RESEARCH ARTICLE

JENER Journal of Empirical and Non-Empirical Research
Volume 2, Issue 5, Page 595-600 | Article No. 73
DOI: 10.4898/jener.v2i5.a73
ISSN: 7895-9216
Journal homepage: https://jenerjournal.com
Journal email: editor@jenerjournal.com

JENER Journal
JENER Journal of Empirical and Non-Empirical Research

Physicochemical, Bacteriological and Selected Heavy Metals Pollution Assessment of Abattoir Effluents at Ikpoba Hill, Benin City, Edo State, Nigeria

[1]Akpoka, OA, and [1]Solanke, EO

[1]Department of Biological Science, College of Natural and Applied Sciences, Igbinedion University.

ARTICLE INFORMATION

Article history:
Published: May 2026

Keywords:
Abattoir Effluent
Physicochemical Parameters
Bacteriological Quality
Heavy Metals
Wastewater

ABSTRACT

Abattoir wastewater constitutes a significant environmental and public health concern owing to its high organic load, elevated nutrient concentrations, and microbiological burden. Despite the documented impacts of slaughterhouse effluents on receiving environments, site-specific data from many Nigerian abattoirs remain limited. This study assessed the physicochemical characteristics, selected heavy metal content, and bacteriological quality of effluents from two abattoirs at Ikpoba Hill, Benin City, Edo State, Nigeria, and evaluated the potential environmental and public health implications of their untreated discharge. Effluent samples were collected aseptically from the drainage outflows of both abattoirs (five samples per site). Samples were analyzed for pH, alkalinity, turbidity, biological oxygen demand (BOD), nitrate, sulphate, phosphate, copper, lead and cadmium by standard procedures. Heterotrophic bacterial counts were determined by pour plate method on nutrient agar; isolates were identified by Gram staining and biochemical characterization according to Barrow and Feltham (2003) and Cheesbrough (2000). Effluents were dark yellowish-red and turbid, with mean pH values of 5.4 and 5.3, below the WHO guideline range of 6.5–8.5. Turbidity (31.8 and 27.3 NTU), BOD (55.2 and 49.56 mg/L), nitrate (64 and 53 mg/L), and phosphate (7.63 and 7.44 mg/L) all exceeded recommended limits. Lead and cadmium were not detected; copper was within permissible limits. Heterotrophic counts ranged from 1.61×10^6 to 2.61×10^6 cfu/mL. Dominant isolates were Escherichia coli, Pseudomonas sp., Bacillus sp., Klebsiella sp., and Enterococcus faecalis. Untreated effluents from both abattoirs pose significant ecological and public health risks. Effective wastewater treatment, improved sanitary management, and regulatory enforcement are urgently required before discharge into the environment.

1. Introduction

An abattoir, also known as a slaughterhouse, is a facility approved for the hygienic slaughter, inspection, processing, preservation, and storage of meat for human consumption (Alonge, 1991). In Nigeria and many other low- and middle-income settings, abattoirs are essential to urban food supply systems, yet they also generate large amounts of liquid and solid wastes whose management is often inadequate (Bello & Oyedemi, 2009; Akinro et al., 2009). Slaughtering operations typically produce wastewater containing blood, fat, grease, suspended solids, undigested intestinal materials, detergents, nutrients, and microorganisms, all of which may alter the quality of receiving soil and water bodies when discharged without treatment (Adesemoye et al., 2006; Kobya et al., 2006; Osibanjo & Adie, 2007; Bustillo-Lecompte & Mehrvar, 2015; Ng et al., 2022).

The environmental significance of abattoir effluents lies not only in their high organic load but also in their microbiological burden. Elevated biochemical oxygen demand and nutrient concentrations can deplete dissolved oxygen and accelerate eutrophication, while faecal organisms introduced from intestinal contents and wash water may contaminate surrounding ecosystems and increase the risk of waterborne disease transmission (Ezeronye & Ubalua, 2005; Rabah et al., 2010). Previous Nigerian studies have documented unacceptable physicochemical characteristics and substantial microbial contamination in abattoir wastewater and in soils or streams impacted by such discharges (Adesemoye et al., 2006; Osemwota, 2010; Osibanjo & Adie, 2007).

