*Microbiology Research International*
**Vol. 14(3), pp. 64-75, September 2026**
**ISSN: 2354-2128**
***Full Length Research Paper***

# Comparative effects of selected indigenous bacterial treatments on the physicochemical characteristics of abattoir wastewater in Port Harcourt, Nigeria

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Accepted 1 September, 2026

**ABSTRACT**

Abattoir wastewater contains high concentrations of organic matter, nutrients, dissolved solids, and diverse microorganisms that may pose environmental and public health risks when discharged without adequate treatment. This study evaluated the bacteriological characteristics of abattoir wastewater and comparatively assessed the effects of selected indigenous bacterial isolates on its physicochemical characteristics. Wastewater samples were collected from selected abattoirs in Port Harcourt, Rivers State, Nigeria. Standard microbiological techniques were used for bacterial enumeration, isolation, characterization, and identification. The growth potential of the bacterial isolates in wastewater-supplemented mineral salt medium was assessed using optical density measurements. Selected *Pseudomonas* sp. and *Bacillus* sp. isolates, together with a separately formulated consortium of probable enteric bacteria, were evaluated under laboratory conditions for 21 days, with physicochemical parameters monitored at seven-day intervals. Mean total heterotrophic bacterial counts ranged from $6.33 \times 10^6$ to $1.60 \times 10^7$ CFU/mL, total coliform counts from $2.63 \times 10^5$ to $5.00 \times 10^5$ CFU/mL, and total faecal coliform counts from $5.00 \times 10^3$ to $1.73 \times 10^4$ CFU/mL. Total *Pseudomonas* counts ranged from 0 to $1.37 \times 10^4$ CFU/mL, Salmonella-Shigella counts from $8.33 \times 10^3$ to $2.80 \times 10^4$ CFU/mL, and total staphylococcal counts from $1.00 \times 10^3$ to $1.33 \times 10^3$ CFU/mL. Fifteen bacterial isolates representing ten probable bacterial taxa, including *Bacillus*, *Pseudomonas*, *Escherichia*, *Klebsiella*, *Salmonella*, *Shigella*, *Staphylococcus*, *Serratia*, *Chromobacterium*, and *Micrococcus*, were recovered. *Pseudomonas* sp. exhibited the highest growth response in the mineral salt medium ($OD_{550}$ = 1.678). After 21 days of treatment, the consortium produced the greatest reductions in electrical conductivity, biochemical oxygen demand, nitrate, and phosphate, with reductions of 2.9%, 5.4%, 19.7%, and 31.5%, respectively, whereas *Pseudomonas* sp. produced the greatest reduction in total dissolved solids (26.7%). Temperature remained relatively stable throughout the treatment period, whereas pH showed a moderate increase. The findings demonstrate differential effects of the selected bacterial treatments on the physicochemical characteristics of abattoir wastewater. Although the consortium produced greater reductions in several parameters, its inclusion of probable *Escherichia coli*, *Klebsiella* sp., and *Salmonella* sp. limits its suitability for environmental application. The study highlights the potential of appropriately characterized indigenous bacterial isolates, particularly *Pseudomonas* sp. and *Bacillus* sp., for further laboratory-scale investigation of abattoir wastewater treatment and emphasizes the need to evaluate microbiological safety alongside treatment performance.

**Keywords:** Abattoir wastewater, bacterial isolates, *Bacillus* sp., bioremediation, *Pseudomonas* sp., physicochemical characteristics, wastewater treatment.

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## INTRODUCTION

Abattoirs are important components of the livestock and meat-production sector, providing animal protein, employment, and economic benefits. However, slaughtering and meat-processing activities generate substantial quantities of wastewater from animal washing, slaughtering operations, cleaning of slaughter slabs and

equipment, and disposal of animal wastes. Abattoir wastewater commonly contains blood, faeces, urine, fats, bones, hides, condemned organs, gastrointestinal contents, and other carcass materials, making it a complex waste stream with considerable potential for environmental pollution (Alonge, 2005; Nafaranda et al., 2011; Chukwu et al., 2011). Increasing meat consumption associated with population growth, urbanisation, and changing dietary patterns has further increased slaughtering activities and the generation of abattoir wastewater (Chukwu et al., 2011; Ogbomida et al., 2016).

