population growth, industrialization, and rapid urbanization have all contaminated the essential elements of life (air, water, and land) (Chhikara et al., 2008; Rezouki et al., 2021). Water pollution is a critical issue because water is used for a variety of purposes (Briggs, 2003; Ihsane et al., 2022), and it is becoming a global problem. The discharge of waste from industries such as metalworking and finishing, textiles and ceramics, and leather tanning into the environment causes a variety of environmental issues. Textile and food industries are two of Morocco's most developed economic sectors in the Fez region. Unfortunately, these are regarded as one of the largest water consumers and thus the most significant source of environmental pollution due to the discharge of a massive volume of potentially hazardous and toxic wastewater, which has a negative impact and reflection

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on tanneries around the world (Boujelben et al., 2019; Bharagava et al., 2018; Faouzi et al., 2023). These industries are extremely diverse, requiring a large amount of clean water as well as a wide range of raw materials, chemicals, dyes, processes, and machinery (Yaseen and Scholz, 2019) The dominant issues associated with this industry are high water consumption and wastewater generation at the end of industrial processes.

Toxic products, heavy metals, and high concentrations of many organic and inorganic compounds are found in dark brown wastewater (Asamudo et al., 2005; Talouizte at al., 2010). Wastewater discharged at various industrial stages poses a significant threat to nearby receiving water bodies. Industrial wastewater contaminates valuable but limited clean water resources. It affects all life forms directly when they consume polluted water and indirectly when they consume crops irrigated with polluted water (Malaviya and Singh, 2012; Rezouki et al., 2021). Since clean water is necessary for industry and the generation of wastewater is difficult to avoid, it is therefore important to conduct a set of studies to remedy this problem before it is released into the environment. From this point of view, the conducted study focused on a more complete diagnosis of the current situation of pollution and a rigorous follow-up of its evolution, which are of great necessity.

MATERIAL AND METHODS

Selection and presentation of the study area

The city of Fez's wastewater collection network is designed so that the WWTP outlet discharges downstream into the Sebou River. The study area is dispersed throughout the city. Table 1 and Figure 1 depict the location and sector of the units investigated. Figure 1 depicts the location of the industrial units studied in this study.

Sites for sampling

Nine places were chosen from the various districts of Fez and samples were obtained (Table 1) on two occasions, a wet time representing the winter and a dry period representing the summer. The sampling sites for the various water samples were chosen with the diverse industrial and artisanal activity in mind. During the year 2021, the wastewater samples were collected in clean plastic bottles with a capacity of 500 ml. The samples were then stored at 4°C during transport to the laboratory for analysis. The wastewater samples for physicochemical analysis were stored according to the general guide for sample storage and handling according to ISO 5667/3 (ISO, 2022) and Good Practice Guide (ONEP, 1999). At each sampling, water temperature, pH and dissolved oxygen were measured in situ using a Consort P407 multi-parameter. The other parameters were carried out in the laboratory, orthophosphates, and total phosphorus were measured by spectrophotometry (Rodier, 1996), whereas nitrates according to the AFNOR T90-015 standard. The chemical oxygen demand (COD) was determined by adopting the AFNOR standard method (T90-101). The biochemical demand (BOD_5) was measured using a BOD meter.

RESULTS AND DISCUSSION

Physico-chemical characteristics of wastewater

The physico-chemical indicators of wastewater quality are often induced by anthropic and industrial activities that modify the characteristics