In addition to organic and microbial contaminants, selected trace metals remain important indicators in wastewater assessment because acidic conditions and poor waste handling can enhance metal mobility and persistence in the environment. For this reason, combined physicochemical, bacteriological, and heavy metal evaluation provides a more complete picture of the environmental quality of abattoir effluents and the risks associated with untreated release (Kobya et al., 2006).

Despite the continuing public health and environmental relevance of slaughterhouse wastes, local evidence from many Nigerian abattoirs remains limited. This study therefore investigated the diversity of microorganisms present in effluents from abattoirs in Ikpoba Hill, Benin City, and determined key physicochemical parameters and selected heavy metal levels in the same effluent samples.

2. Methodology

2.1 The study area

The State abattoir is situated at Ikpoba, Ikpoba-Okha Local Government Area, Benin, Edo State. The study area is located on latitude 06°29′ N and longitude 05°22′ E.

2.2 Sample collection

Effluent samples were collected from two abattoirs located in Ikpoba Hill (Ikpoba-Okha Local Government), Benin, Edo State, Nigeria. Both abattoirs were adjacent to each other. Bijou bottles were used to aseptically draw part of the effluents running off the drainage system just as it was leaving the slaughter pavement. Five samples were collected from each site. All samples were well labelled and transported to the laboratory in an ice-packed container for analyses immediately after collection.

2.3 Analyses of wastewater samples for physico-chemical properties

The effluent samples were analyzed for the following physico-chemical parameters: pH, alkalinity, turbidity, biological oxygen demand (BOD), nitrate, sulphate, phosphate, copper, lead, and cadmium.

2.3.1 pH

The pH values, a measure of hydrogen ion concentration in the samples, were determined using a pH meter 3015 (Jenway, U.K.). Ten millilitres of the effluent sample was transferred into a beaker, the electrode of the pH meter was inserted into the effluent, and the pH reading was taken.

2.3.2 Alkalinity

Alkalinity of water is its acid-neutralizing capacity and is usually expressed as the sum of all titratable bases. The titration method was used to determine the alkalinity as described by Thomas and Lynch (1960). One hundred millilitres of the effluent sample was pipetted into a conical flask. Five drops of indicator (methyl red 0.2% in neutral 95% alcohol with 0.1% bromocresol green) were added. The solution was titrated against concentrated hydrochloric acid until the colour of the indicator matched that of the standard end point.

2.3.4 Turbidity (NTU)

Turbidity of the effluent was determined with a Milton Roy (USA) Spectronic 20D meter.

2.3.5 Biological oxygen demand (BOD)

Biological oxygen demand was determined by the method recommended by APHA (1998). Wastewater sample was drawn into three 250 ml bottles. Winkler reagent was immediately used to treat one of the effluent portions to determine the dissolved oxygen content of the sample collected. The other two bottles were incubated in the dark for five days at 20°C. At the end of the incubation period, dissolved oxygen was determined, and BOD was estimated from the difference between initial dissolved oxygen and final dissolved oxygen after five days.

2.3.6 Nitrogen contents

The nitrogen content of the effluent was determined by the cadmium-reduction method as described by Wood et al. (1967). A glass wool plug was inserted into a reduction column and filled with the effluent sample. Sufficient Cu-Cd granules were introduced into the column. One hundred millilitres of solution composed of 25% 1.0 mg NO3-N/L standard and 75% NH4Cl-EDTA solution was added. The solution was left for 15 min before absorbance was determined at 543 nm against distilled water blank.

2.3.7 Phosphorus

The phosphate concentration of the effluent samples was determined by the spectrophotometric method as described by Mackereth (1963). One hundred millilitres of sample and standard phosphate were mixed with 1 ml Deniges reagent. Five drops of stannous chloride were added and mixed. The solution was transferred to Nessler tubes and the volume was adjusted until the blue colour matched. The phosphorus content was determined from the difference in volume of both blank and the solution.

