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Principal component analysis of physico-chemical parameters of wastewater from the University Hospital Center of Treichville in Côte d'Ivoire

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Abstract: The wastewater treatment plant (WWTP) built in 1966 to treat wastewater from the University Hospital Center of Treichville (UHCT) stopped operating in 1975. The wastewater produced are rejected without any treatment. To this must also be added the lack of scientific data on the quality of the wastewater of the UHCT. Faced with this observation, a physico-chemical study of the wastewater of the UHCT was carried out. Three sampling sites were chosen for this study. The results showed an average temperature of around 28°C, a hydrogen potential (pH) close to 7, a conductivity of around 660 µS/cm, dissolved oxygen (DO) 1.5 mgO_2/L, nitrate ions 10 mg/L, the chemical oxygen demand (COD) and the biochemical demand in five days (BOD_5) are respectively 127 mgO_2/L and 81 mgO_2/L and the values of nitrite and phosphate ions comply with the standards of WHO reject. The COD/BOD_5 ratios of less than 3 show that the wastewater from the UHCT is domestic. Principal component analysis (PCA) showed positive and negative correlations between a few parameters, highly mineralized effluent rich in organic matter, hot, alkaline and rich in nitrate ions, poor in dissolved oxygen, poor in nitrite ions and poor in into phosphate ions.

Keywords *: Analysis; Organic matter; Biodegradable; Hospital; Wastewater; Physico-chemical;*

1. Introduction

Hospital wastewater (HWW) is produced by hospital facilities. It comes from the toilets of patients as well as the different services that make up a health facility (Muhammad et *al*., 2021). According to the literature, HWWs contain pharmaceutical products, organic and inorganic chemicals as well as toxic substances (Liu et *al*., 2023; Chong and Jin, 2012; Casas et *al*., 2015; Selin et *al*., 2020), pathogenic germs developing multi-resistant to antibiotics (Beattie et *al*., 2020; Majumber et *al*., 2021). Thus, HWW constitute real dangers for the environment (Ramírez-Coronel et *al*., 2023; Khan et *al*., 2023; Castellano-Hinojosa et *al*., 2023). In the so-called industrialized countries, large quantities of wastewater are produced and conveyed daily and massively to wastewater treatment plants (WWTPs) for treatment. Unfortunately, these plants have difficulty treating antibiotics and iodinated constrates

(Fono and Sedlak, 2007). In recent decades, HWW have been shown to be sources of freshwater pollution (Ramírez-Coronel et *al*., 2023; Chonova et *al*., 2016; Perrodin et *al*., 2013). In developing countries where there are almost no wastewater treatment plants, large amounts of untreated water are discharged into the environment every day, constituting a serious danger to the aquatic ecosystem that receives it (Sadia et *al*., 2016; Belghyti et *al*., 2009). This is unfortunately the case for the University Hospital of Treichville (UHCT), whose treatment plant, built in 1966, stopped operating in 1975. For four decades, wastewater from this hospital has been discharged into the environment without any treatment. The previous work of our Laboratory has characterized these waters over a period of three months (November 2014 to January 2015). The results of this work showed that the organic charge and microbiological pollution of these waters constitute a risk for the populations since they are discharged into the Ebrié lagoon without any treatment (Sadia et *al*., 2016).

The objective of this work is to determine the physico-chemical parameters of the UHCT wastewater over a long period of study in order to confirm or deny the existing results. Then a statistical study will be carried out using principal component analysis (PCA) to better interpret the results obtained. The parameters that will be analyzed are temperature, hydrogen potential (pH), conductivity, total dissolved solids (TDS), salinity, dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand in 5 days (BOD_5), suspended solids (SS), chloride ions (Cl^-), phosphate ions (PO_4^{3-}), nitrate ions (NO_3^-) and nitrite ions (NO_2^-).

2. Methodology

CHUT is located in the commune of Treichville in Côte d'Ivoire. The said commune is located south of the city of Abidjan, a city situated between latitude 5°19 North and longitude 4°1 West in the south of Côte d'Ivoire. The commune of Treichville is bordered to the north by the commune of Plateau, to the east by the communes of Marcory and Koumassi, to the west by the commune of Yopougon and to the south by the autonomous port of Abidjan. Figure 1 below shows the location of the commune of Treichville in the city of Abidjan as well as the different sampling sites.

To determine the physico-chemical parameters, wastewater samples were collected. These are more than 404 samples were collected from three different sites during the periods from January to July 2015 and March to July 2016. These are site S1, the main collector of wastewater from most UHCT services, site S2 downstream of site S1 receiving wastewater from other services such as cardiac services and general medicine, and site S3 receiving wastewater from infectious disease services. Some parameters were measured directly at the different sampling sites and the others were delivered to the laboratory for measurement. The parameters of temperature, hydrogen potential (pH), conductivity, total dissolved solids (TDS), salinity and dissolved oxygen (DO) were determined at the sampling site. These measurements were made possible by the BANTE 900P multi-parameter with several probes. For the other parameters, namely chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), chloride ions (Cl^-), phosphate ions (PO_4^{3-}), nitrate ions (NO_3^-) and nitrite ions (NO_2^-), they were determined upon arrival at the laboratory. During transport, the wastewater samples were kept at a temperature of about 4 °C.