The pollution potential of abattoir wastewater is primarily associated with its high concentrations of biodegradable organic matter, suspended and dissolved solids, nitrogen, phosphorus, and other constituents. Blood is particularly important because of its high protein and organic content and its substantial contribution to biochemical oxygen demand (BOD) and chemical oxygen demand (COD) (Adelegan, 2002; Merzouki et al., 2005; Aniebo et al., 2009). When discharged without adequate treatment, these organic constituents support intensive microbial decomposition and may result in oxygen depletion in receiving water bodies, thereby adversely affecting aquatic ecosystems. Excessive nitrogen and phosphorus can contribute to nutrient enrichment and eutrophication, while elevated total dissolved solids and electrical conductivity may further impair water quality (Amenu, 2014; Adeyinka et al., 2014).

In Nigeria, inadequate waste-management infrastructure and the proximity of some abattoirs to rivers, streams, and drainage channels have facilitated the discharge of untreated or inadequately treated effluents into the environment (Adelegan, 2002; Adeyemi and Adeyemo, 2007). In addition to physicochemical pollution, abattoir wastewater may contain large and diverse bacterial populations originating from animals, faecal materials, blood, gastrointestinal contents, and contaminated processing surfaces. Potentially pathogenic bacteria, including *Escherichia coli*, *Salmonella*, *Shigella*, and *Staphylococcus*, have been reported in abattoir wastes and associated receiving environments. Consequently, untreated abattoir effluent represents both an environmental pollution problem and a potential public health concern, particularly where receiving water bodies are used for domestic, agricultural, or other human activities. The discharge of abattoir wastewater may also contribute to the environmental dissemination of antimicrobial-resistant bacteria (Akpan et al., 2020; Idu et al., 2023; Udoh and Iloh, 2025).

Effective treatment is therefore necessary to reduce the organic, nutrient, physicochemical, and microbiological pollution associated with abattoir wastewater before its discharge into the environment. Conventional wastewater treatment processes can reduce pollutant concentrations through physical, chemical, and biological mechanisms. However, treatment systems requiring substantial chemical inputs, high energy consumption, specialised infrastructure, or complex operation may be difficult to implement and sustain in settings where abattoirs have limited resources. Consequently, biological treatment approaches have received increasing attention because of their potential to treat complex organic wastes using microorganisms and their metabolic activities.

Microbial bioremediation involves the degradation, transformation, assimilation, or removal of contaminants through the activities of microorganisms under suitable environmental conditions (Sasikumar and Papinazath, 2003). The effectiveness of microbial treatment depends on factors such as the metabolic characteristics of the microorganisms, wastewater composition, pH, temperature, nutrient availability, oxygen conditions, and the nature and concentration of the target contaminants (Strong and Burgess, 2008). Indigenous microorganisms are of particular interest because their prior exposure to the contaminated environment may favour their adaptation and survival under local physicochemical conditions.

Among bacterial groups commonly investigated for wastewater treatment, *Pseudomonas* and *Bacillus* are notable for their metabolic versatility, production of extracellular enzymes, and ability to utilise a range of organic substrates. Their occurrence in wastewater and polluted environments has supported investigations into their potential application in the biological treatment of abattoir effluents (Adeyinka et al., 2014; Ogbomida et al., 2016). Bacterial consortia may also provide broader metabolic capabilities than individual isolates because different organisms can contribute complementary activities in the transformation of complex waste constituents. However, increased treatment performance does not necessarily imply microbiological safety, particularly when a consortium contains bacteria of potential public health importance. Comparative evaluation is therefore necessary to distinguish treatment performance from environmental suitability.

Although bacterial treatment of abattoir wastewater has been investigated, there remains a need for comparative assessment of indigenous bacterial isolates obtained from abattoir wastewater in Port Harcourt and for a clearer evaluation of their effects on individual physicochemical parameters under controlled laboratory conditions. This study therefore comparatively evaluated the effects of indigenous *Pseudomonas* sp., indigenous *Bacillus* sp., and a separately formulated enteric bacterial consortium on selected physicochemical characteristics of abattoir wastewater during a 21-day laboratory treatment period. The study also characterized the bacterial population of the wastewater and assessed the growth responses of selected isolates under wastewater-supplemented mineral salt medium conditions to identify isolates for subsequent treatment evaluation. The findings were intended to provide comparative evidence on the performance of selected indigenous bacterial

treatments while considering the microbiological safety implications of the organisms evaluated.

## MATERIALS AND METHODS

### Study area

The study was conducted at two abattoirs around Rumueme Town in the Port Harcourt metropolis, Rivers State, Nigeria. Sandfield Junction/Illoabuchi Abattoir is located at latitude 4°47′17.623″N and longitude 6°59′7.547″E, while Agip Road Abattoir is located at latitude 4°47′16.614″N and longitude 6°59′7.368″E.