2.3.8 Determination of heavy metals

Ten millilitres of effluent sample was measured into a tube. Thirty millilitres of silver thiourea reagent was added and the mixture was shaken on a mechanical shaker for 2 h. Copper (Cu), lead (Pb), and cadmium (Cd) were determined by aspirating the same extract into an atomic absorption spectrophotometer at their respective wavelengths.

2.4 Media preparation

The medium used for bacteriological analysis was nutrient agar (NA). The medium was prepared according to the manufacturer's instructions.

2.5 Sterilization techniques

Growth media and diluents (distilled water) were autoclaved at 121°C for 15 min. The working bench was surface-sterilized by swabbing with 70% alcohol. Naked flame was also used during inoculation, serial dilution, and subculturing in order to enhance aseptic conditions.

2.6 Estimation of heterotrophic bacteria in the effluent

The heterotrophic plate count tests were conducted according to the standard methods for the examination of water and wastewater (APHA, 2005). Water samples were diluted in sterile peptone water and filtered through 0.45 µm diameter Millipore membrane filters. The filters were then transferred onto R2A agar plates and incubated at 28°C for 48 h. In addition, 1 ml of the effluent sample was serially diluted ten-fold and used in the estimation of aerobic heterotrophic bacterial population by the pour plate method in duplicate. Nutrient agar was used for bacterial isolation and incubation was at 37°C for 48 h. After incubation, plates with 30-300 colonies were chosen for counting and the total plate count for bacteria was expressed as colony forming units (cfu) per millilitre.

2.7 Identification and characterization of bacteria

Five distinct colonies were picked based on differences in colonial morphology and each was phenotypically and biochemically characterized by standard methods (Barrow & Feltham, 2003). After counting and estimation of total bacterial load, morphologically distinct colonies were picked using a sterile inoculating needle and aseptically transferred to sterile nutrient agar slants for further characterization. The isolates were characterized up to genus level as described by Cheesbrough (2000) based on Gram staining, spore staining, motility test, oxidation-fermentation test, indole test, oxidase test, and catalase test.

4. Findings

4.1 Physico-chemical parameters of abattoir effluents

The results of the physico-chemical analyses of abattoir effluents are presented in Table 1. The colour of the effluents collected from the two abattoirs was dark yellowish-red and the samples were turbid in appearance. The mean pH values were 5.4 and 5.3, respectively. The pH values were not statistically different for the effluents from both abattoirs; however, they were not in conformity with the WHO standard range of 6.5-8.5. Total alkalinity mean values measured in mg/L CaCO3 for both abattoirs were 65.59 and 33.94, respectively, and showed a significant difference. The turbidity mean values obtained in Abattoir A and Abattoir B were 31.8 NTU and 27.3 NTU, respectively; both values were greater than the WHO recommended value of 5 NTU. The nitrate content for Abattoir A was 64 mg/L and did not differ significantly from that of Abattoir B (53 mg/L). The phosphate contents in the two study areas were 7.63 mg/L and 7.44 mg/L, respectively, both far above the recommended limit. The sulphate levels for both abattoirs (2.50 and 1.27 mg/L) were much lower than the WHO limit of 250 mg/L. The BOD values obtained for the two study areas were 55.2 mg/L and 49.56 mg/L, respectively, which were markedly higher than the WHO recommended range of 2.0-4.0 mg/L. Copper concentrations (0.31 and 0.14 mg/L) were lower than the WHO limit of 1.3 mg/L, while lead and cadmium were not detected in either study area.