To determine the COD of the sample, 2 mL of wastewater sample is taken and introduced into a COD tube of the HACH product. The whole set is heated in a digester at 150°C for 120 minutes. After cooling, the COD value is read directly with the HACH product DR/6000 spectrophotometer at a wavelength of 620 nm. The BOD_5 was determined by the "manometric" method using the HACH VELP SCIENTIFICA oxitop. Chloride ions were determined by volumetric determination using the Mohr method in the presence of silver nitrate with a few drops of potassium chromate (ISO 9297).

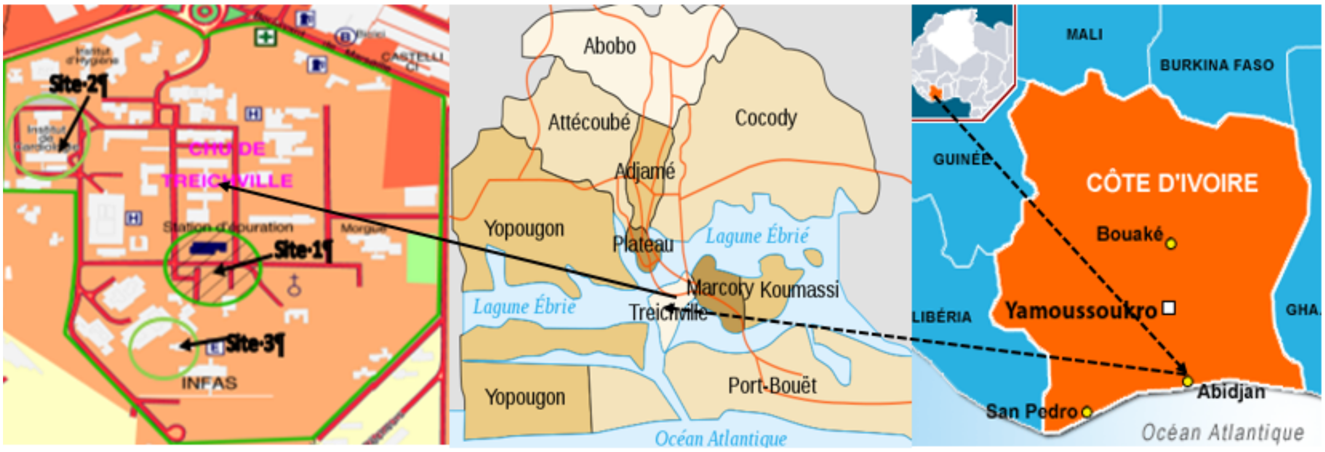

Figure 1. Location of UHCT in Abidjan, Ivory Coast, West Africa. Site S1 is the main wastewater collector for most of the UHCT departments. Site S2 is downstream of site S1 but receives wastewater from other services such as cardiac services and site S3 receives wastewater from infectious diseases services.

Nitrate, nitrite and phosphate ions were determined in the laboratory by the spectrophotometric method. The different HACH reagents are nitraver 5, nitriver 3 and phosver 3 respectively. The different colors developed indicating the presence of these different ions are read on the HACH DR 6000 spectrophotometer at the wavelength of 500 nm (NO_3^-), 507 nm (NO_2^-) and 890 nm (PO_4^{3-}) respectively. Total suspended solids (TSS) were determined by weighing a filter containing the total suspended solids after a two-hour heating process at 105 °C (ISO 11923). For this purpose, a precise volume V (mL) of the collected wastewater was filtered through a weighted filter, diameter 47 millimeters (mm), porosity 0.8 micro meter (µm). The results were consolidated using Excel and for the principal component analysis (PCA), XLSTAT 2017 software was used.

3. Results and Discussion

Figures 2 through 7 represent the results of combined data from over 404 samples collected at the different sampling sites. These figures show the evolution of the different parameters at the sampling sites.

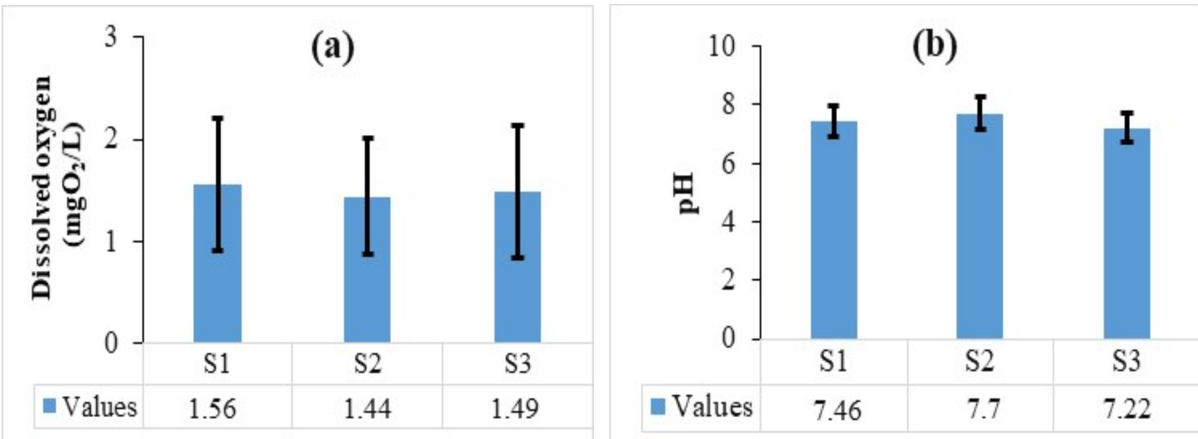

Figure 2. Evolution of dissolved oxygen and hydrogen potential according to the sampling sites