Table 1. Representation of the different study stations

	Study stations	Type of wastewater discharge
S1	Hay benslimane station	Domestic discharges
S2	Fez jdid station	Domestic discharges/ discharges from artisanal activities
S3	Fez el bali station	Domestic discharges/ discharges from artisanal activities
S4	Jnan el Ouard station	Domestic discharges/ discharges from craft and industrial activities
S5	Talaa station	Domestic discharges
S6	Mellah station	Domestic discharges/ discharges from artisanal activities
S7	Dekkarat station	Industrial discharges
S8	Bab ftouh station	Domestic discharges/ discharges from artisanal activities
S9	Ain nokbi station	Domestic discharges/ discharges from craft and industrial activities
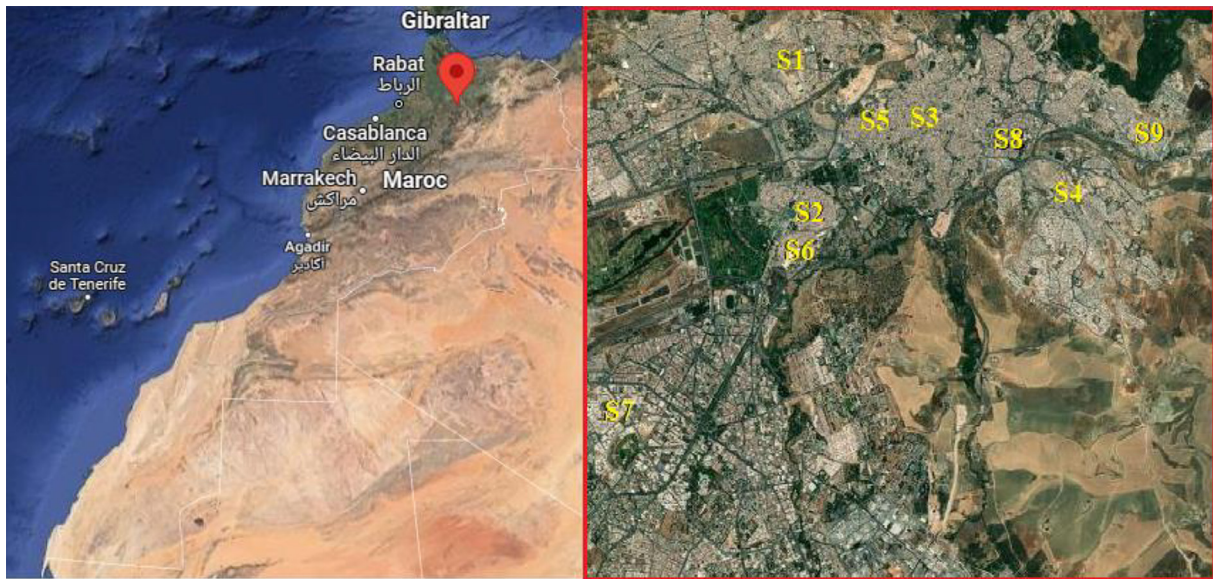
Figure 1. Map of the wastewater network of the city of Fez and location of the sampling sites

of these waters. Thus, the measurements of these parameters can inform us about the degree of pollution and the possibility of using these waters in irrigation.

The temperature

The recorded temperatures (Figure 2) oscillate between 24.6°C (Station S8) and 29.9°C (Stations S9) in wet periods, and between 26.5°C (Stations S8) and 38.3°C (Stations S3) in dry periods. These temperature variations are due to the different anthropic and industrial activities in the stations (Hbaiz et al., 2022), and the samples were taken during periods when the population and the industries were active.

Hydrogen potential (pH)

