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Water Quality Assessment of Slaughterhouse Wastewater Draining into the Oued Beht River, Morocco

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ABSTRACT

Slaughterhouses are known for high water consumption due to the variety of processes requiring water. The wastewater produced by these facilities significantly impacts the environment. This study aimed to assess the level of pollution caused by slaughterhouse waste discharged into the Beht River in Sidi Slimane, Morocco. From October 2012 to July 2013, ten urban wastewater collectors (C1 to C10) were selected based on their location—either within the slaughterhouse area or carrying wastewater from it. Water samples were collected from these collectors and subjected to chemical and bacteriological analyses. The parameters measured included total suspended solids (TSS), biological oxygen demand over five days (BOD_5), chemical oxygen demand (COD), fecal coliforms (FC), and fecal streptococci (FS). In addition, a multivariate analysis was conducted, including principal component analysis (PCA) of the studied parameters. The results indicated an increase in contamination levels, particularly FC and FS, from upstream to downstream. The PCA revealed two principal components explaining 60.8% of the variance and demonstrated a strong correlation between physical, chemical, and temporal factors. The analyses showed increasing pollution levels and decreasing oxygen concentrations over time. When analyzed by station, the data explained 56.86% of the variance, confirming a strong correlation between physical, chemical, and spatial factors. Higher levels of pollution were observed at collectors C1 to C10 compared to the effluents from slaughterhouse outlets P1 and P2. The high microbial load in the water samples indicates significant fecal contamination, pointing to substantial pollution from slaughterhouse waste.

INTRODUCTION

The slaughterhouse produces effluents, partly because it brings the physiological fluids of slaughtered animals into contact with the external environment and partly because it uses water as a solvent for cleaning tasks **(Asfers *et al.*, 2016a; Ait Messaad *et al.*, 2022a)**. After reviewing general information on the various roles water plays in the food industry, the focus will shift to how water is consumed in slaughterhouses. The necessary tools for analyzing the pollutant load of the effluent will then be outlined, followed by an examination of this load across different types of slaughterhouses. This approach aims to identify the characteristics of the slaughterhouse's environmental impact, both organic and microbiological **(Jaber *et al.*, 2017; Lotfi *et al.*, 2020a; Bendary & Hegab, 2024)**.

Slaughterhouses generate a large amount of waste from the slaughter and preparation of animals. The volume of products to be processed increases significantly when the establishment includes, in addition to slaughtering, tripe-gutting and fecal matter disposal facilities.

Liquid effluents and solid waste, generating numerous harmful microorganisms that spread in the water environment, are likely to cause serious human infections **(Asfers *et al.*, 2016b; Ait Messaad *et al.*, 2022b; Chakit *et al.*, 2024)**. The process of chemical contamination of groundwater is characterized by vertical migration of the polluting fluid in the unsaturated environment between the ground surface and the water table, leaving in its wake impregnated soils at a concentration close to saturation **(Lachheb *et al.*, 2024)**. The contents of the soluble fractions of the polluting product change by time and distance from the source under the effect of dilution, convection, dispersion due to the tortuosity of the flows between the grains of the ground, and finally, fixation or degradation phenomena. Once the piezometric surface is crossed, the propagation of the pollutant encounters practically no obstacles. In the aquifer, due to the scarcity or absence of oxygen, organic matter, and microorganisms, the purifying role is reduced compared to the saturated zone **(Lamrani Alaoui *et al.*, 2008; Lachheb *et al.*, 2024)**.

The pollution released directly depends on the blood recovery rate, the fecal matter disposal method, the size of the tripe-gutting facility, and the presence of activities such as salting and canning **(Bendary & Hegab, 2024)**.

Slaughterhouse effluents are assessed using numerous parameters due to their wide range of pollutant loads. These parameters include: biological oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), and other parameters such as pH, toxicity, detergents, etc.