Figure 2 shows the evolution of dissolved oxygen (DO) and hydrogen potential (pH) at sites S1, S2 and S3. In Figure 2a, we notice that the average DO values are respectively (1.56 ± 0.65) mgO_2/L on S1, (1.44 ± 0.57) mgO_2/L on S2 and (1.49 ± 0.65) mgO_2/L on S3. Figure 2b shows the average pH values which are 7.46 ± 0.52 on S1, 7.70 ± 0.55 on S2 and 7.22 ± 0.54 on S3, respectively.

Figure 3 shows the evolution of temperature and conductivity at sites S1, S2 and S3. In Figure 3a we can see that the average temperature values are respectively (28.14 ± 1.53) °C at S1, (28.14 ± 1.53) °C at S2 and (28.39 ± 1.60) °C at S3. Figure 3b shows the respective mean values of conductivity which are (532.89 ± 128.40) µS/cm for S1, (767.03 ± 183.20) µS/cm for S2 and (680.29 ± 237.62) µS/cm for S3.

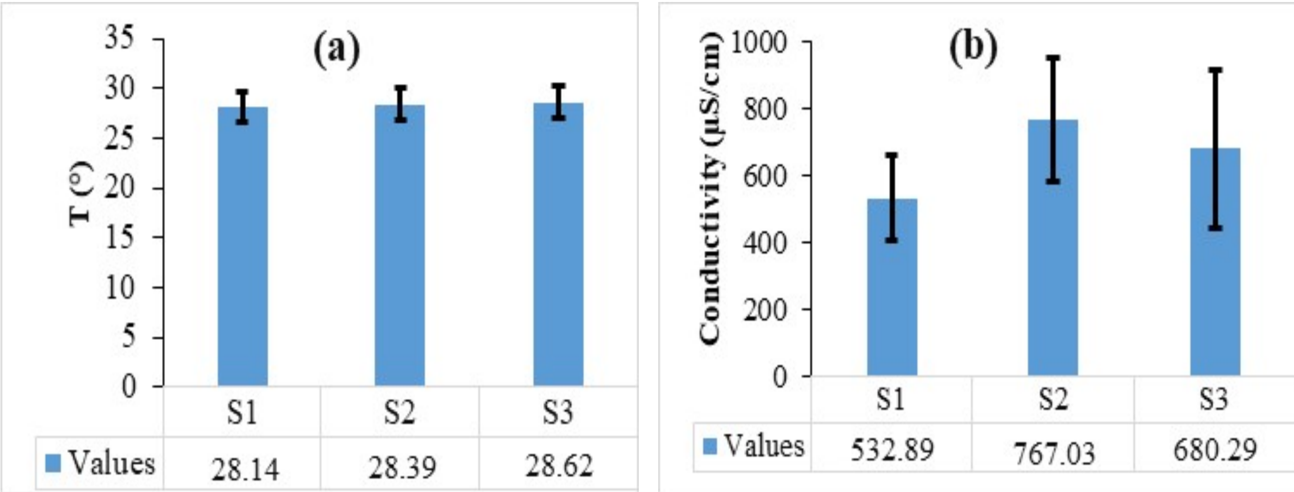

Figure 3. Temperature and conductivity evolution according to the sampling sites

Figure 4 shows the evolution of total dissolved solids (TDS) and salinity at sites S1, S2 and S3. It is observed in Figure 4a that the mean values of TDS are respectively (264.94 ± 65.18) mg/L for S1, (383.21 ± 91.49) mg/L for S2 and (340.06 ± 118.71) mg/L for S3. In Figure 4b, the average salinity values are (0.26 ± 0.07) PSU for S1, (0.38 ± 0.09) PSU for S2 and (0.33 ± 0.12) PSU for S3, respectively. Figure 5 shows the evolution of chemical oxygen demand (COD) and five-day biochemical oxygen demand (BOD_5) at sites S1, S2 and S3. It can be seen in Figure 5a that the average COD values are respectively (115.53 ± 35.76) mgO_2/L for S1, (134.37 ± 35.64) mgO_2/L for S2 and (132.05 ± 57.12) mgO_2/L for S3. In Figure 5b, the mean BOD_5 values are (77.19 ± 27.55) mgO_2/L for S1, (77.28 ± 30.49) mgO_2/L for S2 and (90.89 ± 37.42) mgO_2/L for S3, respectively.