The evolution of the pH of the discharges of the city of Fez (Figure 3) throughout the study period showed significant spatiotemporal fluctuations: it is relatively alkaline to neutral with the recording of a maximum value during the dry period of 9.43 at station S3 and a minimum value of 7.63 at station S6 against these values decrease in the wet period to reach a minimum value of 6 to S9 and a maximum value of 8.27 to S3. The average pH values obtained in some stations are close to neutrality and acceptable for irrigation according to the Moroccan irrigation standards (MEM, 2002), and in the range of limits of direct
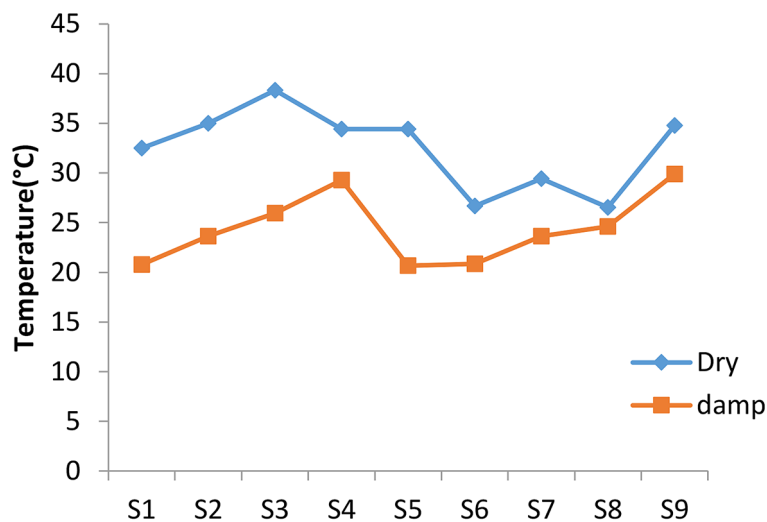
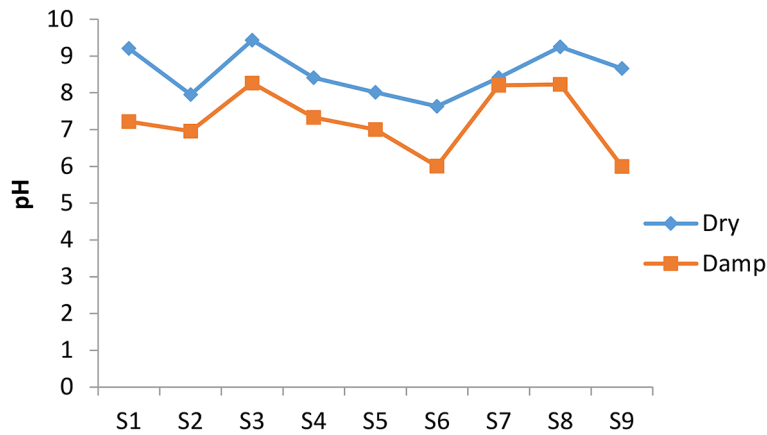**Figure 2.** Variation of average temperature values

Figure 3. Spatio-temporal variation of mean pH values

discharges which is between 6.5 and 8.5 (MTEDD, 2022).These results are in agreement with those reported by Jaziri (1999) (Eljaziri, 1999) in Meknes and by El Krati, (2000) (El Krati, 2000) in Sidi Bennour. However, it should be noted that the pH values below 5 or above 8.5 affect the growth and survival of microorganisms (Mara, 1976).

Turbidity

Water turbidity (Figure 4) is caused by the presence of finely divided suspended matter, such as clay, silt, silica grains, organic matter, and so on. The degree of turbidity is measured by appreciating the abundance of these matters (Jemali and Kefati, 2002). The studied stations present high turbidity levels especially in wet periods, the maximum value was recorded in station S3 (531.7 mg/l of suspended matter). The high turbidity of the wastewater favors a high consumption of oxygen, which results in low levels of dissolved oxygen that oscillate between 2.13 mg/l during the wet period (S5) and 2.36 mg/l (S7)

during the dry period as the minimum value for both periods. This leads us to the conclusion that the wastewater of the city of Fez exceeds the Moroccan discharge standards, which range between 5 and 30 (discharge standards), indicating that the wastewater is highly turbid.

Dissolved oxygen (DO)

The concentration of dissolved oxygen (Figure 5) varies between 2.36 mg/l (S7) and 9.33 mg/l (S3) in the dry period and 2.13mg/l (S5) and 9.86mg/l (S3) in the wet period, indicating a high organic load in the wastewater and that the wastewater in Fez is under-saturated in oxygen, enhancing anaerobic fermentation and the release of foul odors.

Biological oxygen demand BOD_5 and chemical oxygen demand COD

The low levels of organic matter (COD and BOD_5) recorded during the wet season are due to dilution by rainwater. In turn, the high organic
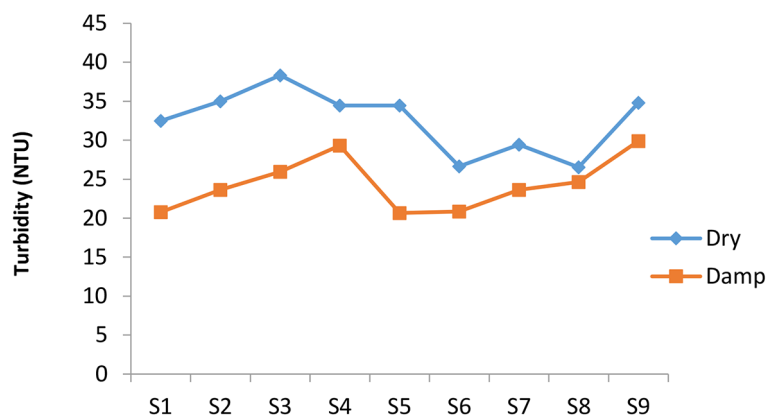

