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Physicochemical Characterization of Wastewater From the Masina Public Slaughterhouse (Kinshasa, Democratic Republic of the Congo)

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ABSTRACT

Introduction
Slaughterhouse effluent is a major source of organic pollution that can impair surface water quality, particularly in developing countries where wastewater treatment infrastructure remains inadequate.

Purpose
This study assessed the physicochemical quality of wastewater from the Masina public abattoir in Kinshasa to evaluate pollution levels and associated environmental risks.

Methods
A longitudinal observational study was conducted during the wet and dry seasons of 2025. Sixteen sampling campaigns were executed, comprising ten in situ measurement events and six laboratory analysis events. Samples were collected from four distinct points: the slaughter area, the collection point (collector), the discharge point, and an upstream reference site on the N'djili River. Analyzed parameters included temperature, pH, electrical conductivity, turbidity, total suspended solids (TSS), biological oxygen demand (BOD_5), chemical oxygen demand (COD), and nitrates (NO_3^-). Data were subjected to analysis of variance (ANOVA) followed by Fisher's Least Significant Difference (LSD) test ($\alpha = .05$).

Results
Significant seasonal variations were observed ($p < .05$), with pollutant concentrations consistently higher during the dry season. The highest organic loads occurred at the collector, where COD reached 190.27 ± 1.07 mg/L and BOD_5 reached 121.13 ± 3.83 mg/L, significantly exceeding international guideline limits. High nitrate concentrations were recorded at the collector, reaching 450.46 ± 2.53 mg/L. The BOD_5/COD ratios ranged from 0.54 to 0.65 across sites, confirming that the effluents are highly biodegradable.

Conclusion
Untreated effluent from the Masina public abattoir is a major contributor to the degradation of water quality in the N'djili River. Implementing biological treatment systems, such as constructed wetlands, is essential to mitigate environmental degradation and safeguard public health.

INTRODUCTION

Water is essential for sustaining life, socio-economic development, and ecosystem function. However, rapid population growth, urbanization, and industrial expansion place increasing pressure on global aquatic resources, particularly in developing nations (United Nations, 2023; United Nations Environment Programme [UNEP], 2016). Industrial effluents represent a major source of anthropogenic pollution, deteriorating surface water quality and compromising agricultural, domestic, and recreational water uses. Over 80% of wastewater generated in developing countries is discharged without prior treatment, leading to ecosystem degradation and health risks associated with fecal pathogens and chemical contaminants (United Nations, 2023).

Slaughterhouses generate large volumes of wastewater characterized by elevated loads of organic matter, suspended solids, nutrients, and microorganisms. These effluents originate from carcass washing, facility sanitation, and the disposal of blood, animal tissues, and digestive contents (Belghyti et al., 2009; Bustillo-Lecompte et al., 2015). Direct discharge of untreated slaughterhouse wastewater depletes dissolved oxygen in receiving water bodies, induces eutrophication, and disrupts aquatic life.

In sub-Saharan Africa, high loads of chemical oxygen demand (COD), biological oxygen demand (BOD_5), nitrogen, and phosphorus in slaughterhouse effluents have been documented in Cameroon, Benin, and Nigeria (Kengne et al., 2014; Saizonou et al., 2010). In Kinshasa, Democratic Republic of the Congo (DRC), industrial wastewater management infrastructure is severely deficient, leading to direct discharges into urban drains and rivers (Kaza et al., 2018; Musibono et al., 2006). Discharges into the N'djili River—a crucial surface water resource for the region—have contributed significantly to localized environmental degradation (Bipendu et al., 2017).

The Masina public abattoir is one of Kinshasa's primary slaughterhouses, supplying beef across the metropolitan area while conducting pre-slaughter veterinary checks (Business et Finances, 2015; DeskEco, 2024). However, the facility lacks wastewater treatment infrastructure, allowing process effluents to drain toward the N'djili River (Musibono et al., 2006). Despite the environmental risk, empirical data on the physicochemical composition of this wastewater and its impact on the receiving river remain sparse.

The objective of this study was to evaluate the physicochemical quality of wastewater from the Masina public abattoir to quantify pollution levels and environmental risks. Specifically, the study aimed to:

i. Characterize the physicochemical parameters of the wastewater across key process points;

ii. Compare parameter concentrations against international discharge standards (International Finance Corporation [IFC], 2007); and

iii. Evaluate the impact of seasonal variations (wet vs. dry season) on pollutant concentrations.