### Sample collection

Six wastewater samples were collected from the two selected abattoirs. Three sampling points were selected within each location to account for spatial variation in wastewater characteristics and bacterial populations. One wastewater sample of approximately 500 mL was aseptically collected from each sampling point into sterile high-density polyethylene (HDPE) bottles, giving a total of six wastewater samples. The samples were appropriately labelled, placed in an ice-packed container, and transported immediately to the Department of Microbiology Laboratory, Rivers State University, for bacteriological and physicochemical analyses.

### Culture media, reagents, and equipment

The materials and equipment used included sterile sample bottles, test tubes, pipettes, conical flasks, measuring cylinders, Petri dishes, glass slides, wire loops, Pasteur pipettes, filter paper, aluminium foil, cotton wool, a Bunsen burner, microscope, UV-visible spectrophotometer, oven, autoclave, and incubator. The culture media used included nutrient agar, MacConkey agar, mannitol salt agar, Salmonella–Shigella agar, eosin methylene blue agar, and cetrimide agar. Reagents and stains included crystal violet, Lugol's iodine, safranin, hydrogen peroxide, oxidase reagent, Kovac's reagent, and reagents required for the biochemical tests.

### Preparation of culture media

The culture media were prepared according to the manufacturers' instructions. Nutrient agar (28 g/L), MacConkey agar (55 g/L), mannitol salt agar (111 g/L), Salmonella–Shigella agar (63 g/L), eosin methylene blue agar (36 g/L), and cetrimide agar (48 g/L, supplemented with 1% glycerol) were prepared in distilled water. Where applicable, the prepared media were sterilized by autoclaving at 121°C and 15 psi for 15 min, allowed to cool to approximately 45°C, and aseptically dispensed into sterile Petri dishes.

### Sample preparation and serial dilution

Sterile normal saline was prepared by dissolving 8.5 g of sodium chloride in 1 L of distilled water. Nine millilitres of the prepared saline were dispensed into sterile test tubes and autoclaved at 121°C and 15 psi for 15 min. Ten-fold serial dilutions of each wastewater sample were performed by transferring 1 mL of the wastewater sample into 9 mL of sterile normal saline and mixing thoroughly. Serial dilution was continued to $10^{-5}$.

### Enumeration and isolation of bacteria

For bacterial enumeration, 0.1 mL aliquots of appropriate sample dilutions were inoculated in duplicate onto the appropriate sterile agar plates using the spread-plate technique. The inoculum was evenly distributed over the agar surface using a sterile glass spreader. The plates were incubated in an inverted position at 37°C for 24 h. Following incubation, colonies were counted, and representative colonies were selected based on distinct colonial characteristics. Selected colonies were purified by repeated streaking and maintained on appropriate media for subsequent characterization and identification.

### Characterization and identification of bacterial isolates

Bacterial isolates were characterized based on colonial morphology, cellular morphology, Gram reaction, motility, and standard biochemical tests. Colonial characteristics assessed included colony size, shape, colour, margin, elevation, texture, and pigmentation. Based on the combined morphological and biochemical characteristics, isolates were assigned to probable bacterial taxa.

Gram staining was performed using crystal violet, Lugol's iodine, 70% alcohol, and safranin, followed by microscopic examination under the ×100 objective using immersion oil. Motility was determined using semi-solid agar following inoculation by a single stab and incubation at 37°C for 24 h. Diffuse growth away from the stab line was interpreted as a positive motility reaction.

Biochemical characterization included citrate utilization, oxidase, catalase, indole, methyl red, Voges–Proskauer, and sugar fermentation tests. Citrate utilization was indicated by a colour change from green to blue, oxidase activity by the development of a purple colour, and catalase activity by immediate bubble formation following exposure to hydrogen peroxide. Indole production was determined using tryptophan broth and Kovac's reagent,

while methyl red and Voges–Proskauer reactions were assessed using glucose phosphate broth and the respective reagents. Sugar fermentation was evaluated using glucose, sucrose, fructose, maltose, and lactose in phenol red peptone water containing Durham tubes. Colour change and gas production were recorded as indicators of carbohydrate fermentation.

**Screening of bacterial isolates for growth potential in mineral salt medium**

Bacterial isolates recovered from the three sampling points at each of the two selected abattoir locations were characterized and screened for their growth potential in mineral salt medium (MSM). Selected isolates representing *Pseudomonas* sp., *Bacillus* sp., and probable enteric bacteria were evaluated under nutrient-limited conditions. The screening was used to identify isolates with comparatively greater growth potential for subsequent use in the wastewater treatment experiment.