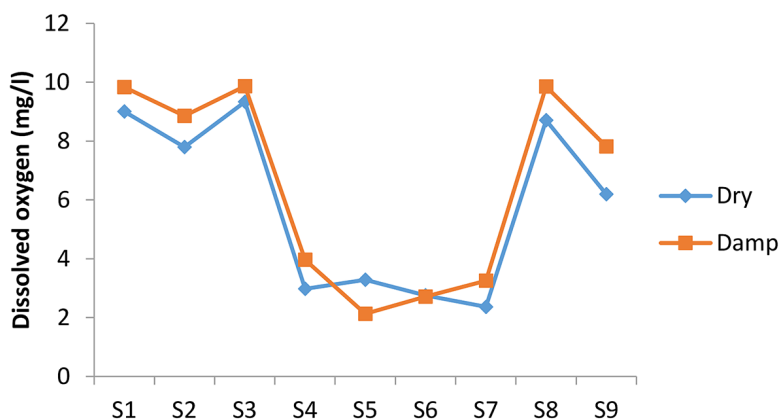**Figure 4.** Spatio-temporal variation of mean Turbidity values

Figure 5. Spatial and temporal variation of mean dissolved oxygen values

matter contents recorded during the dry season could be explained by the absence of rain and an increase in the water and air temperature, which allows a contribution to the sewer of water more loaded with organic matter. The biochemical oxygen demand (BOD_5) (Figure 6), which represents the amount of biodegradable organic matter, is the main quality parameter typically studied to indirectly evaluate the global organic load contained in a wastewater. The BOD_5 levels were measured between 300 mg/dl O_2 (S1) and 10250 mg/dl O_2 (S9) in wet periods and 312 mg/dl O_2 (S5) and 10299.01 mg/dl O_2 (S9) in dry periods. The average BOD_5 values are greater than 100 mg O_2/l, which is considered the limit value for direct discharge (MEM, 2002). According to surface water quality standards (MEM, 2002), this wastewater is classified as very poor. Given the poor quality of raw wastewater, its direct use for irrigation in agriculture could harm the receiving environment and cause physical-chemical and biological

clogging at the soil level, owing primarily to the presence of suspended solids, salt precipitation, and algae growth on the irrigated soil's surface (Landreau, 1987 ; Ratel et al., 1986).

As for the COD (Figure 7), chemical oxygen demand which accounts for the quantity of the main carbonaceous elements, biodegradable or not, likely to be chemically oxidized in the receiving environment, the highest values were recorded during the dry period with a maximum value of 10259.66 mg/l at S9 and a minimum value of 119mg/l recorded at S6, these values are higher than 500 mg of O2/l considered as a limit value for direct discharge (MEM, 2002). Furthermore, according to surface water quality standards (MEM, 2002), this wastewater is of very poor quality (> 80 mg/l). The recorded average COD value is lower than that found in Sana'a (Yemen) (1888.53 mg O_2/l) (Raweh et al., 2011). They are, however, higher than those found in Gharb's Souk Elarba (235.2 mg O_2/l) (Kbibch, 2011).
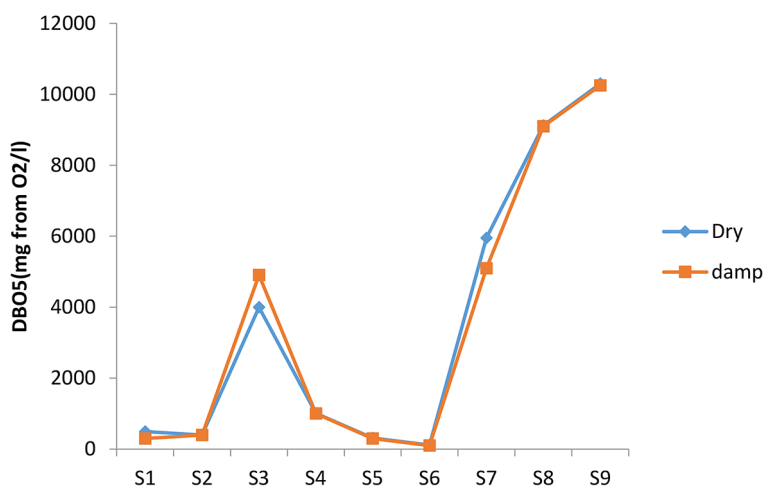