METHODS

Study Area

The study was conducted at the Masina public abattoir, located in the Abattoir neighborhood, Masina municipality, Kinshasa, DRC **(Figure 1)**. The facility covers approximately 120 m^2 and is bounded to the north by the Don Bosco convent, to the south by the former CEAZA compound, to the east by Mobutu Boulevard, and to the west by residential housing and the N'djili River.

Sampling Protocol and Experimental Design

A longitudinal study design was executed across two distinct hydrological periods in 2025: the wet season and the dry season. Sampling was performed across four functional sites along the drainage pathway:

a. **Site 1 (Slaughter area):** Direct effluent collection point inside the slaughter house.

b. **Site 2 (Collection point / Collector):** The primary internal drainage junction accumulating combined wastewater.

c. **Site 3 (Discharge point):** The point where internal drainage discharges into the surrounding environment near the river bank.

d. **Site 4 (Upstream discharge point):** A reference point located upstream on the N'djili River prior to effluent mixing.

Sixteen sampling campaigns were conducted: ten for in situ parameters and six for detailed laboratory analyses. Spot samples were collected in sterile, rinsed polyethylene bottles between 07:00 AM and 10:00 AM during peak operational activity. Samples were stored in insulated coolers at 4°C and transported to the Central Analysis Laboratory (LCA) at the General Commission for Atomic Energy/Kinshasa Nuclear Research Centre (CGEA/CREN-K) within 6 hours.

In Situ and Analytical Methods

In Situ Measurements

Temperature (°C), pH, electrical conductivity (µS/cm), and turbidity (NTU) were measured in situ at a depth of 30 cm using calibrated multi-parameter probes (EZ-9909SP and Water Quality Tester).

Laboratory Chemical Analyses

All laboratory tests followed standard protocols (American Public Health Association et al., 2023):

a) **Chemical Oxygen Demand (COD):** Measured via potassium dichromate digestion in an acidic medium followed by spectrophotometric determination using a HACH DR/2400 spectrophotometer (mg O_2/L).

b) **Biological Oxygen Demand (BOD_5):** Quantified using five-day incubation at 20°C in the dark using the dilution method (mg O_2/L).

c) **Total Suspended Solids (TSS):** Determined gravimetrically by filtering a known sample volume through a standard membrane filter followed by drying to constant mass at 105°C (mg/L).

d) **Nitrates (NO_3^-):** Measured spectrophotometrically using the cadmium reduction method (NitraVer 5, HACH DR/2400) (mg/L).

Biodegradability Assessment

Effluent biodegradability was evaluated using the ratio of BOD_5 to COD BOD_5/COD) and COD to BOD_5 (COD/BOD_5). According to established classifications (Bamba, 2022; Grosclaude, 1999; Rodier et al., 2009):

- COD/BOD_5 < 3: Easily biodegradable effluent
- 3 ≤ COD/BOD_5 ≤ 5: Moderately biodegradable effluent
- COD/BOD_5 > 5: Recalcitrant/difficult to biodegrade

Data Analysis

Data were tabulated in Microsoft Excel 2013 and analyzed using Origin (v6.1) and R (v4.6.0). Parametric assumptions were confirmed using Hartley's test for variance homogeneity (Dagnelie, 1975; Hartley, 1959). One-way Analysis of Variance (ANOVA) was applied to test for significant differences between sites and seasons. Differences between means were determined using Fisher's Least Significant Difference (LSD) test at $\alpha = .05$.

Spatial coordinates were determined using a Garmin Etrex 64s GPS receiver, and maps were produced using ArcGIS v10.8. Parameter compliance was assessed against World Bank Group/IFC EHS guidelines for meat processing (IFC, 2007).

RESULTS

General Physicochemical Profile

The general physicochemical parameters measured across the four sampling locations during both the wet and dry seasons are presented in **Table 1**.

Table 1:
General Physicochemical Parameters Measured Across Sampling Sites and Seasons