Special attention must be paid to sludge, chemical cleaning waste, and tanning waste. Due to their composition, it is advisable to separate and treat them separately, as they contain high levels of NTK, toxicity, and metals that could significantly affect the rest of the waste if mixed.

Wastewater from these slaughterhouses is considered very harmful to the receiving environment when it is discharged without any prior treatment. Thus, for economic reasons, this industry is increasingly forced to reduce its pollutant load and to reconsider recycling and recovery channels, which is also advantageous from a perspective of overall resource and environmental management.

Slaughterhouse discharges have been classified by the American Environmental Protection Agency as among the most harmful to the environment. The Sidi Slimane Municipal Slaughterhouse is a fixed station where all operations (bleeding, skinning and evisceration) are carried out in the same place. The carcasses are then hung on hooks from the rail network for evacuation to the "fiscal" weighing and health inspection. The average quantity of meat prepared in this slaughterhouse is around 4,500kg/ day and it produces on average 2,400kg/ day of waste. This slaughterhouse is not yet equipped with systems for recovering slaughter by-products for possible recovery. Blood samples, stomach contents, feces, and urine of animals and possibly other organic constituents are drained with the cleaning water to the collector and are then discharged directly into the sea **(El-Morhit *et al.*, 2008)**. The objective of this work was on the one hand, to characterize the discharges from the municipal slaughterhouse of the city, discharged into the sea in their raw state, and on the other hand, to study their impact on the quality of the receiving waters.

The current work aimed to characterize the wastewater from the slaughterhouse and the water from some domestic points in order to evaluate the impact of the slaughterhouse waste on the quality of the water using a multivariate analysis.

MATERIALS AND METHODS

1. Study area

The city of Sidi Slimane is located on the southern edge of the Gharb plain, 70km from the city of Kenitra. Sidi Slimane is crossed by the Beht River. This river originates in the Azrou area, where several wadis in this region converge, including the Tigrigra and Ifrane wadis. While crossing the central plateau, the Beht wadi is fed by the contributions of numerous wadis such as: Bou Achouch, Kharouba, etc.

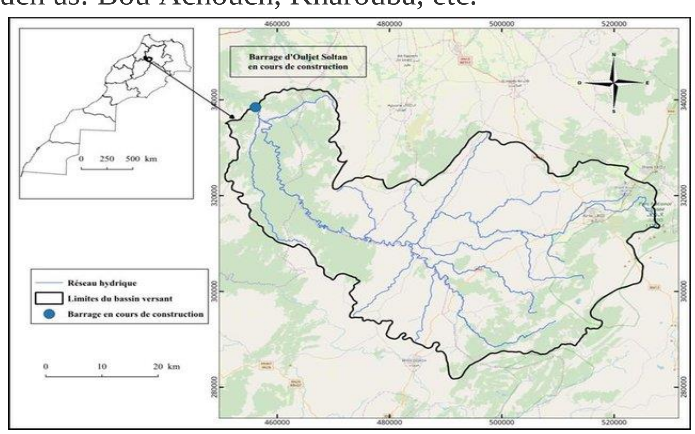

Fig. 1. Study area location

It is located in the irrigated sector of the Beht River on an area of 30,000 ha. The area is served by the El Kansra dam 30km south of Sidi Slimane. The predominant crops in the area are beets, cotton, oranges, cereals. Wastewater and rainwater are channeled into a unitary-type sanitation system characterizing the right zone of the city of Sidi Slimane. In the left zone of the city, a mixed network including main collectors and one of the secondary collectors operates in single mode, and a pseudo-separative mode characterizes the rest of the network. The total length of the sanitation network is 150km, serving approximately 86% of the population. Other uses of individual sanitation systems are septic tanks or cesspools. In 2012, red meat production was 970 tons, 60% of which was beef and 40% sheep. The wastewater from this discharge is loaded with solid waste, fat, abundant organic matter (rumen debris), and concentrated with the blood of slaughtered animals.

The city of Sidi Slimane has a slaughterhouse for receiving and inspecting animals before slaughter, as well as for quality control of the meat intended for final consumption.

