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Physico-Chemical Analysis of Slaughterhouse Wastewater to Develop Appropriate Treatment: The Case of Souk el Arbaa. Morocco

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Abstract

This study aimed to characterize and estimate the pollution potential of wastewater discharged into the Mda River, due to effluents from the city's municipal slaughterhouse, with the goal of formulating recommendations for appropriate treatment to reduce the serious impact on not only public health and the environment, but also on the city's socio-economic activities. A systematic inventory was conducted over the period from January to December 2018. Furthermore, physico-chemical analyses show that the slaughterhouse's wastewater reveals a significant pollutant load in terms of organic matter, with COD (average = 280 mg/L), BOD5 (average = 186 mg/L), TSS (average = 300 mg/L), and mineral matter expressed as Chlorides (average = 350.5 mg/L), Electrical Conductivity (average = 2690 µs/cm), with a pH of 7.57. The average concentration of ammonium ions is around 11.4 mg/L, while that of Nitrates is approximately 1.74 mg/L. Despite the high organic load of this wastewater (BOD5/COD ratio = 0.66 and TSS/BOD5 = 1.66), it shows satisfactory biodegradability. The examination of the COD/BOD5 ratio = 1.50 highlights the biodegradable nature of the wastewater from the city's municipal slaughterhouse, for which treatment appears to be entirely appropriate.

Subject Areas

Public Health, Life Sciences, Environmental Sciences

Keywords

Wastewater, Physico-Chemistry, Pollution, River Mda, Morocco

1. Introduction

The town of Souk el Arbaa, like other Moroccan towns, is faced with environ-

mental degradation caused by a set of factors, particularly the collection and disposal of raw sewage. This phenomenon has been more pronounced in recent years due to an economic and social transition with additional pressures caused by demographic growth, climate change, and urbanization. Slaughterhouses, as a small industry, use a remarkable volume of water for washing, eliminating fecal waste, stomach contents, and blood. These processes require an evacuation system separating solid waste and fats, as well as a specific treatment. Various studies have been conducted to investigate and treat this type of wastewater using treatment plants, either through aerobic methods [1] and [2] or by using anaerobic techniques [3] and [4]. There are also other treatment methods for purifying slaughterhouse wastewater, such as sand filtration [5] and electrocoagulation [6]. It should be pointed out that many Moroccan cities have collected data on the quality of wastewater from slaughterhouses; however, there is limited data on the characterization and treatment of wastewater from the Souk el Arbaa slaughterhouse. Given its proximity, the Mda River remains the only wastewater collection point in the city, which constitutes a concerning source of pollution. The main objective of the study in the city is to define the characteristics of the slaughterhouse's wastewater discharge by carrying out a physico-chemical analysis identifying certain key and global parameters of wastewater pollution. Finally, it aims to identify measures to protect the receiving environment, as it is an essential source of water for livestock and the irrigation of the agriculture of people living nearby, and by suggesting a means of adequate treatment of this waste.

2. Material and Methods

2.1. Study Area

The city of Souk el Arbaa is located on the northern edge of the Gharb plain, 120 km from the Moroccan capital. It is equipped with a unitary sewage system adapted to the topography, discharging more than 80% of its wastewater into the Mda River [2]. The average temperature ranges between 13˚C in December and 26˚C in August. While the average annual rainfall is 700 mm, the dry period is relatively long; stretching from June to September; during this period, the monthly rainfall barely exceeds 9 mm (See **Figure 1**).

Figure 1. Geographical location of the city of Souk el Arbaa.

2.2. Experimental Protocol

2.2.1. Physicochemical Analyses

Wastewater sampling was conducted a monthly basis, from January 2018 to December 2018, at the slaughterhouse discharge point. Samples were stored in accordance with the general guide for the storage and handling of samples [7].

2.2.2. Parameters & Methods Analyses (See Table 1)

Table 1 below represents the physicochemical parameters studied in our research, the analysis methods used, and their sources.

Table 1. The studied parameters and the analysis methods.