Parameter	Season	Slaughter Area	Collection Point	Discharge Point	Upstream Reference	p-value
Temperature °C	Wet	23.48 ± 0.80^{d}	23.97 ± 0.42^{c}	26.35 ± 1.02^{a}	24.91 ± 0.56^{b}	<.001
	Dry	23.39 ± 0.79^{d}	24.21 ± 0.35^{c}	26.18 ± 1.03^{a}	24.88 ± 0.57^{b}	
pH	Wet	8.43 ± 0.26^{a}	6.41 ± 0.29^{d}	7.14 ± 0.05^{c}	7.49 ± 0.17^{b}	<.001
	Dry	7.39 ± 0.26^{a}	5.19 ± 0.08^{d}	6.01 ± 0.20^{c}	6.43 ± 0.06^{b}	
Conductivity ($\mu\text{S/cm}$)	Wet	2,564.70 ± 82.32^{b}	3,315.60 ± 218.65^{a}	85.50 ± 1.72^{c}	58.00 ± 5.25^{d}	<.001
	Dry	3,164.70 ± 245.58^{b}	3,845.60 ± 35.78^{a}	109.90 ± 4.53^{c}	160.60 ± 12.79^{d}	
Turbidity (NTU)	Wet	1,232.90 ± 58.40^{b}	1,580.30 ± 58.40^{a}	44.20 ± 1.99^{c}	29.30 ± 1.77^{d}	<.001
	Dry	1,592.90 ± 79.03^{b}	1,920.30 ± 43.67^{a}	\$75.70 ± 2.63^{c}	54.20 ± 2.35^{d}	
TSS (mg/L)	Wet	89.03 ± 0.46^{b}	123.88 ± 9.32^{a}	72.05 ± 0.64^{c}	36.47 ± 1.24^{d}	<.001
	Dry	95.01 ± 0.64^{b}	119.61 ± 9.26^{a}	75.93 ± 0.77^{c}	\$38.39 ± 10.98^{d}	

Note: Means in the same row followed by different superscript letters are significantly different according to Fisher's LSD test ($p < .05$). TSS = Total Suspended Solids.

Water temperatures across sites ranged between 23.39°C and 26.35°C. The pH exhibited significant variation ($p < .001$), dropping from slightly basic values at the slaughter area (8.43 ± 0.26 in wet season) to markedly acidic values at the main collection point (5.19 ± 0.08 in dry season). Electrical conductivity and turbidity peaked at the collection point, reaching 3,845.60 ± 35.78 µS/cm and 1,920.30 ± 43.67 NTU during the dry season, respectively. TSS followed a similar spatial pattern, reaching its maximum (123.88 ± 9.32 mg/L) at the collection point.

Indicators of Organic Pollution and Nutrients

The concentrations of COD, BOD_5, and nitrates across all monitoring sites are presented in **Table 2**.

Table 2:
Organic Pollution Indicators (COD, BOD_5) and Nitrates (NO_3^-) Across Sites and Seasons

Parameter	Season	Slaughter Area	Collection Point	Discharge Point	Upstream Reference	p-value
COD ($\text{mg O}_2/\text{L}$)	Wet	161.55 ± 1.17^b	173.11 ± 1.41^a	158.05 ± 0.96^c	95.93 ± 0.68^d	<.001
	Dry	179.52 ± 1.00^b	190.27 ± 1.07^a	170.38 ± 0.58^c	106.79 ± 0.59^d	
BOD5 ($\text{mg O}_2/\text{L}$)	Wet	91.18 ± 0.26^b	111.13 ± 4.06^a	86.85 ± 2.56^c	35.41 ± 8.52^d	<.001
	Dry	99.16 ± 0.26^b	121.13 ± 3.83^a	93.81 ± 2.53^c	39.52 ± 8.48^d	
Nitrates (mg/L)	Wet	368.66 ± 0.90^c	425.43 ± 2.55^a	384.27 ± 1.20^b	297.06 ± 0.78^d	<.001
	Dry	389.66 ± 0.89^c	450.46 ± 2.53^a	401.27 ± 1.22^b	310.06 ± 0.79^d	

Note: Means in the same row followed by different superscript letters are significantly different according to Fisher's LSD test ($p < .05$). COD = Chemical Oxygen Demand; BOD_5 = Five-day Biological Oxygen Demand.

The collection point recorded the highest organic loads, with COD peaking at 190.27 ± 1.07 mg/L and BOD_5 reaching 121.13 ± 3.83 mg/L during the dry season. Both metrics dropped slightly at the discharge point (170.38 ± 0.58 mg/L COD and 93.81 ± 2.53 mg/L BOD_5), but remained substantially elevated compared to the upstream reference site (106.79 ± 0.59 mg/L COD and 39.52 ± 8.48 mg/L BOD_5). Nitrate concentrations were highest at the collector during the dry season (450.46 ± 2.53 mg/L) and lowest upstream during the wet season (297.06 ± 0.78 mg/L).

Biodegradability Indices

The biodegradability ratios calculated across the effluent sampling locations are detailed in **Table 3**.