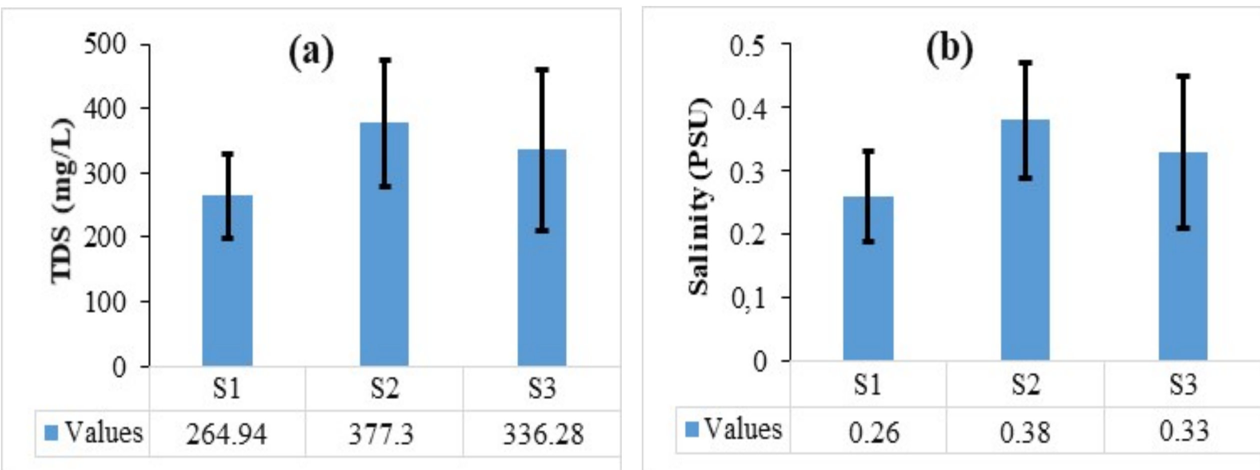

Figure 4. Evolution of total dissolved solids and salinity according to the sampling sites

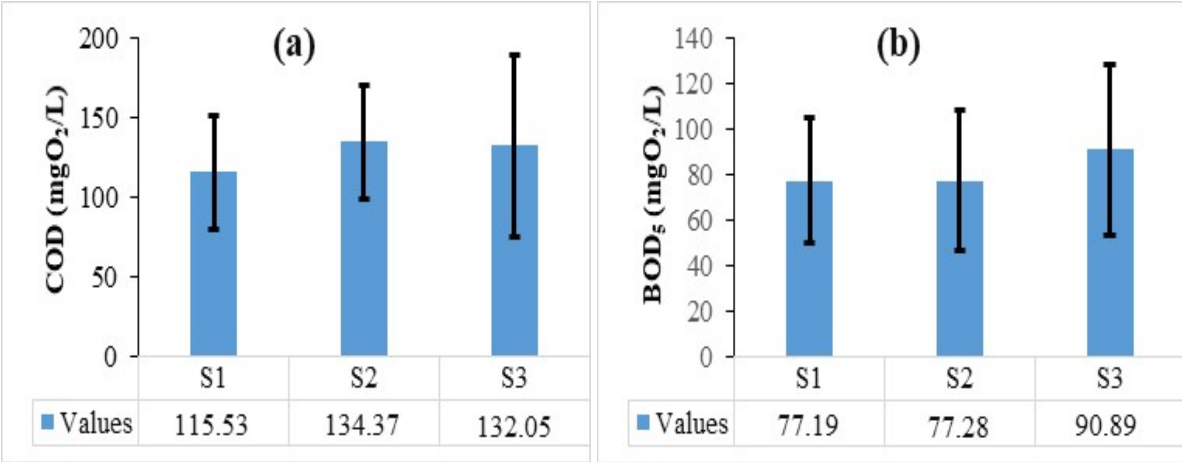

Figure 5. Evolution of COD and BOD_5 according to the sampling sites

Figure 6 shows the evolution of dissolved suspended solids (DSS) and chloride ions at sites S1, S2 and S3. On Figure 6a, we notice that the average values of DSS are respectively (14.02 ± 12.84) mg/L for S1, (11.77 ± 9.43) mg/L for S2 and (11.14 ± 10.88) mg/L for S3. In Figure 6b, the mean values of chloride ions are (53.70 ± 9.70) mg/L for S1, (103.77 ± 23.01) mg/L for S2 and (54.34 ± 12.88) mg/L for S3, respectively. Figure 7 shows the evolution of nitrate, nitrite and phosphate ions at sites S1, S2 and S3. In Figure 7a, the average values of nitrate ions are respectively (10.69 ± 6.82) mg/L for S1, (10.42 ± 6.93) mg/L for S2 and (11.14 ± 9.12) mg/L for S3. In Figure 7b, the average values of nitrite ions are respectively (0.50 ± 0.32) mg/L for S1, (0.40 ± 0.27) mg/L for S2 and (0.16 ± 0.21) mg/L for S3. It is observed in Figure 7c that the average values of phosphate ions are (4.20 ± 1.01) mg/L for S1, (4.47 ± 1.35) mg/L for S2 and (4.95 ± 1.48) mg/L for S3, respectively.

The average DO value varies very little when moving from one site to another. The values found are low and are in the same range as those found by Idrissi in the characterization of hospital wastewater from Azilal, Morocco (Idrissi et *al*., 2015). The low values are characteristic of anoxic wastewater, due to their consumption by aerobic bacteria to oxidize biodegradable compounds (Merghem et *al*., 2016). This is a real problem for the environment because wastewater that is deficient in dissolved oxygen emits strong foul odors (Adje et *al*., 2019; Evens et *al*., 2001). This low DO value may also affect the treatment of this hospital effluent (Trilok et *al*., 2014). As for pH, the average value at all three sites suggests that the wastewater is slightly basic.