Parameters	Methods analyses	Untie	Sources
Température	pH meter brand PHB-1 cell	˚C	Water Analysis, Rodier, 2005 [7]
pH	pH meter brand PHB-1 cell		Water Analysis, Rodier, 2005 [7]
Electrical Conductivity	Conductimeter type (WTW LF330/Tetra Con® 325, and type J DDS-308A)	s/cm	Water Analysis, Rodier, 2005 [7]
Dissolved Oxygen	pH meter brand PHB-1 cell	(mg/L)	Water Analysis, Rodier, 2005 [7]
Suspended Solids (TSS)	Filtration on a paper filter	mg/L	Norme EN 872:1996 [8]
Chlorides and alkalinity expressed in $CaCO_3$	Chlorides and alkalinity expressed as $CaCO_3$ are determined by the pre-dosed tablet counting method	mg/L	Norme NFT 90-10 [8]
BOD5	Determined with a BOD Oxi-Top meter following incubation at 20˚C for 5 days.	mg/L	According to the technique described by DIN [9]
COD	Method by oxidation with $KMnO_4$	mg/L	DIN 38409-H52. [10]
Nitrates	method.-photometric with 2.6 - diméthylphénol	mg/L	According to the technique DIN [11]
Nitrite	photometric	mg/L	According to the technique according to DIN [12]

3. Results & Discussion

3.1. Physico-Chemical Parameters of Mixed Slaughterhouse Wastewater

The pollution of raw wastewater is assessed based on the determination of sever-

al physico-chemical parameters that characterize it, and Table 2 groups together the physico-chemical characteristics of the slaughterhouse wastewater.

Table 2. Physicochemical parameters of wastewater from the souk el Arbaa slaughterhouse.

Parameters	Min value	Max value	Average	Ecart-type	Number of samples
Temperature	16.8	29	22.9	8.61	10
pH	7.2	7.94	7.57	0.52	10
DO (mg/L)	1.1	1.6	1.35	0.353	10
CE (µs/cm)	2670	2710	2690	28.28	10
Chlorides (mg/L)	298	403	350.5	215.66	10
Alkalinity (mg/L de $CaCO_3$)	120	195	157.5	53.03	10
BOD (mg/L)	162	210	186	33.94	10
COD (mg/L)	230	330	280	70.71	10
TSS (mg/L)	220	380	300	141.42	10
NH_4^+ (mg/L)	8.55	14.25	11.4	4.03	10
Nitrates (mg/L)	0.88	1.55	1.215	0.47	10
Nitrites (mg/L)	0.5	0.8	0.65	0.212	10

3.2. Discussion

3.2.1. Potential of Hydrogen & Temperature

The wastewater samples from the slaughterhouse show a relatively neutral pH, with optimum values between 7.2 and 7.94. When the pH is below 5 or above 8.5 the growth of micro-organisms is directly affected. As a result, the pH is an important factor in interpreting corrosion in the piping of purification facilities. The temperature ranges between 16.8˚C and 29˚C, with an average of 22.9˚C.

3.2.2. Electrical Conductivity

It reflects the overall degree of mineralization, informing us about the salinity level. This is a numerical expression of the water's capacity to conduct an electrical current, measured in millisiemens per centimeter. These findings imply that the waters from the studied slaughterhouse significantly contribute to high levels of conductivity in the water during both wet periods and dry seasons. The values range from 2670 µs/cm to 2710 µs/cm, with an average of 2690 µs/cm. Significantly, the recorded EC (Electrical Conductivity) concentrations have values exceeding the World Health Organization (WHO) standard, which is 500 µS/cm.

3.2.3. Chlorides

Chloride levels are crucial indicators of water quality, reflecting potential contamination and salinity. The consequences of chloride levels in water are significant. High chloride concentrations can have a negative impact on human health and have ecological consequences, affecting those dependent on water resources.

They also pose a potential threat to aquatic ecosystems by disrupting the salinity balance, which can harm aquatic organisms, their habitats, and the overall health of ecosystems (Madhav, *et al*., 2020) [13]. The average levels recorded the slaughterhouse wastewater are 350.5 mg/L, with extreme values (from 298 mg/L as the minimum value to 403 mg/L as the maximum value). These concentrations are higher than those of the Kenitra slaughterhouse (Belghyti *et al*., 2009) [14], and exceed the World Health Organization (WHO) discharges standard of 250 mg/L. The wastewater is moderately saline with a predominance of sodium chloride, given that there are salt deposits upstream of the discharges. Additionally, the high chloride concentration results from the fact that drinking water is too concentrated in chloride (**Table 2**).