Table 3:
Biodegradability Ratios of Wastewater Samples Across Seasons

Sampling Location	Season	COD (mg/L)	BOD^5 (mg/L)	BOD_5 /COD Ratio	COD/BOD_5 Ratio	Biodegradability Classification
Slaughter Area	Wet	161.55 ± 1.17	91.18 ± 0.26	0.56	1.77	Highly Biodegradable
	Dry	179.52 ± 1.00	99.16 ± 0.26	0.55	1.81	Highly Biodegradable
Collection Point	Wet	173.11 ± 1.41	111.13 ± 4.06	0.64	1.56	Highly Biodegradable
	Dry	190.27 ± 1.07	121.13 ± 3.83	0.64	1.57	Highly Biodegradable
Discharge Point	Wet	158.05 ± 0.96	86.85 ± 2.56	0.55	1.82	Highly Biodegradable
	Dry	170.38 ± 0.58	93.81 ± 2.53	0.55	1.82	Highly Biodegradable

The COD/BOD_5 ratios ranged between 1.56 and 1.82, consistently remaining below the standard threshold of 3.0. Correspondingly, BOD_5/COD ratios ranged between 0.55 and 0.64.

Guideline Compliance Summary

Comparison of observed seasonal means with international IFC standards (IFC, 2007) is summarized in **Table 4**.

Table 4:
Compliance Status of Effluent Parameters Against IFC (2007) Guideline Thresholds

Parameter	IFC Standard	Dry Season Status	Wet Season Status	Non-Compliant Sites
Temperature	<30°C	Compliant	Compliant	None
pH	6.0–9.0	Non-Compliant	Compliant	Collection Point (Dry Season, pH = 5.19)
Conductivity	1,000 µS/cm	Non-Compliant	Non-Compliant	Slaughter Area, Collection Point
Turbidity	100 NTU	Non-Compliant	Non-Compliant	Slaughter Area, Collection Point
TSS	50 mg/L	Non-Compliant	Non-Compliant	Slaughter Area, Collector, Discharge Point
BOD5	30 mg/L	Non-Compliant	Non-Compliant	All Sites (Including Upstream Reference)
COD	90 mg/L	Non-Compliant	Non-Compliant	All Sites (Including Upstream Reference)
Nitrates	50 mg/L	Non-Compliant	Non-Compliant	All Sites (Including Upstream Reference)

DISCUSSION

Dynamics of Organic Loads and Physicochemical Parameters

The characterization reveals that effluent generated by the Masina public abattoir carries heavy loads of organic matter, particulate pollutants, and nitrogenous waste. Concentrations progressive increased from the initial slaughter floor to the central collector. This progression reflects the progressive accumulation of unrecovered slaughter by-products—including animal blood, tissue scraps, subcutaneous fat, urine, and paunch contents—washed into unlined drainage channels during floor sanitation. Similar pollutant accumulation dynamics in slaughterhouse drainage networks have been documented in Morocco (Belghyti et al., 2009) and Canada (Bustillo-Lecompte et al., 2015).

The decline in pH to acidic levels at the main collector (5.19 ± 0.08) during the dry season is attributed to the rapid microbial fermentation of complex organic substrates in stagnant drain sections. Under high ambient temperatures (23.39ºC to 26.35ºC), anaerobic decomposition of lipids and proteins generates volatile fatty acids, driving system acidification (Tchobanoglous et al., 2014). Conversely, the extremely high conductivity (>3,800 muS/cm) and turbidity (>1,900 NTU) measured at the collector stem from the dissolution of inorganic salts present in animal body fluids and the heavy suspension of insoluble organic particulates (Saizonou et al., 2010).

Eutrophication and Environmental Impacts on the N'djili River

The concentrations of COD (190.27 mg/L), BOD_5 (121.13 mg/L), and nitrates (450.46 mg/L) recorded at the collector far exceed the discharge guidelines established by the IFC (2007) (90 mg/L, 30 mg/L, and 50 mg/L, respectively). Comparison of parameter values upstream versus downstream of the discharge zone confirms that effluent input degrades the baseline quality of the N'djili River (Bipendu et al., 2017; Musibono et al., 2006).

The introduction of excessive BOD_5 and COD into the river stimulates heterotrophic bacterial growth, leading to rapid dissolved oxygen depletion in the water column. In parallel, nitrate loadings exceeding 400 mg/L introduce extreme nutrient enrichment, promoting algal blooms and subsequent eutrophication (Bustillo-Lecompte et al., 2015). High total suspended solids (>110 mg/L) restrict photosynthetically active radiation (PAR) penetration, further destabilizing benthic and pelagic aquatic communities.