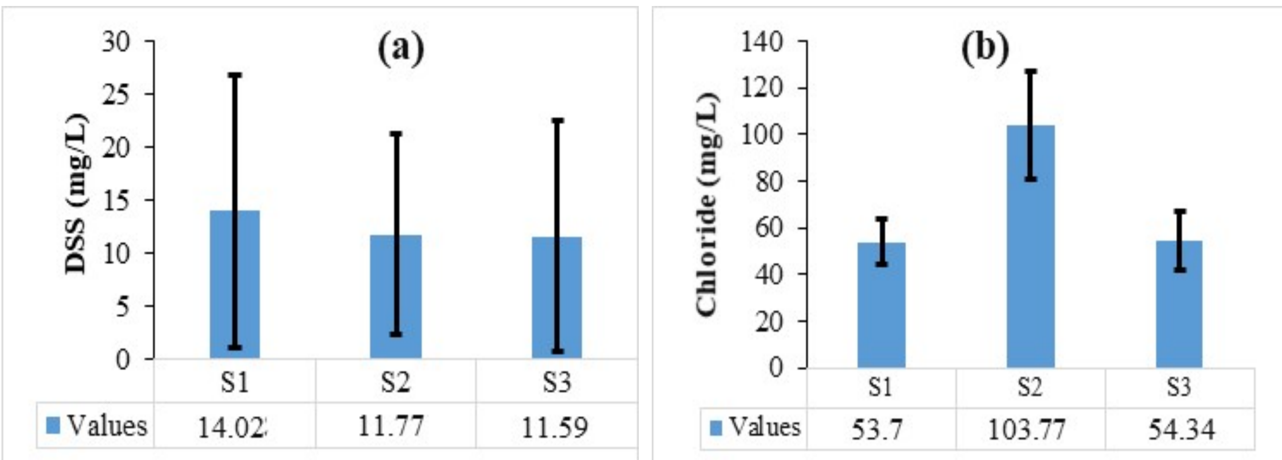

Figure 6. Evolution of dissolved suspended solids and chloride ions according to the sampling sites

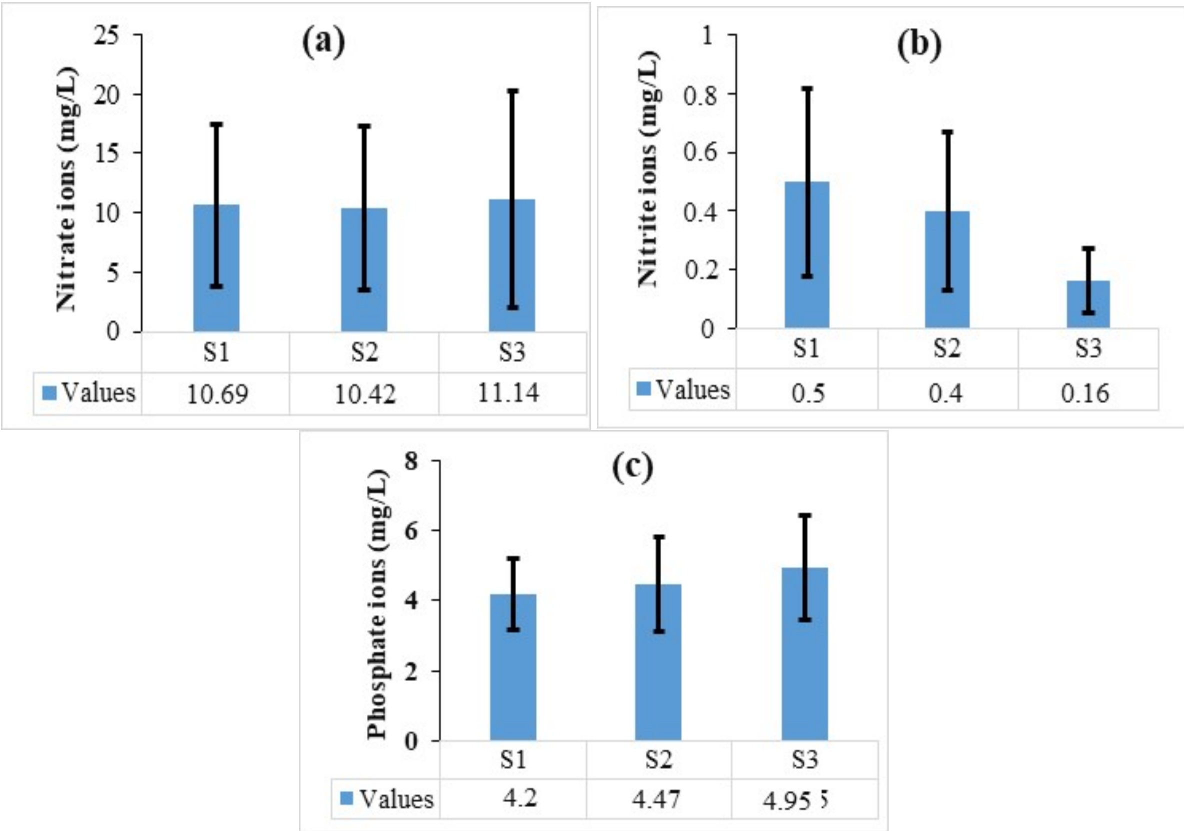

Figure 7. Evolution of nitrate, nitrite and phosphate ions according to the sampling sites