Table 1: Physico-chemical parameters of abattoir effluents

Parameters	Abattoir A	Abattoir B	WHO limit
Colour	Dark yellowish-red	Dark yellowish-red	-
Appearance	Turbid	Turbid	-
pH	5.4 ± 0.129	5.3 ± 0.093	6.5-8.5
Alkalinity (mg/L)	65.59	33.94	100-200
Turbidity (NTU)	31.8	27.3	5
BOD (mg/L)	55.2 ± 0.341	49.56 ± 0.942	2.0-4.0
NO3 (mg/L)	64 ± 0.964	53 ± 1.284	40
SO4 (mg/L)	2.50 ± 0.148	1.27 ± 0.729	250
PO4^3- (mg/L)	7.63 ± 0.236	7.44 ± 0.868	<0.5
Cu (mg/L)	0.31 ± 0.051	0.14 ± 0.015	1.3
Pb (mg/L)	ND	ND	0.015
Cd (mg/L)	ND	ND	0.005

Key: ND- Non detectable

4.2 Selected heavy metals pollution assessment of abattoir effluents

The selected heavy metals assessed in the effluent samples are presented in Table 2. Copper was detected in both abattoirs at concentrations below the WHO guideline value, whereas lead and cadmium were not detected in either sample.

Table 2: Selected heavy metals pollution assessment of abattoir effluents

Heavy metal	Abattoir A	Abattoir B	WHO limit
Cu (mg/L)	0.31 ± 0.051	0.14 ± 0.015	1.3
Pb (mg/L)	ND	ND	0.015
Cd (mg/L)	ND	ND	0.005

4.3 Total mean viable counts for bacterial isolates in the effluent samples

The total mean viable counts for bacterial isolates are presented in Table 3. Abattoir A effluent samples had mean total heterotrophic bacterial counts ranging from 2.12 × 10^6 cfu/ml to 2.61 × 10^6 cfu/ml, with an average mean value of 2.38 × 10^6 cfu/ml. In contrast, Abattoir B effluent samples had mean total heterotrophic bacterial counts ranging from 1.61 × 10^6 cfu/ml to 2.11 × 10^6 cfu/ml, with an average value of 1.89 × 10^6 cfu/ml. A significant difference was observed between the average counts of Abattoirs A and B at the 5% level of significance.

Table 3: Total mean viable counts for bacterial isolates in the effluents (x10^4 cfu/ml)

Effluent sample	Abattoir A	Abattoir B
1	212	194
2	243	211
3	230	201
4	243	161
5	261	176
X ± S.E	237.8*	188.6

Key: * shows that the average mean value of Abattoir A is significantly higher than that of Abattoir B at 5% level of significance. S.E = standard error.

4.4 Phenotypic characterization of microbial isolates obtained from abattoir effluents

Table 4: Phenotypic characterization of microbial isolates obtained from abattoir effluents

Isolate	Colonial characteristic	Microscopic characteristics	Biochemical tests										Suspected isolate
			Co	Ca	Ox	Ur	Ci	In	Mr	Vp	Ma	La	
1	Circular, moist, smooth and of entire margin; flat and pink	Gram-negative rods	-	+	+	-	+	+	+	+	+	+	Escherichia coli
2	Mucoid colony on MacConkey agar plate	Gram-negative rods	-	+	+	-	+	-	-	-	+	-	Pseudomonas aeruginosa
3	Serrated dry colony on nutrient agar plate	Gram-positive rods	-	+	+	-	+	-	-	+	-	-	Bacillus sp.
4	Yellow pigmented colony on nutrient agar plate	Gram-negative rods	-	+	-	+	+	-	-	+	+	+	Klebsiella pneumoniae
5	Mucoid colony on MacConkey agar plate	Gram-negative rods	-	+	+	-	+	-	-	-	+	-	Pseudomonas aeruginosa
6	Yellow mucoid colony on mannitol salt agar plate	Gram-positive cocci in clusters	-	-	-	-	-	-	-	+	+	+	Enterococcus faecalis

Key: Co = coagulase; Ca = catalase; Ox = oxidase; Ur = urease; Ci = citrate; In = indole; Mr = methyl red; Vp = Voges-Proskauer; Ma = mannitol; La = lactose.