3.2.4. Total Nitrogen

Nitrates, like other nitrogen forms, rapidly evolve in the natural environment according to the nitrogen cycle [15]. The presence of nitrogen in wastewater can be either organic or mineral. Organic nitrogen is characterized as a constituent of proteins, polypeptides, amino acids, and urea. Mineral nitrogen, which includes ammonium (NH_4^+), nitrites (NO_2^-), and nitrates (NO_3^-), make up the majority of total nitrogen. The nitrate values recorded in the wastewater discharges vary considerably over the study period. Thus, the nitrate level in the effluents of the municipal slaughterhouse range between 0.88 mg/L and 1.55 mg/L, with an average concentration of 1.21 mg/L, and they are slightly lower than those recorded in the effluents of the Kenitra slaughterhouse. Comparing the average nitrate concentrations in the analyzed wastewater with the quality standard for irrigation water shows that these concentrations are below 50 mg/L, which suggests that these effluents are acceptable for irrigating crops [16]. Whereas the ammonium ion (NH_4^+) concentration values range between 8.55 mg/L and 14.25 mg/L, with an average of around 11.5 mg/L (**Table 2**). These remain slightly lower than those recorded in the wastewater of the Eljadida slaughterhouse and those recorded in the wastewater from the Kenitra slaughterhouse [17]. The AMMONIUM form is not toxic. However, in water with a pH higher than 7.5 a fraction can be transformed into AMMONIA (ammonia gas suspended in water), which is toxic for fish and organisms living in water, even at low concentrations, (The rise in temperature and pH amplifies the phenomenon).

3.2.5. Alkalinity

The variations in wastewater alkalinity are closely related to those of the degree of mineralization (electrical conductivity, total hardness, pH), which also provides an indication of the degree of oxidation of organic compounds (in the case of wastewater). The concentration of carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) in water depends on the CO_2 content as the latter is highly soluble in water [16] (207 times more than oxygen), and its solubility depends on temperature and atmospheric pressure. The $CaCO_3$ content is slightly high in the analyzed samples, which could be attributed to the wastewater discharges that are

less loaded with fermentable organic materials likely be oxidized, resulting in high CO_2 production [17]. $CaCO_3$ is slightly soluble in water; however, the presence of CO_2 gives water a much greater dissolving power by transforming calcium carbonate into calcium bicarbonate, which is more soluble in water according to the following reaction:

$$CaCO_3 + CO_2 \rightarrow Ca\left(HCO_3\right)_2 \rightarrow Ca^{2+} + 2HCO_3^-$$

For comparison, Massé and Masse [18], reported average values between (83 and 900 mg/L) in $CaCO_3$, and very high values between 667 and 1056 mg/L for slaughterhouse effluents in Canada, in two separate studies.

3.2.6. Organic Matter & Suspended Solids

To indirectly assess the total organic load present in wastewater, the following main quality parameters are used: the biochemical oxygen demand (BOD5) is defined by the amount of oxygen consumed by micro-organisms to ensure the biological degradation of organic matter. This measure provides an approximation of the biodegradable organic matter load in an urban discharge, and the chemical oxygen demand (COD), which represents the quantity of oxygen consumed, in mg/L, by chemically oxidizable materials present in effluent. Mineral and organic particles present in the receiver are suspended solids.

3.2.7. Biochemical Oxygen Demand (BOD)

In this way, the concentration of BOD levels recorded fluctuate between 162 mg/L (minimum value) and 210 mg/L (maximum value), with an average value of 186 mg/L (**Table 2**). By examining the surface water quality grid, it can be seen that the quality of wastewater from the Souk el Arbaa city slaughterhouse is extremely poor, exceeding 25 mg/L. The high values of BOD could be explained by the abundance of organic matter (stomach debris) and by the concentration of this effluent by the blood from the municipal slaughterhouse discharges.

3.2.8. Chemical Oxygen Demand (COD)

Throughout the study period, it was observed that COD values show a non-negligible variation. Indeed, the pollutant load of slaughterhouse wastewater, as measured by its COD, remains one of the most important criteria used in designing wastewater treatment to determine the degree of treatment required. Moreover, the recorded values are 230 mg/L as the minimum value and 330 mg/L as the maximum value, with an average of about 280 mg/L, which are slightly higher than the values found in the wastewater of the Kenitra slaughterhouse. The COD values are lower than those of urban waters in Morocco (500 - 1500 mg/L) [18]. These average values are below 500 mg/L, considered as the direct discharge limit value. Furthermore, these wastewaters are classified as very poor according to the surface water quality standards [19].