The average pH values close to the value 7, are due to the high water use in the UHCT whose average daily volume amounts to 707.24 m^3 per day. The average pH values obtained in this work are consistent with those found in other hospital wastewaters. In Turkey, for example, the pH of hospital wastewater is about pH = 7 (Altin et *al*., 2003). Other authors have found almost the same pH values for hospital wastewater (Selin et *al*., 2020; Sadia et *al*., 2016). UHCT wastewater can support the growth of microorganisms (Hutchinson, 1957; Rutter, 1973). These average pH values at the different sites meet the World Health Organization (WHO) wastewater discharge standard, which states that the pH of a wastewater should be between 6.5 and 8.5 (WHO, 1973). The average temperature values recorded at the various sites are below 30°C. Based on these values, the temperature of the UHCT WWTPs cannot adversely affect the bacterial flora and microbiological activity in the receiving environment (Hutchinson, 1957; Rutter, 1973; WHO, 1973). DSS values fluctuate because UHCT activities are dynamic. This parameter is important because it represents total organic and inorganic particles in the wastewater. The values obtained for this parameter in all water samples are less than 20 mg/L. This value, according to the WHO, is considered as the limit value of DSS for direct wastewater discharge (WHO, 1973). This result can probably indicate that most of the pollutants present in the UHCT wastewater are soluble. This explains the very low DSS values obtained. The TDS values are below 1000 mg/L, the limit value for direct wastewater discharge according to WHO guidelines (WHO, 1973). The TDS values of the UHCT wastewater are not zero, indicating that it would contain dissolved matter such as organic matter. The conductivity values obtained are lower than those found by Aziz in the characterization of Erbil HWW (Aziz et al., 2014), whose values range from 1010 µS/cm to 2232 µS/cm. For these conductivity values, it would be necessary to use a supporting electrolyte in an electrochemical treatment of UHCT wastewater. However, Goldman and Home suggested that conductivity values above 500 µS/cm in a wastewater treatment system could be considered difficult to treat (Goldman and Horne, 1983). Chloride in this wastewater come from NaCl (saline) infusion fluids injected into patients and passed by those patients through urine and feces. Its high concentration at site 2 is due to wastewater from the general medicine departments, which house a large proportion of hospitalized patients, as well as to wastewater from departments downstream of the treatment plant such as the dermatology and cardiology departments. The phosphate ions contained in these waters come from the detergents (sodium phosphate and sodium hypochlorite double salt) used in the various departments and also from phosphate organic matrices (Hébert and Légaré, 2000). COD and BOD_5 are important parameters for the characterization of water bodies, wastewater, industrial water and wastewater treatment plant effluents (Bartram and Balance, 1996). The COD and BOD_5 values obtained at UHCT are very low compared to those determined by Al-Ajlouni et al. after characterization of wastewater from 12 hospitals (Al-Ajlouni et *al*., 2013). The low values determined in this hospital are due to the effect of microorganisms on the raw wastewater before sampling. The dilution effect caused by the large amount of water used by CHUT (707.24 m^3 per day) may also explain the low values of these two parameters. Despite these low values, they are still above the WHO limit values of 90 mgO_2/L for COD and 30 mgO_2/L for BOD_5 (WHO, 1973). To better interpret the biodegradability of UHCT wastewater, COD/BOD_5 ratios were calculated and the results are shown in Table 1. The biodegradability of a wastewater is its ability to be treated effectively by a biological method. The COD/BOD_5 ratio provides physical information on the biodegradability of a wastewater. In other words, this ratio accounts for the fraction of biodegradable material among all oxidizable organic matter (Makhoukh et *al*., 2011).

Table 1. Average COD and BOD_5 values and average COD/BOD_5 ratios

Sites	**COD (mgO_2/L)**			**BOD_5 (mgO_2/L)**			**COD/BOD_5**		
	Min	Max	Moy	Min	Max	Moy	Min	Max	Moy
Site 1	47	197	115.53 ± 35.76	26.05	141	77.19 ± 27.55	1.30	2.15	1.67 ± 0.23
Site 2	42	202	134.37 ± 35.64	23.32	145	77.28 ± 30.49	1.24	2.82	1.84 ± 0.35
Site 3	68	339	132.05 ± 57.12	37	196	90.89 ± 37.42	1.22	2.05	1.48 ± 0.20