4.5 Percentage frequency of occurrence of bacterial isolates from effluent samples

The results of the percentage frequency of occurrence of the bacterial isolates are presented in figure 1. A total of five distinct bacterial groups were recorded from the study samples: Escherichia coli, Pseudomonas sp., Bacillus sp., Klebsiella sp., and Enterococcus faecalis. In the effluent samples collected from Abattoir A, the percentage frequency of occurrence was E. coli (31.1%), Pseudomonas sp. (24.5%), Enterococcus faecalis (18.6%), Bacillus sp. (17.6%), and Klebsiella sp. (8.2%). In the effluent samples collected from Abattoir B, the corresponding frequencies were E. coli (35.3%), Pseudomonas sp. (20.7%), Bacillus sp. (19.3%), Enterococcus faecalis (17.3%), and Klebsiella sp. (7.4%). Generally, E. coli had the highest frequency of occurrence in both abattoir effluent samples, while Klebsiella sp. had the lowest frequency of occurrence.

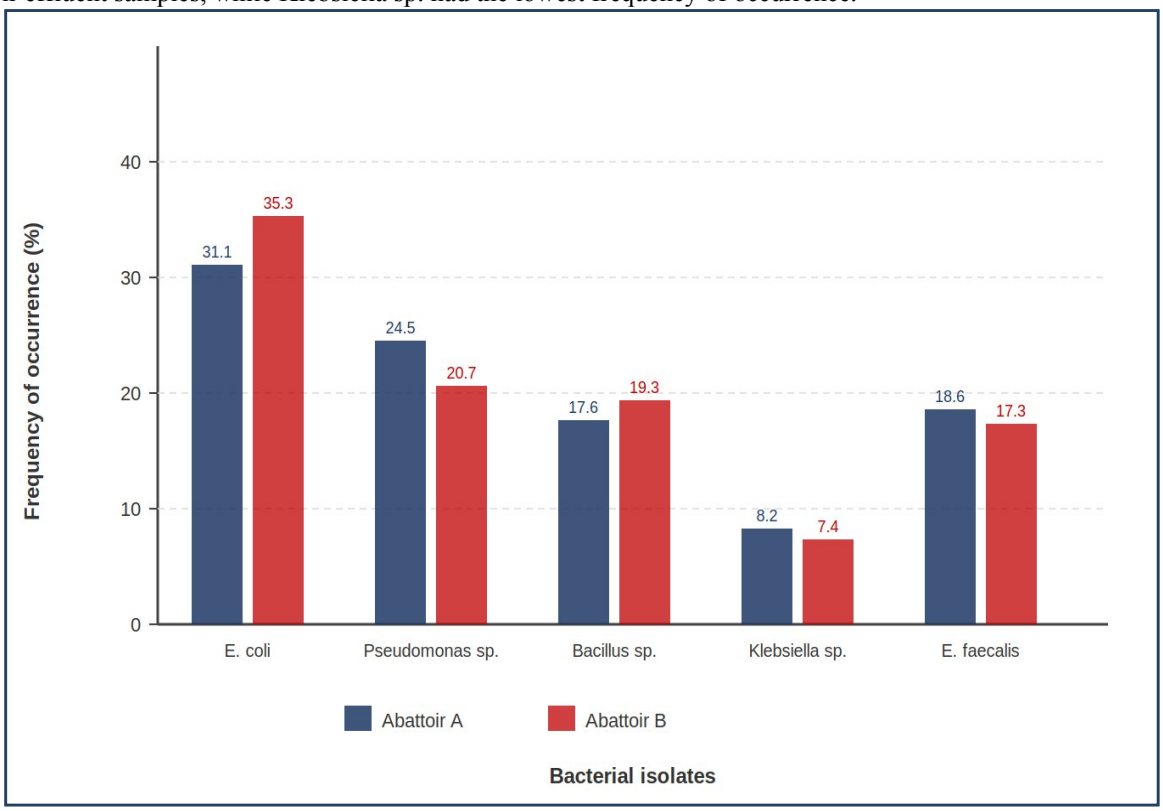

Figure 1. Percentage frequency of occurrence of bacterial isolates recovered from effluent samples of Abattoir A and Abattoir B, Ikpoba Hill, Benin City.