3.2.9. Total Suspended Solids (TSS)

Turbidity serves as an indicator of water clarity, reflecting the presence of sus-

pended particles (TSS), which contribute to the water's composition through their ion exchange effects or absorption on both trace chemical elements and microorganisms. The turbidity levels in this study were lower than what was recorded by [14] (Belghyti *et al*., 2009), who analyzed water samples from the Sebou River, where slaughterhouse effluents were discharged. High levels of turbidity can hinder photosynthesis by preventing sunlight penetration into the river, which in turn would lead to a decrease in dissolved oxygen production and a reduction in plant survival. According to the results, it is noted that the wastewater from the slaughterhouse carries the same loads as Moroccan urban wastewaters, which TSS concentrations of range between 250 and 700 mg/L [20]. Moreover, these average TSS values in the analyzed wastewater are higher than the value set by Moroccan standards [16] (**Table 3**). The found values are lower than those recorded in Kenitra and Eljadida. The degradation reactions—aerobic—of organic matter and more broadly, the biological balance of aquatic environments are influenced by the presence of dissolved oxygen. In wastewater treatment systems, its total disappearance is often accompanied by the emergence of H2S in the air, resulting from the reduction of sulfur compounds present in the effluents, and resulting from the acidic attack on the concrete of the pipes [18]. Based on the recorded values of dissolved oxygen in the wastewater, it can be concluded that these waters are classified from medium quality to very poor [21].

3.3. Evaluation of Organic Pollution in Wastewater

To better understand the origin of the wastewater from the studied effluents of

Table 3. Limit values for different discharges, whether direct (Stormwater), Indirect (Wastewater), or water intended for crop irrigation.

Parameters	VLR direct rejetion	VLR indirect rejetion	Water intended for irrigation
Temperature	30˚C	35˚C	35˚C
pH	6.5 - 8.51	6.5 - 8.51	6.5 - 8.5
BOD	100 mg/L	500 mg/L	-
COD	500 mg/L	1000 mg/L	-
TSS	50 mg/L	600 mg/L	2000 mg/L
C.E	2780 µS/cm	-	8.7 µS/cm
Azote Kjeldahl	30 Mgh/L	-	-
total Phosphore	10 mgP/L	10 mg/L	-
Chlorides (Cl)	Chlore actif Cl_2 (0.2 mg/L)	--	Surface irrigation (350 mg/L) Sprinkler irrigation (105 mg/L)

the slaughterhouse, it is essential to calculate the COD/BOD5, BOD5/COD, TSS/BOD5 ratios, and to evaluate the Oxidizable Matter (OM) (Table 4).

3.3.1. BOD5/COD Ratio

The BOD5/COD ratio is often considered to define industrial pollution because it provides very interesting information about the origin of wastewater pollution and the available treatment options. For our research, this ratio presents a high value of approximately 0.664 (Table 4). This generally applies to discharges loaded with organic matter. These wastewaters are quite unstable due to their organic load, meaning they will quickly transform into "digested" forms with odors emitting risk. Indeed, the waters contain mainly organic substances, since it only drains wastewater from the slaughterhouse.

3.3.2. COD/BOD5 Ratio

The COD/BOD5 ratio provides an indication of the origin of organic pollution and also allows estimating the biodegradability of an effluent by indicating the characteristics of these wastewaters. If the COD/BOD5 ratio is less than 3, the waters are of a domestic nature [18]. The wastewater from the municipal slaughterhouse presents a COD/BOD5 ratio ranging from 1.419 mg/L to 1.571 mg/L (Table 4), which is consistent with that of urban wastewaters with a domestic predominance. However, since the COD/BOD5 ratio is less than 3, it can be concluded that even though the wastewater from this discharge presents a high organic load, it is easily biodegradable.

3.3.3. TSS/BOD5 Ratio & Oxidizable Matter (OM)

The degradation of oxidizable matter by absorbing oxygen does not impact environments, but it can lead to hypoxia or even anoxia of the waters when excessive. The waters are then described as "eutrophied". It is difficult to directly measure the organic compounds present in water. Therefore, the amount of oxygen required for their degradation is assessed in the laboratory, using either biochemical or strictly chemical methods, in accordance with standardized instructions. According to Table 4, a high BOD5/COD ratio (0.66) is observed for the wastewater of the municipal slaughterhouse, confirming that the wastewater discharged by this outlet contains a high concentration of organic matter. An average TSS/BOD5 ratio of 1.61 confirms the estimation of oxidizable Matter,

Table 4. Ratios of slaughterhouse wastewater.