Seasonal Modulation of Effluent Concentration

Seasonal comparison confirmed statistically significant variations ($p < .05$) across parameters, with dry season samples consistently yielding higher pollutant levels. This difference is primary governed by hydrological dilution rather than operational changes in slaughter volume. During the rainy season, storm runoff dilutes the open drainage network, lowering measured concentrations. In contrast, the dry season lacks dilution water, causing organic matter, biological fluids, and suspended solids to concentrate within the drainage channels (Kengne et al., 2014).

Effluent Biodegradability and Remediation Strategies

The calculated COD/BOD_5 ratios (1.56 to 1.82) fall well below the critical threshold of 3.0, while BOD_5/COD ratios (>0.50) confirm that the organic fraction of the wastewater is readily biodegradable (Bamba, 2022; Grosclaude, 1999; Rodier et al., 2009). These findings demonstrate that biological wastewater treatment technologies are suitable for this site.

Given the operational and economic constraints in Kinshasa, complex mechanized treatment plants may be difficult to sustain. Low-cost nature-based solutions—specifically constructed wetlands (macrophyte lagoons using *Typha latifolia* or *Eichhornia crassipes*) or passive combined anaerobic-aerobic baffled reactors—offer viable options (Kengne et al., 2014). Constructed wetlands have demonstrated high efficiency in removing BOD_5, TSS, and nitrates from slaughterhouse wastewater under tropical climate conditions in Central Africa (Kengne et al., 2014).

Public Health Risks and Policy Governance

Beyond ecological degradation, the direct discharge of untreated abattoir waste poses significant health risks to downstream riparian populations in Masina and Limete who utilize N'djili River water for domestic washing, urban agriculture, and recreational activities. Although microbiological parameters were not measured in this study, slaughterhouse effluents typically carry high loads of zoonotic and fecal pathogens, including *Escherichia coli*, *Salmonella* spp., and intestinal parasites (Saizonou et al., 2010).

The persistence of untreated discharges highlights a key regulatory gap in the DRC. The absence of specific national emission standards for industrial and agrifood effluents complicates municipal enforcement. Formulating sector-specific discharge regulations, establishing routine environmental monitoring, and integrating primary grease-and-blood interceptors at the slaughterhouse are essential steps toward sustainable urban environmental management.

Study Limitations

This study has three main limitations:

i. Sampling was limited to two hydrological seasons in a single year, which may not capture long-term interannual variation;

ii. Microbiological analyses (fecal coliforms, enterococci) were not conducted, preventing full quantification of pathogen risks; and

iii. Heavy metals and trace organic contaminants were not analyzed.

Future research incorporating microbial source tracking, heavy metal screening, and pilot-scale constructed wetland testing will further support evidence-based sanitation planning in Kinshasa.

CONCLUSIONS

This study demonstrates that untreated wastewater discharged from the Masina public abattoir contains high concentrations of organic matter, suspended solids, and nitrates, exceeding international guideline limits. Discharges directly degrade the water quality of the N'djili River, threatening aquatic life and public health downstream. Because the effluent displays high biodegradability ($COD/BOD_5 < 2$), biological treatment systems—specifically constructed wetlands or macrophyte lagoons—offer viable, cost-effective solutions for effluent remediation in Kinshasa. Developing enforceable national regulations and implementing regular water quality monitoring are imperative to safeguard regional aquatic ecosystems.

Use of Artificial Intelligence (AI) Declaration: The authors declare that no generative artificial intelligence was used in the conception and design of the study, data collection, data analysis, interpretation of results, or the generation or modification of the primary research data. Artificial intelligence-assisted language tools were used solely to improve the English translation, grammar, spelling, and overall linguistic clarity of the manuscript. All scientific content, interpretations, conclusions, and the final version of the manuscript were critically reviewed, verified, and approved by the authors, who take full responsibility for the content of this article.

Authors' Contributions: K.B.P.: Conceptualization, Data Curation, Writing – original draft. L.S.W.: Formal Analysis. M.L.C.: Writing – review & editing. M.K.C.: Supervision, Writing – review & editing. D.M.E.: Supervision, Writing – review & editing. B.M.E.: Supervision, Writing – review & editing.

Data Availability Statement: The datasets generated and analyzed during the current study are not publicly available because they contain information that could compromise participant confidentiality. However, anonymized data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to approval by the University of Kinshasa and applicable institutional ethical policies.

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