3. Study sites and sampling

Water samples were collected from ten urban wastewater collectors (C1 to C10), located inside the slaughterhouse, and the collector of P1 carrying domestic wastewater and wastewater derived from P2 of the slaughterhouse (Table 1). 1-liter and 500ml polyethylene bottles were used to collect wastewater samples.

Table 1. Location of output collectors at domestic points

Station	Location (m)	X;Y
C1	31.41	450495.27;406335.44
C2	36.15	450639.05;406515.07
C3	36.93	450679.51;406505.61
C4	36.98	450733.75,406503.03
C5	37.58	450794.88;406515.07
C6	36.73	450847.40; 406528.90
C7	35.29	450893.03; 406555.55
C8	34.93	450915.42; 406569.30
C9	34.13	451020.45; 406766.49
C10	32.69	451174.00; 407020.52
P1	30.40	451136.28; 407153.38
P2	30.66	451108.09;407152.80

3. Physico-chemical and bacteriological analysis

The physicochemical analyses of slaughterhouse waste and effluents (pH, temperature T, suspended matter MES, chemical oxygen demand COD, biochemical oxygen demand BOD5, water, dry matter DM, total Kjeldahl nitrogen NTK, total phosphorus PT, non-protein nitrogen NNP, crude protein PB, fat MG, carbohydrates, and ash) were carried out according to the methods described in the AFNOR standard **(Bendary & Hegab, 2024)**. The physical parameter measure was conducted immediately *in situ*, while the chemical and microbiological variables analysis was conducted in the laboratory after one hour of sampling. To determine the load of microorganisms indicating fecal pollution, inoculations were carried out from the samples at different incubation times and temperatures on the selective culture media: BLBVB for fecal coliforms (CF), Slanetz and Bartley for fecal streptococci (SF) (Difco). For the search and counting of eggs and helminths, the Willis technique and the Baerman technique were used **(Bibi *et al.*, 2023)**.

Bacteriological analysis targeted pollution indicator germs, including fecal coliforms (FC) and fecal streptococci (FS) **(Rodier, 2009)**. Using a 0.45µm thick filter membrane, each 100ml dilution was filtered and then placed in a culture medium specific to fecal coliforms (FC). These bacteria are recognizable by their rounded yellow appearance (in Tergitol agar medium). These germs were incubated at 44°C for 48h for FC. Fecal streptococci (FS) are characterized by a brick-red appearance after incubation at 37°C in a culture medium (Slanetz yellow).

3. Statistical analysis

A descriptive analysis was performed using SPSS software. To correlate physical, chemical, spatial (collectors), and temporal (months of the year) parameters, a principal component dimension reduction was performed. Also, a multiple correspondence analysis (MCA) was applied to reveal the relationship between environmental and bacteriological parameters of the study sites, using the same software.

RESULTS

1. Physico-chemical and bacteriological parameters

In order to evaluate the influence of human activities on the quality of wastewater drained by Oued Beht in the city of Sidi Slimane, a statistical analysis was applied to all parameters in different seasons. With PCA, this statistical method allows the initial quantitative variables that are more or less correlated with each other to be transformed into new quantitative variables, decorrelated, called principal components **(Lawniczak, 2016)**. This method is widely used to interpret hydrochemical data **(Jain *et al.*, 2010)**.

PCA was performed on a data matrix composed of 10 samples: 12 x 1 stations in the rainy season and 10 samples: 12 x 1 stations in the dry season. The parameters of temperature, pH, total suspended solids, chemical oxygen demand, biochemical oxygen demand, conductivity, ammonium nitrate, chlorides and phosphates were measured. Descriptive analyses of the physicochemical parameters of the water quality of the river Beht in the following months (Table 2).