Table 1 shows that the average COD/BOD_5 ratio at site 1 varies between 1.3 and 2.15 with an average value of 1.67 ± 0.23. At site 2, this ratio varies between 1.24 and 2.82 with a mean value of 1.84 ± 0.35 and at site 3, it varies between 1.22 and 2.05 with a mean value of 1.48 ± 0.20. The COD/BOD_5 ratios at the different sites are less than 3. This shows that the wastewater from the UHCT is of a domestic nature and therefore contains biodegradable pollutants. The results obtained are consistent with those found for wastewater from hospitals in Tumaco (Colombia) and Yaoundé (Cameroon) and with results reported by other authors (Gnagne and Brissaud, 2003; Casas et al., 2015). The BOD5/ COD report that the ability to biodegradation is not conducive to biological treatment; this finding revealed that these kinds of pollutants are too aggressive than the polyphenolic compounds responsible of the olive oil mill wastewaters (Bouknana *et al.* 2014). Values below 3 of this ratio were also found for domestic wastewater (Amadou et al., 2011). To better interpret the results obtained from the physicochemical analyses, a statistical study using principal component analysis (PCA) was done. PCA is a multi-variate analysis method that allows the simultaneous study of a large number of non-representable variables in a space greater than three dimensions. It is a technique that specifies the relationships between the different variables and the phenomena at the origin of these relationships. The Pearson correlation matrix constructed is presented in Table II. For significant correlations, the Pearson correlation coefficient p must be less than 0.05 (Kaouani et al., 2007). Significant values are represented by bold values. The values in Table 2 that will be analyzed are those in bold. Among these values, we distinguish positive and negative values. A positive value at the intersection of two different parameters indicates a positive correlation between these two parameters and a negative value indicates a negative correlation between these two parameters. Variables with a positive correlation move in the same direction. This is the case, for example, of chloride and conductivity where there is a positive correlation between them. These two parameters evolve in the same direction. In other words, the conductivity increases with the concentration of chloride. The variables for which there is a negative correlation, evolve in the opposite direction. This is the case for example for dissolved oxygen and temperature. Otherwise, the concentration of dissolved oxygen decreases when the temperature increases. This evolution is in agreement with the data of thermodynamics which establish that the solubility of gases decreases when the temperature increases. Thus, analysis of the Pearson correlation matrix between the parameters yields the correlation summary shown in Table 3.

Table 2. Correlation matrix between physico-chemical parameters (Pearson)

Variables	OD	T (°C)	pH	Cond	TDS	Sal	DSS	COD	Cl^-	NO_3^-	NO_2^-	PO_4^{3-}
OD	**1**											
T (°C)	**-0.996**	**1**										
pH	-0.072	0.072	**1**									
Cond	-0.277	0.271	-0.013	**1**								
TDS	-0.276	0.271	-0.012	**1.000**	**1**							
Sal	-0.274	0.268	-0.010	**0.999**	**0.999**	**1**						
DSS	-0.116	0.121	0.095	-0.090	-0.088	-0.081	**1**					
COD	-0.090	0.086	0.100	**0.549**	**0.548**	**0.550**	0.002	**1**				
Cl^-	-0.243	0.243	0.349	**0.565**	**0.564**	**0.566**	-0.049	**0.412**	**1**			
NO_3^-	0.152	-0.144	-0.249	0.204	0.204	0.203	0.000	0.381	0.059	**1**		
NO_2^-	-0.209	0.204	0.331	-0.177	-0.177	-0.177	0.123	-0.024	0.063	**-0.524**	**1**	
PO_4^{3-}	0.107	-0.109	**-0.410**	0.200	0.201	0.200	0.088	0.111	0.049	0.390	**-0.595**	**1**

When we observe the distribution of eigenvalues (Figure 8), we see that after the first two values, the drop-off is made. Therefore, the first two axes are sufficient to represent the information collected on the UHCT wastewater as a whole. The first factorial plane made up of the F1 and F2 axes, allowed us to construct the correlation circle (Figure 9) between these different parameters. The correlation circle presented in **Figure 9** shows that the first factorial plane, made up of the F1 and F2 axes, represents 56.45% of the total inertia. This is sufficient to account for most of the inertia. Thus, the correlation coefficients between the different correlated parameters are recorded in **Table 4**. Observation of the correlation circle formed by the F1 and F2 axes shows that the F1 axis (horizontal), represents 34.70% of the total inertia and is predominantly positive pole. This axis is strongly positively correlated with conductivity (r =0.958), TDS (r = 0.957) and salinity (r = 0.957). This is shown by their position on the edge of the correlation circle and their proximity to this axis. This axis is also positively correlated with COD (r = 0.656) and chloride (r = 0.671). This axis presents highly mineralized effluent rich in organic matter. Therefore, it expresses both the mineralization and organic pollution of the studied wastewater. The F2 axis represents 21.75% of the total inertia. It has two poles, a positive pole formed by temperature (r = 0.640), hydrogen potential (r = 0.533) and nitrate ions (r = 0.760) and a negative pole formed by nitrite ions (r = -0.635), phosphate ions (r = -0.662) and dissolved oxygen (r = -0.642). This axis expresses warm, alkaline effluent rich in nitrate ions. In contrast, it expresses an effluent poor in dissolved oxygen, poor in nitrite ions and poor in phosphate ion. The DSS are not correlated with any axis.