Figure 6. Spatial and temporal variation of average BOD_5 values

Nitrates (NO$_3^-$)

Nitrates NO$_3^-$ (Figure 8) have agricultural origins and also come from the mineralization of organic nitrogen and the oxidation of ammonium. The highest nitrate concentrations are recorded at S1 with a value of 12.83 mg/l during the dry period and a minimum value of 7.08 mg/l recorded at S5 during the wet period. These results are higher than those found in the wastewater of the city of Oujda (Abouelouafa et al., 2002) as well as the cities of Abidjan (Gnagne et al., 2015) and Kenitra (Belghyti et al., 2009).

Orthophosphates and total phosphorus

For the recorded contents of orthophosphates and total phosphorus do not show considerable variations. Total phosphorus (Pt) (Figure 9) and orthophosphates (PO$_4^{3-}$) (Figure 10) in wastewater show average maximum values of about 0.9 mg/l (S5)

and 0.6 mg/l (S9) respectively in dry periods. This could be explained by the absence of rainfall and the fact that rainwater could provide a diluting effect to urban wastewater, in addition to the great human activity during this season which is of great contribution in products rich in phosphorus compounds (especially detergents). Phosphorus has a domestic origin (faeces and detergents) and also agricultural (fertilizers) and industrial (chemical industry) (Rima and Saida, 2020). The discharge of phosphorus into the receiving environment is an essential cause of its eutrophisation because this phosphorus is a limiting factor of plant growth responsible for this phenomenon (Djemame and Moumene, 2011).

Evaluation of the organic pollution of wastewater

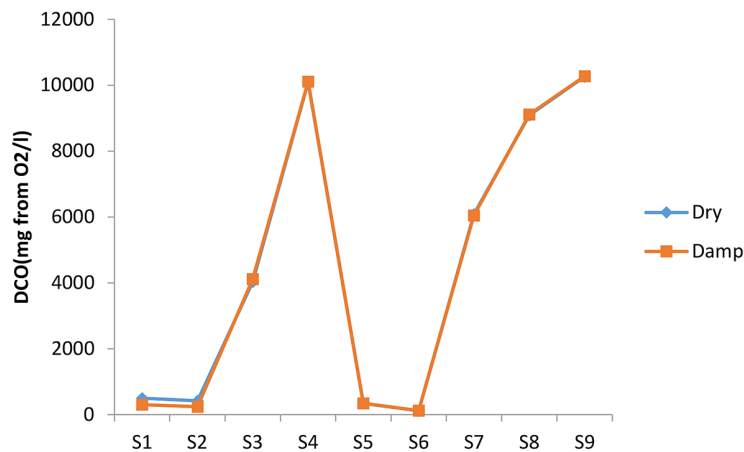The COD/BOD$_5$ ratio is critical for defining an effluent's treatment chain. Indeed, a low COD/

Figure 7. Spatial and temporal variation of average DCO values
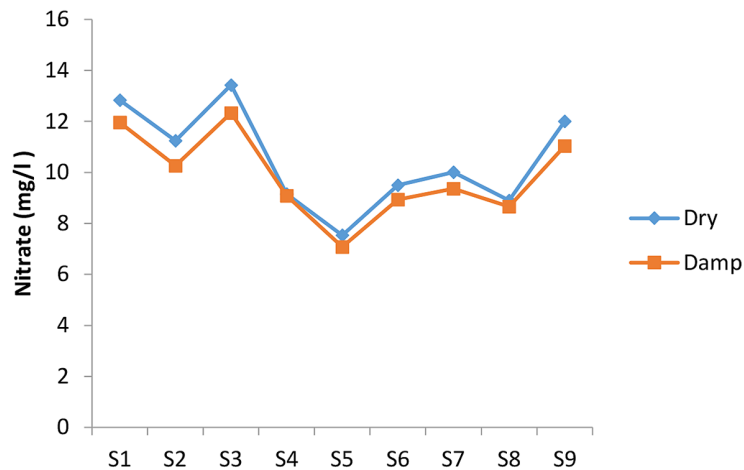