Table 2. Location of output collectors at domestic points

Parameter	Mean ± SD	Mean	Standard deviation
T °C	18.63±0.64	18.51	1.46
Ph	7.52±0.103	7.52	0.09
Conductivity (δ / cm)	1376.79±64.69	1379.93	103.99
NO3- (mg/l)	2,914±0.77	2.91	0.47
NH_4^+ (mg/l)	47.05±15.39	47,43	5.48
Nt (Total nitrogen)	102.31±83.26	99.14	11.67
Cl- (Chlorides) mg/l	221.62±17.26	219.74	20,24
Total phosphorus (mg/l)	17.75±6.08	17,796	2,448
BOD5 (mg O_2/l)	728.72±1077.07	723,949	40,286
COD (mg O_2/l)	1645.93±2705.26	1633,226	50,221
Total suspended solids (mg/l)	416.32±76.32	413,436	40,045
FC (CFU/100ml)	39114000	51251535,016	6,891
FS (CFU/100ml)	10075408	10474598,269	6,424

2. Principal component analysis

Principal component analysis explained 60.75% of the total variance with F140.05% and F220.70%. Water alkalinity was expressed by the strong correlation between pH, temperature, and biological indicators of fecal contamination.

The F1 axis reveals a contrast between nitrate-polluted waters and waters polluted by organic matter **(Lamrani Alaoui, 2014)** defining an increasing pollution gradient from left to right, months, which leads to a decrease in oxygen and an increase in the pollution parameters BOD5, COD, phosphates, chlorides, and total nitrogen, reflecting strong mineralization **(Jain, 2010)**. At the same time, the F2 axis showed an increase in conductivity from left to right (Fig. 2).

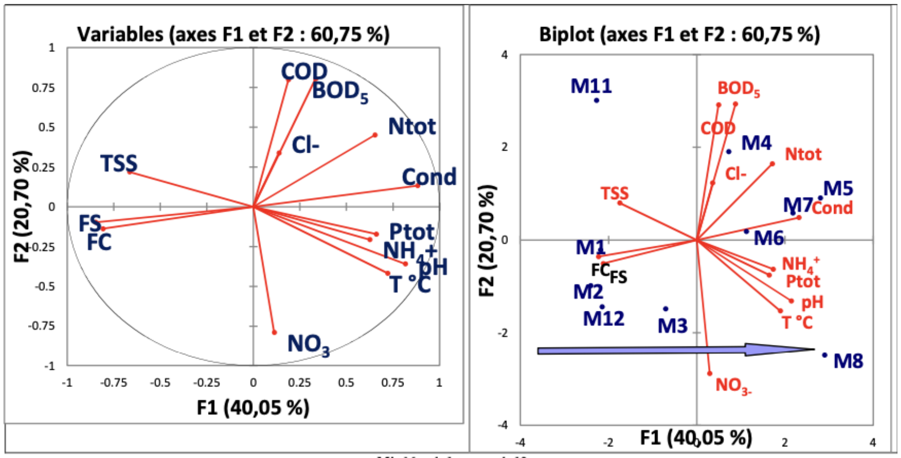

Fig. 2. Correlation between physicochemical parameters and month

Table (3) shows a descriptive analysis of the physicochemical and bacteriological parameters of the water quality of the river Beht per station.

Table 3. Measure of physico-chemical and bacteriological parameters of Oued Beht water according to stations

Parameter	Mean ± SD	Mean
T °C	18.630	0.638
pH	7,526	0.103
Conductivity (δ / cm)	1376.792	64,690
NO3- (mg/l)	2.914	0.775
NH_4^+ (mg/l)	47.051	15.388
Nt (Total nitrogen)	102,307	83.260
Cl- (Chlorides) mg/l	221.625	17.265
Total phosphorus (mg/l)	17.747	6.076
BOD5 (mg O_2/l)	728.723	1077.068
COD (mg O_2/l)	1645.926	2705,261
Total suspended solids (mg/l)	416.318	76.325
FC (CFU/100ml)	39114100	51251635
FS (CFU/100ml)	10075508	10474698

3. COD/BOD5 ratio

Fig. (3) presents the pollution assessment in different stations (C1 to C10 and P1 and P2). Fig. (3) shows high pollution of organic matter in terms of BOD5 and COD and for the station P1, which could be due to the discharge point of the slaughterhouse.