4.6 Discussion

As shown in Table 1, the bacteriological counts were highest in the abattoir effluent and downstream sampling point, whereas upstream water showed lower counts. The mean downstream TAVC (4.67×10^4 cfu/mL) was markedly higher than the upstream value (2.12×10^3 cfu/mL). In the same way, mean TCC increased from 1.95 MPN mL upstream to 18.3 MPN/ mL downstream, while mean ECC increased from 3.75 cfu/mL upstream to 1.44×10^1 cfu/mL downstream. The abattoir effluent itself contained mean

TAVC, TCC, and ECC values of 7.45×10^3 cfu/mL, 72.5 MPN/mL, and 9.25×10^1 cfu/mL, respectively, while the abattoir well water also showed contamination with mean TCC and ECC values of 23 MPN/mL and 5.38 cfu/mL. This pattern supports the view that the abattoir is an important source of microbial contamination to the receiving stream. Similar observations have been reported for abattoir-impacted water bodies in Nigeria, where downstream receiving waters showed bacterial loads comparable to raw effluent (Nafarnda et al., 2012; Akpan et al., 2020; Akpoka et al., 2023). All downstream TCC and ECC values exceeded the WHO guideline threshold for drinking water, which requires that E. coli and thermotolerant coliforms be undetectable in any 100 mL sample (WHO, 2011). Notably, a mean ECC of 3.75 cfu/mL was also recorded at the upstream site, with E. coli detected in three of the four sampling rounds. This upstream contamination suggests that faecal inputs from diffuse land-use activities or other pollution sources exist upstream of the abattoir, and it limits the extent to which the upstream site can serve as a truly uncontaminated baseline.

As described in the Results, substantial volumes of blood, wash water, paunch contents, and rendering residues entered the stream during operations, consistent with the high organic loads documented in similar abattoir-adjacent water bodies (Nafarnda et al., 2012; Adelegan, 2002). The discharge pathway, combining direct drainage to the sludge pond, overflow into the stream, and surface runoff from open rendering, provides multiple routes for bacteriological contamination of both the stream and the on-site well.

Published estimates indicate that only about 35% of a slaughtered cow's live weight constitutes edible meat, while approximately 65% consists of blood, bones, fat, hides, paunch contents, and other non-carcass materials (Omole & Longe, 2008). Previous studies further report that slaughter activities generate substantial quantities of blood, manure, paunch contents, and wastewater capable of contributing significant organic and suspended-solid loads to receiving water bodies when improperly managed. For an average 550 kg cow, approximately 13.6 kg (≈13–14 L) of blood may be generated during slaughter (Gannon et al., 2004, as cited in Omole & Longe, 2008). Applying this estimate to the approximately 10 cattle slaughtered daily at the Okokpon abattoir suggests that slaughter operations could generate roughly 130–136 L of blood per day, alongside substantial volumes of wastewater and organic solid waste. A large proportion of these wastes eventually reaches the nearby water body after only brief delay in the sludge pond. Since the bones are sold, the fat, grease, and some of the paunch contents contribute substantially to the suspended solids that pollute both the stream and the adjoining soil. The organisms identified from the effluent, well water, and stream samples (Tables 2 and 3) included Escherichia coli, Staphylococcus aureus, Staphylococcus epidermidis, Bacillus cereus, Bacillus subtilis, Serratia marcescens, Pseudomonas aeruginosa, and Chromobacterium violaceum. he occurrence of E. coli in particular is epidemiologically important because it is an established indicator of recent faecal contamination in water intended for domestic use (Odonkor & Ampofo, 2013; WHO, 2011); its predominance in abattoir effluents in this region has been independently corroborated, with E. coli recording the highest frequency of occurrence in effluents from two Benin City abattoirs (Akpoka et al., 2023). The presence of C. violaceum, a Gram-negative rod native to tropical soils and freshwater environments, is consistent with the geographic setting of this study and further indicates the integration of environmental bacteria with faecal contaminants in the receiving stream. More recent studies have also shown that slaughterhouse wastewater may act as a reservoir of antimicrobial-resistant E. coli and other Gram-negative bacteria, reinforcing the public health significance of direct discharge into streams and shallow water sources (Akpan et al., 2020; Chowdhury et al., 2025).