Figure 8. Spatial and temporal variation in mean nitrate values

BOD_5 ratio indicates the presence of a high proportion of biodegradable matter and allows for the consideration of biological treatment. A high value of this ratio, on the other hand, indicates that a large portion of the organic matter is not biodegradable and that a physicochemical treatment is preferable in this case. The COD/BOD_5 ratio can be used to determine whether wastewater discharged directly into the receiving environment has domestic wastewater characteristics (COD/BOD_5 ratio less than 3) (MEM, 2022). The findings of this report indicate the significance of pollutants with little or no biodegradability. The results are shown in Table 2.

The average COD/BOD_5 ratio is between 1 and 2 in comparison to wastewater with a COD/BOD_5 ratio less than 3 [6]. As a result, even though urban wastewater contains a high organic load, it is easily biodegradable. These findings are consistent with those of Gnagne and Brissaud (2003) and

Zerhouni (2003). For the station S4, which represents Jnan Lward, organic discharges of domestic origin are not difficult to biodegrade. To characterize industrial pollution, we frequently consider the BOD_5/COD ratio, which provides very interesting information about the origin of wastewater pollution and treatment options. This ratio is relatively average in this study, hovering around 0.9. This is typical of discharges containing organic matter. This organic load makes these wastewaters rather unstable, as they will quickly evolve into "digested" forms, potentially releasing odors. This type of wastewater is, in fact, primarily organic.

STATISTICAL DATA ANALYSIS

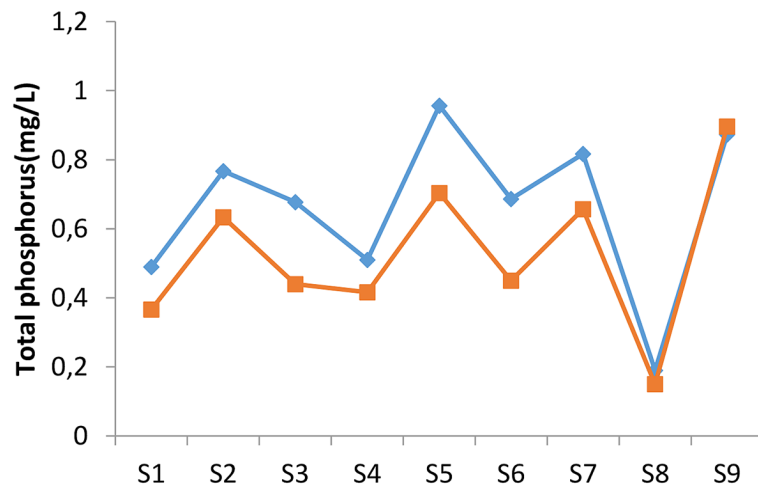To study the correlations between the variables (physico-chemical), a principal

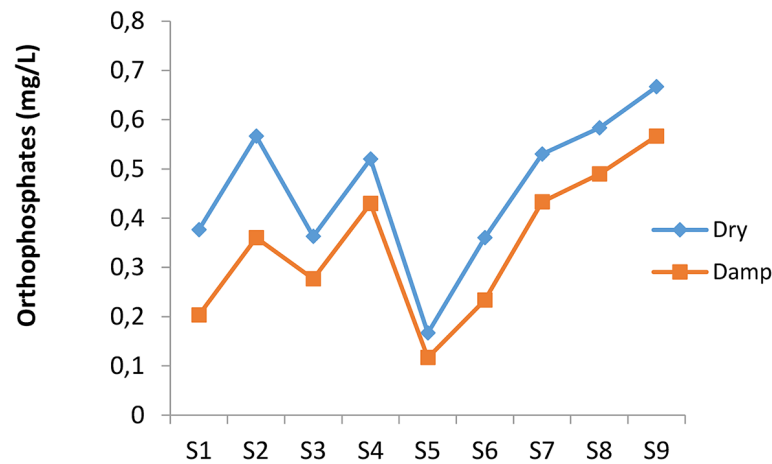**Figure 9.** Spatial and temporal variation in mean orthophosphate values