Table 3. Summary of correlations between parameters

Variables	DO	T (°C)	pH	Cond	TDS	Sal	DSS	COD	Cl^-	NO_3^-	NO_2^-	PO_4^{3-}
DO	**1**											
T (°C)	-	**1**										
pH			**1**									
Cond				**1**								
TDS				+	**1**							
Sal				+	+	**1**						
DSS							**1**					
COD				+	+	+		**1**				
Cl^-				+	+	+		+	**1**			
NO_3^-										**1**		
NO_2^-										-	**1**	
PO_4^{3-}			-								-	**1**

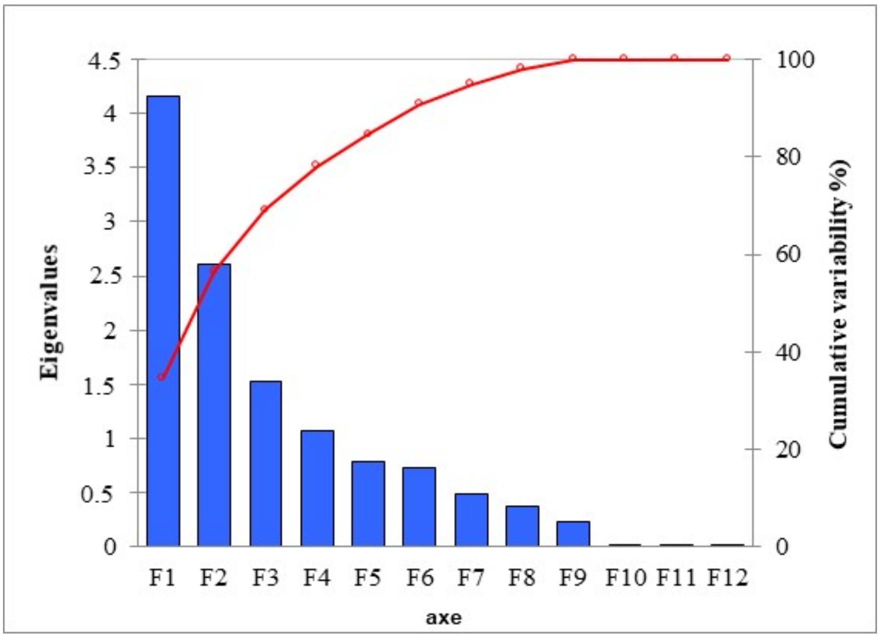

Figure 8. Eigenvalues and cumulative variability (%)

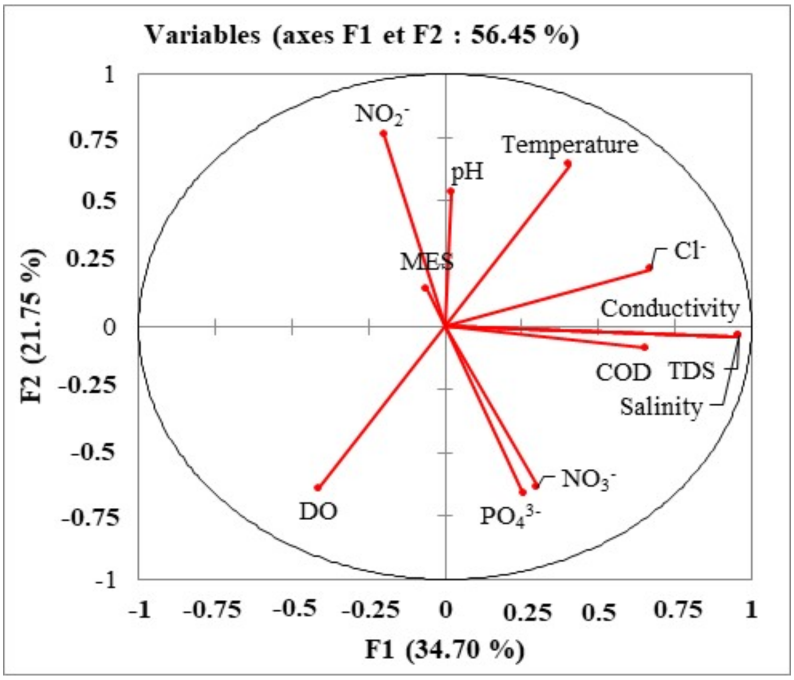

Figure 9. Correlation circle between the different parameters

Table 4. Correlation coefficients between the different parameters

	OD	T (°C)	pH	Cond	TDS	Sal	DSS	COD	Cl^-	NO_3^-	NO_2^-	PO_4^{3-}
F1	-0.411	0.407	0.023	**0.958**	**0.957**	**0.957**	-0.058	**0.656**	**0.671**	0.301	-0.197	0.257
F2	**-0.642**	**0.64**	**0.533**	-0.039	-0.039	-0.04	0.147	-0.086	0.227	**-0.635**	**0.76**	**-0.662**

Conclusion

At the end of this work, we can affirm that the UHCT wastewater presents physico-chemical parameters whose average values respect the WHO wastewater discharge standards. These are temperature, hydrogen potential, nitrite and phosphate ions, good average values of conductivity, TDS and salinity. The wastewater from this facility has on average a high content of nitrate ions and COD and BOD_5 values higher than the discharge values recommended by the WHO. Fortunately, the COD/BOD_5 ratios showed that the UHCT wastewater is biodegradable. The PCA analysis showed positive and negative correlations between some parameters, highly mineralized effluent rich in organic matter, warm, alkaline effluent rich in nitrate ion, an effluent poor in dissolved oxygen, poor in nitrite ion and poor in phosphate ion.

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Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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