The presence of these bacteria in high counts constitutes a serious public health hazard because contamination of domestic water with enteric organisms increases the risk of waterborne disease transmission. This concern is reinforced by broader global evidence linking unsafe water, sanitation, and hygiene to a substantial preventable disease burden (WHO, 2023; Wolf et al., 2023). The offensive odour and mosquito breeding documented at the abattoir site further corroborate poor sanitary conditions in the study area. Overall, the findings indicate that untreated abattoir discharge is compromising the microbiological quality of Okokpon Stream and exposing nearby residents to avoidable health risks.

Several limitations of the present study should be acknowledged. The four-week sampling window may not capture seasonal variation in contamination levels, as rainfall patterns and stream flow fluctuate across the year in this region. Physicochemical parameters (pH, dissolved oxygen, turbidity, and temperature) were not measured, which limits mechanistic interpretation of the bacterial distribution data. Finally, antibiotic resistance profiling of the isolates was not performed; given accumulating evidence that abattoir effluents harbour antimicrobial-resistant organisms (Akpan et al., 2020; Chowdhury et al., 2025), future studies at this site should incorporate resistance characterization.

5. Conclusion and Recommendations

5.1 Conclusion

This study demonstrated that untreated abattoir effluent discharge is the primary driver of faecal bacteriological contamination in Okokpon Stream, with downstream counts for total coliforms, E. coli, and total aerobic viable bacteria all substantially exceeding WHO drinking-water guidelines; the abattoir well water was similarly impacted, extending risk to workers on site. The organisms identified, including Escherichia coli, Staphylococcus aureus, Serratia marcescens, Pseudomonas aeruginosa, and Chromobacterium violaceum, are of recognized public health significance, and their presence in water accessed by the surrounding community represents a preventable exposure risk. It is therefore recommended that primary treatment infrastructure be installed before effluent reaches the stream, the contaminated on-site well be replaced with a protected water source, and the local government environmental health department enforce routine microbial monitoring of Okokpon Stream in line with national environmental standards.

5.2 Recommendations

Abattoir operators at Ikpoba Hill should install functional wastewater treatment facilities capable of reducing organic load, nutrient concentrations, and microbial burden to permissible limits before discharge. Routine physicochemical and microbiological monitoring should be institutionalised, and regulatory agencies should enforce compliance with existing effluent discharge standards. Future studies should extend assessment to include antimicrobial resistance profiling of isolated organisms and additional heavy metal parameters.

References

[1] Adelegan, A. J. (2002). Environmental policy and slaughterhouse waste in Nigeria. In Proceedings of the 28th WEDC Conference, Kolkata, India.

[2] Akpan, S. N., Odeniyi, O. A., Adebowale, O. O., Alarape, S. A., & Adeyemo, O. K. (2020). Antibiotic resistance profile of Gram-negative bacteria isolated from Lafenwa abattoir effluent and its receiving water (Ogun River) in Abeokuta, Ogun State, Nigeria. Onderstepoort Journal of Veterinary Research, *87*(1), e1-e8. https://doi.org/10.4102/ojvr.v87i1.1854

[3] Akpoka, O. A., Solanke, E. O., Akinyeye, A. J., & Mekomah, H. U. (2023). Bacteria diversity of two abattoir effluents in Ikpoba Hill and Oluku, Benin City, Nigeria and their potential public health implications. Microbes and Infectious Diseases, *4*(3), 954–959. https://doi.org/10.21608/MID.2022.114174.1226

[4] American Public Health Association. (2000). Standard methods for the examination of water and wastewater (20th ed.). American Public Health Association.

[5] Anyata, B. U., & Nwaiwu, C. M. O. (2000). Setting of effluent standards for water pollution control in Nigeria. Journal of Civil and Environmental Systems Engineering, *1*(1), 47-66.