Figure 10. Spatial and temporal variation of average total phosphorus values

Table 2. Wastewater rations in the city of Fez

	Stations	Averages	Interpretation		Stations	Averages	Interpretation
	S1	1.004	Easily biodegradable		S1	0.995	Easily biodegradable
	S2	0.826	Easily biodegradable		S2	1.21	Easily biodegradable
	S3	0.915	Easily biodegradable		S3	1.093	Easily biodegradable
	S4	10.049	Hardly biodegradable		S4	0.099	Easily biodegradable
COD/BOD$_5$	S5	1.1207	Easily biodegradable	DBO$_5$/DCO	S5	0.892	Easily biodegradable
	S6	1.117	Easily biodegradable		S6	0.895	Easily biodegradable
	S7	1.098	Easily biodegradable		S7	0.910	Easily biodegradable
	S8	0.999	Easily biodegradable		S8	1.00	Easily biodegradable
	S9	0.999	Easily biodegradable		S9	1.00	Easily biodegradable

component analysis (PCA) was performed. PCA was applied on the data including nine water samples and nine variables: Biochemical Oxygen Demand (BOD$_5$), Biochemical Oxygen Demand (COD), Nitrates (NO$_3^-$), Orthophosphates (PO$_4$), Total Phosphorus (TP), Dissolved Oxygen (DO), Hydrogen Potential (pH), Temperature (°C) and Turbidity (Tu). The treatment of these physico-chemical data by PCA gives several results which are presented in Table 3, and Figure 11. Table 3 is a correlation matrix which presents univariate statistical analyses, whereas Figure 11 presents the factorial plan (Dim1- Dim 2).

Univariate correlation analysis

The examination of the correlation matrix between the variables shows a correlation between DO*NO$_3^-$ (0.69); PO$_4$*DCO (0.74); PO$_4$*DBO$_5$ (0.72) and COD *DBO$_5$ (0.74). These results show that there is not much correlation between the different physico-chemical parameters of the studied wastewater, this can be explained by the presence of external factors influencing the special variation of these parameters these factors are only the different sources of domestic, agricultural and industrial pollution.

The analysis of the results shows that most of the information is explained by the first two factorial axes. The first two factors express 60.71% of the variance, of which 40.22% for dimension 1 and 20.49% for dimension 2. The representation of the data in the plane (Dim 1– Dim 2) gives a fairly satisfactory account of the proximity of the elements. The results of PCA analysis show that the first factor (Dim 1) which contributes with 40.22% inertia is defined by the parameters PO$_4$, BOD$_5$ and COD in its positive part (Figure 11) so it defines the organic pollution of wastewater in Fez. The second factor (Dim 2) is defined by the parameters NO$_3$ (0.94) and dissolved oxygen (DO) (0.94) in its positive part. The high nitrate values are the result of nitrogen pollution.