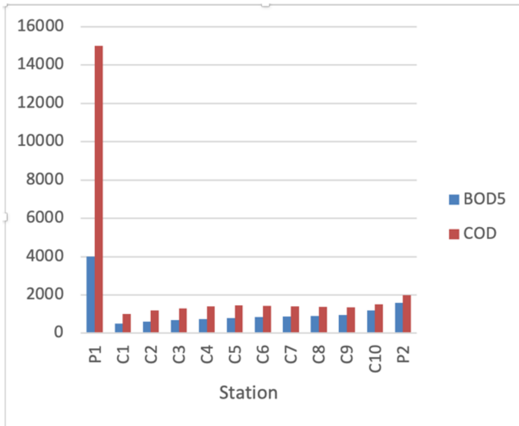

Fig. 3. COD and BOD5 measures according stations

The analyses showed a high value of the COD/BOD5 ratio (2486) in the wastewater from the municipal slaughterhouse P1, indicating an overload of the wastewater drained from the collector with organic matter (Fig. 4).

The estimated COD and BOD_5 were 10,607.048 and 4,284 mg O_2/l, respectively. The organic load of the wastewater from this collector was easily biodegradable.

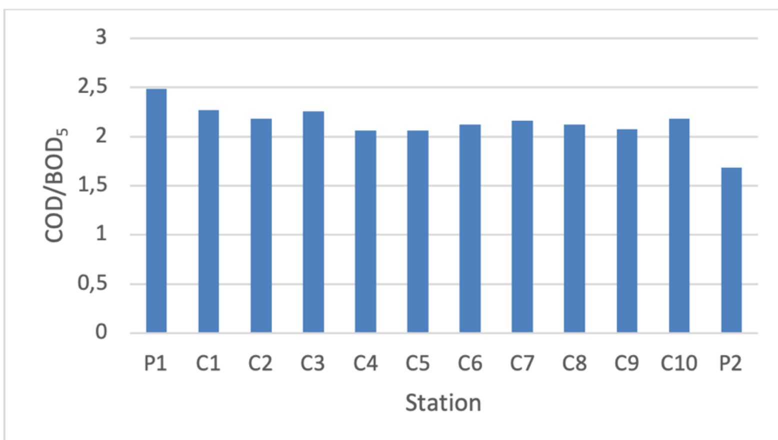

Fig. 4. Performance ratios at different stations.

Well water therefore presents a real danger for consumption due to its pollution by nitrogen compounds and other chemical pollutants and should therefore not be used as observed in the houses surrounding the Sidi Slimane slaughterhouse, for washing dishes. The microbiological load of the analyzed well water shows total mesophilic aerobic quanta microbials between 300 and 21,000 CFU/mL. Samples taken more than 800 meters from the slaughterhouse are not very contaminated since the quanta of the total aerobic mesophilic flora are between 300 and 2400 CFU/mL. The results obtained for the search for *Escherichia coli* in the water from the slaughterhouse as well as the water from the wells of zones A and B are shown below. In the slaughterhouse well, quanta were notied varying between 4.0 10 3 and 1.40 10 4 CFU/100 mL for fecal coliforms with a peak of 6.0 10 3 CFU/100 mL for *Escherichia coli*. This is detrimental to the microbiological quality of the water from this well and results in the undrinkability of this water.

DISCUSSION

Our work revealed an average nitrite level three times higher than the limit of 3.2mg/ L permitted by the Beninese standard for drinking water. As previously reported, the low oxygenation of this groundwater explains these high nitrite levels. For well water, ammonium levels were estimated at more than three times those of water classified as unclassified by European legislation (8mg/ L) regarding water quality. These values are thirty times higher than the limit for water quality intended for human consumption **(Rodier *et al.*, 2009)**.