[6] Adelegan, J. A. (2002). Environmental policy and slaughterhouse waste in Nigeria. In Proceedings of the 28th WEDC Conference, Kolkata, India.

[7] Buchanan, R. E., & Gibbons, N. E. (Eds.). (1994). Bergey's manual of determinative bacteriology (9th ed.). Williams & Wilkins.

[8] Chaves, P. C., Castillo, L. R., Dendooven, L., & Escamilla-Silva, E. M. (2005). Poultry slaughter wastewater treatment with an up-flow system. Bioresource Technology, *96*, 1730-1736.

[9] Chowdhury, N. S., Tasnia, R., Nahar, N., Hossain, Z. Z., Ferdous, J., Akhter, H., & Begum, A. (2025). Slaughterhouse wastewater as a reservoir of thermotolerant Escherichia coli with antimicrobial resistance and virulence potential in Dhaka, Bangladesh. International Journal of Microbiology, 2875935. https://doi.org/10.1155/ijm/2875935

[10] Gannon, B., McGee, M., & O'Kiely, P. (2004). *Beef production from two- and three-year-old bulls slaughtered at two live weights*. Grange Research Centre, Teagasc.

[11] Hamid, A., Bhat, S. U., & Jehangir, A. (2020). Local determinants influencing stream water quality. Applied Water Science, 10, Article 24.

[12] Kosek, M., Bern, C., & Guerrant, R. L. (2003). The global burden of diarrhoea disease, as estimated from studies published between 1992 and 2000. Bulletin of the World Health Organization, 81(3), 197-204.

[13] McMinn, B. R., Korajkic, A., Kelleher, J., Diedrich, A., Pemberton, A., Willis, J. R., Sivaganesan, M., Shireman, B., Doyle, A., & Shanks, O. C. (2024). Quantitative fecal pollution assessment with bacterial, viral, and molecular methods in small stream tributaries. Science of the Total Environment, 951, 175740. https://doi.org/10.1016/j.scitotenv.2024.175740

[14] Nafarnda, W. D., Ajayi, I. E., Shawulu, J. C., Kawe, M. S., Omeiza, G. K., Sani, N. A., Tenuche, O. Z., Dantong, D. D., & Tags, S. Z. (2012). Bacteriological quality of abattoir effluents discharged into water bodies in Abuja, Nigeria. ISRN Veterinary Science, 2012, 515689.

[15] Odonkor, S. T., & Ampofo, J. K. (2013). Escherichia coli as an indicator of bacteriological quality of water: An overview. Microbiology Research, 4(1), e2.

[16] Omole, D. O., & Longe, E. O. (2008). An assessment of the impact of abattoir effluents on River Illo, Ota, Nigeria. *Journal of Environmental Science and Technology*, *1*(2), 56–64.

[17] Wolf, J., Johnston, R. B., Ambelu, A., Arnold, B. F., Bain, R., Brauer, M., Brown, J., Caruso, B. A., Clasen, T., Colford, J. M., Esteves Mills, J., Evans, B., Freeman, M. C., Gordon, B., Kang, G., Lanata, C. F., Medlicott, K. O., Prüss-Ustün, A., Troeger, C., Boisson, S., & Cumming, O. (2023). Burden of disease attributable to unsafe drinking water, sanitation, and hygiene in domestic settings: A global analysis for selected adverse health outcomes. The Lancet, 401(10393), 2060-2071. https://doi.org/10.1016/S0140-6736(23)00458-0

[18] World Health Organization. (2011). Guidelines for drinking-water quality (4th ed.). World Health Organization.

[19] World Health Organization. (2023, September 13). Drinking-water. https://www.who.int/news-room/fact-sheets/detail/drinking-water

[20] Wright, J., Gundry, S., & Conroy, R. (2004). Household drinking water in developing countries: A systematic review of microbiological contamination between source and point-of-use. Tropical Medicine & International Health, 9(1), 106-117.