Table 3. Spearman correlation analysis of target metals in the study waters
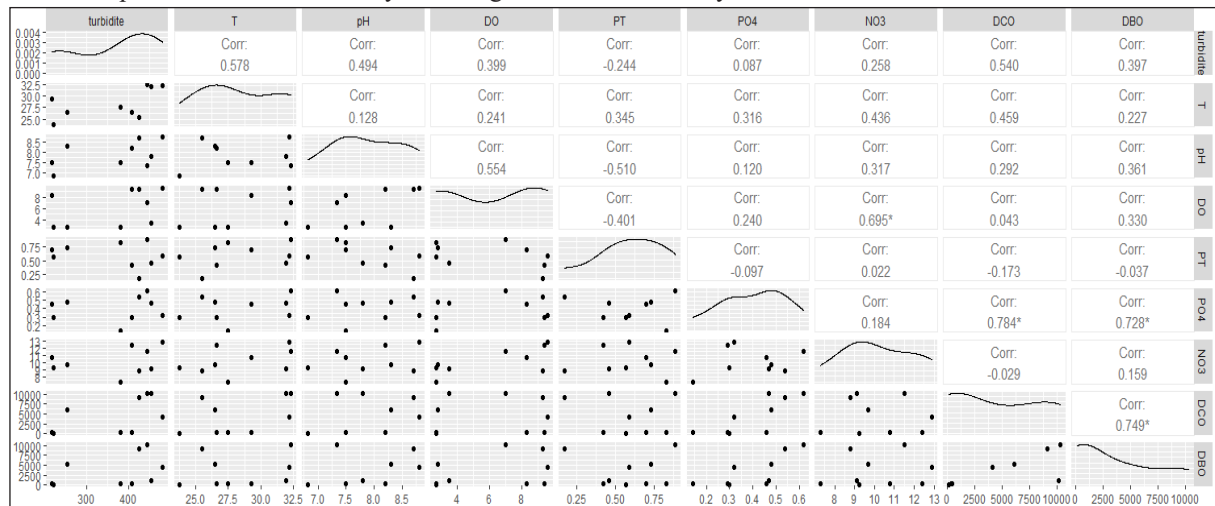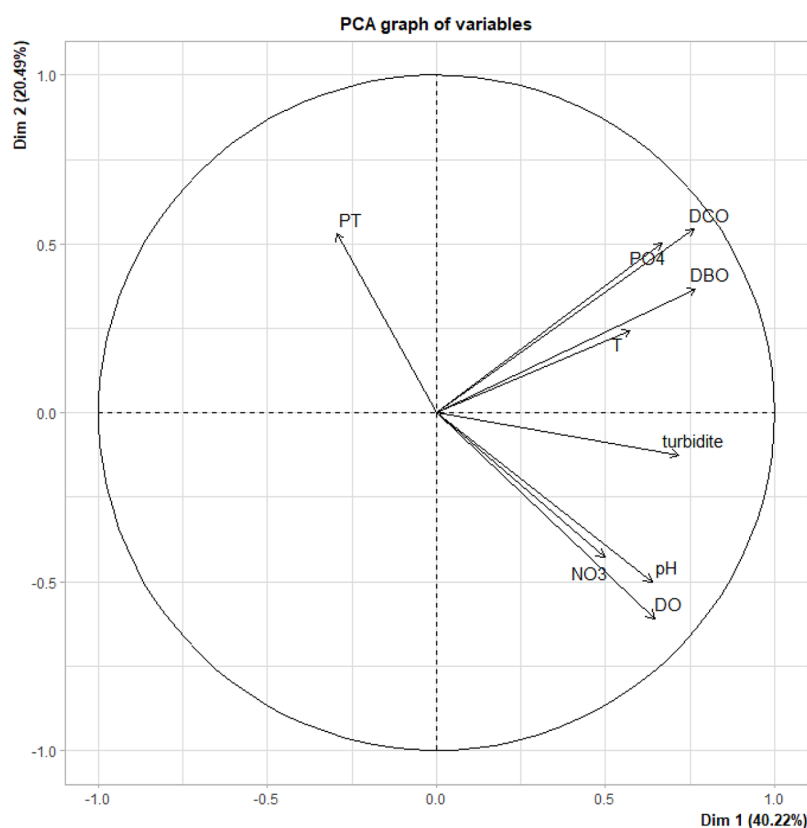
Figure 11. Principal component analysis in the factorial plane (Dim1–Dim2)

CONCLUSIONS

The increase in population and the decrease in water supply due to climate change make water reuse a mandatory task. In particular, the use of wastewater for irrigation is becoming a profitable economic activity in several countries, including Morocco, especially in times of drought. Wastewater not only provides the necessary moisture, but also additional nutrition; however, this use can cause risks of environmental and public health impacts. According to the obtained findings, the wastewater from the city of Fez generates a significant pollution load when discharged into receiving environments such as Oued Fes, a tributary of the great river Sebou. The analysis of the COD/BOD$_5$ ratio demonstrates the biodegradable nature of Fez's wastewater. This wastewater appears to be easily biodegradable, and a biological treatment appears to be appropriate. The treatment of this wastewater is required in order to produce the water that meets Morocco's Ministry of Environment's standards for direct and indirect discharges (2002). In terms of COD, BOD$_5$, and SM, the city of Fez generates the wastewater suitable for biological treatment (suspended matter).

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