	Min	Max	Avg	Standard deviation
BOD5/COD	0.704	0.636	0.664	0.038
COD/BOD5	1.419	1.571	1.505	0.107
TSS/BOD5	1.358	1.809	1.612	0.318
Oxidizable materials (mg/L)	184.6	250	217.3	46.24

which is estimated at about 228.34 mg/L. Furthermore, the ratio between COD and BOD5 is low (1.505), leading to the conclusion that the quantity of organic matter present in the wastewater from this discharge is readily biodegradable, as highlighted by Henze *et al.* [22].

3.3.4. Pearson Correlation Matrix for Water Quality Parameters

The Pearson correlation results for the physic-chemical parameters over d the study period are depicted in the correlation matrix in (Table 5) below. The correlation matrix reveals significant relationships between various water quality parameters. Significantly, temperature exhibits a strong negative correlation with dissolved oxygen (−0.694), suggesting that as temperature increases, dissolved oxygen tends to decrease. This inverse relationship is indicative of potential contamination, affecting the water's acidity. Moreover, dissolved oxygen (DO) shows a strong positive correlation with Nitrites (0.606), implying that higher Nitrites are associated with increased DO levels, and a strong positive correlation between temperature and electrical conductivity (0.811). However, certain correlations, such as those between Nitrates and NH_4^+ (−0.484), indicate complex interactions within the aquatic system.

According to Figure 2 and Figure 3, there is a 1.0 correlation between BOD5 and COD, suggesting a perfect positive correlation. This indicates that, in this specific dataset, BOD5 and COD vary in the same manner.

3.3.5. Calculation of Flows and Pollutant Loads

By the year 2030, the allocation for the city of Souk el Arbaa is 76 L/capita/day. Thus, the volume discharged by the inhabitants is estimated to be 80% of the potable water supply (PWS) allocation.

According to data from Table 6, the wastewater from the collectors of the city of Souk el Arbaa and that of the slaughterhouse produce a pollutant load in BOD5 of approximately 887.74 Kg/day, while that in TSS is about 1431.84 Kg/day

Table 5. Pearson correlation coefficients for physicochemical parameters in water samples.

Variables	T˚C	pH	CE	TSS	DO	BOD	Chlorides	NH_4^+	NO_2^-	NO_3^-
T˚C	1									
pH	0.339	1								
CE	0.811	−0.117	1							
TSS	−0.096	−0.057	−0.264	1						
DO	−0.694	−0.288	−0.531	0.027	1					
BOD	0.264	0.084	0.081	0.551	−0.674	1				
Chlorides	0.399	−0.145	0.481	0.431	−0.665	0.812	1			
NH_4^+	0.470	0.293	0.373	0.066	−0.741	0.557	0.469	1		
NO_2^-	−0.262	−0.139	−0.030	−0.458	0.521	−0.683	−0.584	−0.316	1	
NO_3^-	−0.410	−0.263	−0.113	−0.246	0.606	−0.618	−0.463	−0.484	0.875	1

Table 6. Flow and pollutant load of the city and the municipal slaughterhouse.

Data	Unit	Values
Daily flow	m^3/j	4772.28
Average hourly flow	m^3/h	198.86
Peak flow	m^3/h	332.06
Diurnal flow	m^3/h	298.26
BOD5 load	Kg/j	887.74
TSS load	Kg/j	1431.84

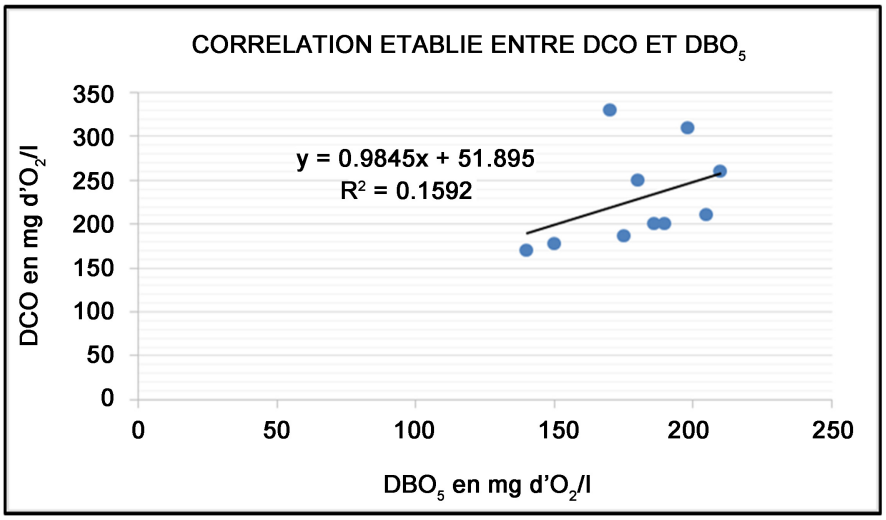

Figure 2. Correlation established between BOD_5 and COD of the wastewater from the Souk el Arbaa slaughterhouse discharge (Morocco), showing that $R^2 = 0.1592$ ($y = 0.9845x + 51.895$).