The physicochemical study shows a neutral pH, a steady BOD5 average of 728.723 mg O2/l and COD of 1645.926 mg O2/l, and a monthly BOD5 average of 723.949 mg O2/l and COD of 1633.226 mg O_2/L. An oscillating monthly conductivity between 1,267.333 and 1579.08349 S/cm **(Lotfi *et al.*, 2020b; Bibi *et al.*, 2023)**.

The use of such water for washing and rinsing carcasses and viscera constitutes a major risk of compromising the hygienic quality of these foodstuffs. The high bacterial loads observed in the water from the wells in both zones A and B could also be explained by the proximity of the latrines to these wells **(Lotfi *et al.*, 2020b)**. According to our surveys, 13.33% of the latrines are equipped with sumps, whose walls facilitate the infiltration of wastewater from the pits into the ground, thus leading to contamination of the water table. It should be noted, however, that despite these risks of contamination, the values of the parameters observed at the slaughterhouse well are significantly higher than those observed in the wells of more distant houses. This confirms our hypothesis of the infiltration of slaughterhouse waste into the water table.

Slaughterhouses are places where water consumption is very high because of the multiple uses made of them. Wastewater from these industries is not without impact on the environment **(Lawniczak *et al.*, 2016)**. This study made it possible to carry out the physicochemical and microbiological characterizations of wastewater from the slaughterhouse and some traditional wells in the city of Sidi Slimane and to evaluate the impact of slaughterhouse waste on the quality of the water table. The values obtained for the different parameters at the level of traditional domestic water points around the slaughterhouse are almost all beyond Beninese and international standards **(Jain *et al.*, 2010)**.

The PCA diagram is formed by the F1xF2 axes, which explained 56.86% of the total variation, with F1 accounting for 31.15% and F2 accounting for 25.71%.

According to the F1 axis (31.15%), it reflects highly mineralized and chloride-rich water; this axis is associated with the pollution indicators BOD5, COD, Pt, and NH4+, unlike oxygenated water. F1 therefore defines a mineralization gradient of organic pollution from left to right of component 1. The F2 axis (25.71%) is associated with suspended solids and conductivity. The pH position on the negative side of component 2 is strongly correlated with temperature, indicating oxygen-rich water, far from the impact of P1 slaughterhouse effluent **(Lotfi *et al*., 2020b)**. Axis 2 defines a pollution axis of natural organic and mineral particles carried by the river during the rainy season. This phenomenon could be explained by the drainage of natural organic matter from the watershed into the Beht River, particularly at the upstream stations of the study area (C1 to C10), which are domestic discharges from the city of Sidi Slimane. However, in the downstream part of the stations (P1 and P2), fecal contamination is detected at this point by the presence of fecal coliform bacteria and fecal *streptococci* carried by water from the P1 outlet of the municipal slaughterhouses **(Jain *et al.*, 2010)**.

The groundwater of the Sidi Slimane slaughterhouse and its surroundings is then polluted and cannot be used for consumption. Comparison of the values of the physicochemical and microbiological parameters obtained for the water samples from the well located inside the slaughterhouse and the water samples from the wells in zone A and those from the wells in zone B showed a significant difference, particularly in terms of microbiological parameters. The degradation of the water table could partly be due to the poor management of waste from the slaughterhouse because, for the well water, the peaks of microbiological quanta were observed at the level of that of the well located inside the slaughterhouse **(Ako *et al.*, 2012)**.

CONCLUSION

The physicochemical parameters that are loaded are not compatible with the standards of wastewater. The multivariate analysis highlights the influence of stationary and monthly seasonal variations and anthropogenic human activities on water quality. In addition to seasonal and human factors, other factors such as heavy metals and pesticides need further investigation. Indeed, the very high microbial load of this water testifies to its pronounced pollution in fecal matter by the waste generated within the slaughterhouse. It is therefore urgent to rehabilitate and improve the system for treating this waste.

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