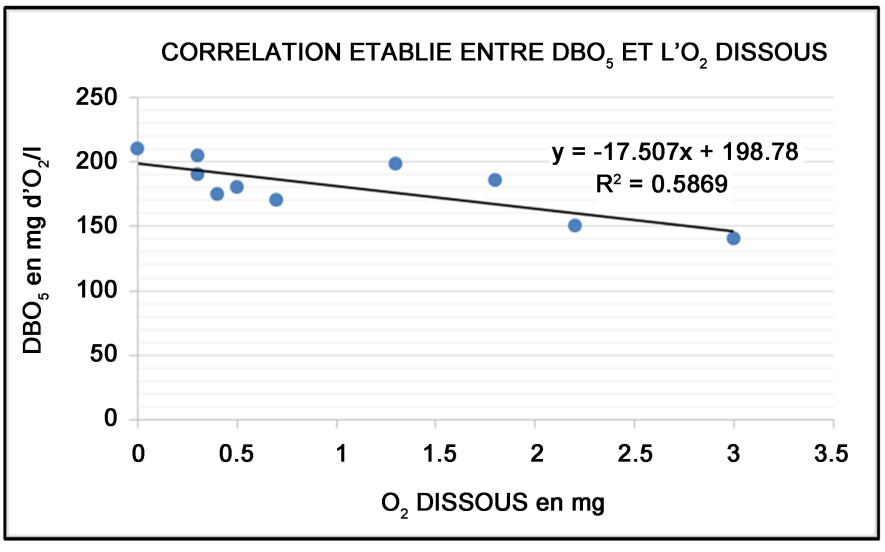

Figure 3. Correlation established between BOD_5 and dissolved O_2 of the wastewater from the Souk el Arbaa slaughterhouse discharge (Morocco), showing that $R^2 = 0.5869$ ($y = 17.507x + 198.78$).

(Table 5). The daily flow amounts to approximately 4772.28 m^3/day, with an average hourly rate of 198.86 m^3/h, and a peak flow of 332.06 m^3/h. The diurnal flow, which corresponds to the 16 consecutive daylight hours during which the station can receive the largest volume of wastewater, is around 298.26 m^3/h. The values indicated in Table 6 are similar to those of cities in its category (with a population between 20,000 and 100,000 inhabitants) [23]. This will aid in the future design of a wastewater treatment plant in the city of Souk el Arbaa. Once the degree of organic pollution has been assessed, it can be noted that all the studied parameters (notably BOD5, COD, and TSS) classify the wastewater from the city and the slaughterhouse in the category of medium to high concentrations.

4. Conclusions

Based on the analysis of the results, it appears that the pollution criteria for the city's wastewater, especially with regard to BOD5, COD, and TSS, classify the analyzed wastewater in the medium to high concentration category. This wastewater presents an organic load that is 5 to 7 times higher. In addition to the presence of organic matter, it contains the necessary amounts of organic nitrogen to meet the needs of the purifying microorganisms in biological systems. However, low concentrations of orthophosphates may pose a problem for biological treatment.

It can be deduced that the wastewater coming from these discharges is easily biodegradable, even if the rates of BOD5/COD and TSS/BOD5 are increasing. According to the analysis of the COD/BOD5 ratio, it is clear that the slaughterhouse's wastewater is biodegradable, suggesting that a biological treatment is entirely appropriate. According to the Ministry of the Environment, it is essential to treat this wastewater to obtain an effluent that meets the standards for direct and indirect discharges. The slaughterhouse produces wastewater that is suitable for biological treatment concerning BOD5, TSS, and nutrients (nitrates, nitrites, and orthophosphates). The raw wastewater from the city's municipal slaughterhouse has to be treated, as it contains physicochemical pollution parameters that significantly exceed the general limits for direct and indirect discharges into the receiving environment. This water leads to the contamination of the receiving watercourses, consequently causing enormous nuisances for the residents, neighboring users, and faunal resources.

Conflicts of Interest

The authors declare no conflicts of interest.

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