Briefly, 0.1 mL of each bacterial broth culture was inoculated into 5 mL of MSM broth supplemented with 0.1 mL of sterile abattoir wastewater in separate test tubes. The inoculated media were incubated at 37°C for 5 days. Bacterial growth was assessed by measuring optical density at 550 nm using a UV-visible spectrophotometer. Isolates showing comparatively high optical density values were selected for the subsequent wastewater treatment experiment.

**Wastewater treatment experimental setup**

For the treatment experiment, composite wastewater was prepared by combining equal volumes of wastewater from the two selected locations. Specifically, 100 mL of wastewater from Sandfield/Illoabuchi Road and 100 mL from Agip Road were combined to obtain 200 mL of composite wastewater for each experimental flask and dispensed into sterile 500-mL Erlenmeyer flasks. The individual bacterial treatments were inoculated with 1 mL of a 24-h culture of the selected indigenous *Pseudomonas* sp. or *Bacillus* sp., while the consortium treatment received 1 mL of the prepared mixed bacterial inoculum. An uninoculated control containing the same composite wastewater-mineral salt medium mixture was maintained under identical experimental conditions. The flasks were incubated at room temperature and periodically shaken to facilitate mixing and aeration.

The experiment lasted for 21 days, and samples were collected on Days 7, 14, and 21 for physicochemical analysis. The consortium was included solely as a comparative laboratory treatment to evaluate the response of a mixed bacterial population relative to the individual bacterial treatments. It was not intended or proposed as a candidate for direct environmental application because the consortium contained probable enteric bacteria.

Dissolved oxygen was not measured during the experiment only during the initial wastewater characterization; therefore, the oxygen status of the experimental system could not be directly established. Consequently, changes in nitrate concentration were interpreted only as changes in nitrate concentration and were not used as definitive evidence of nitrification or denitrification.

**Physicochemical analysis**

At the designated sampling intervals, treated and control wastewater samples were analysed using standard laboratory procedures. The physicochemical parameters determined were temperature, pH, total dissolved solids (TDS), electrical conductivity (EC), five-day biochemical oxygen demand ($BOD_5$), nitrate, and phosphate. Changes in these parameters over the 21-day experimental period were used to assess the effects of the individual bacterial treatments and bacterial consortium on the physicochemical characteristics of the abattoir wastewater.

The percentage removal efficiency for each parameter was calculated using:

Removal efficiency (%) = [(Initial concentration − Final concentration) / Initial concentration] × 100

where the initial concentration represents the Day 0 value and the final concentration represents the Day 21 value. Negative values indicated an increase in the measured parameter during treatment rather than removal.

$BOD_5$ removal efficiency was calculated using the same equation:

$BOD_5$ removal efficiency (%) = [(Initial $BOD_5$ − Final $BOD_5$) / Initial $BOD_5$] × 100

Because ammonium, nitrite, dissolved oxygen, and total nitrogen were not determined, nitrogen transformation pathways and the occurrence of nitrification or denitrification were not inferred from changes in nitrate concentration alone.

**Data analysis**

Data were analysed using IBM SPSS Statistics, Version 25. Descriptive statistics were used to summarize the bacteriological and physicochemical characteristics of the abattoir wastewater. Bacterial counts were expressed as colony-forming units per millilitre (CFU/mL), while

physicochemical parameters were presented as measured concentrations or values with appropriate units. The growth potential of bacterial isolates during screening was assessed based on optical density at 550 nm.

Percentage reductions in TDS, EC, $BOD_5$, nitrate, and phosphate were calculated by comparing the initial (Day 0) and final (Day 21) concentrations for each bacterial treatment and the uninoculated control. The performance of indigenous *Pseudomonas* sp., indigenous *Bacillus* sp., and the bacterial consortium was compared descriptively based on the magnitude of change and percentage reduction in the selected physicochemical parameters over the 21-day treatment period.

## RESULTS

### Physicochemical characteristics of abattoir wastewater

The physicochemical characteristics of the abattoir wastewater are presented in Table 1. The results showed considerable variation in the measured quality parameters between the two sampling locations. Temperature values were relatively similar, ranging from 28.2°C at Sandfield/Iloabuchi Road Abattoir (S1) to 28.5°C at Agip Road Abattoir (S2). The pH was 7.20 at S1, whereas S2 recorded a lower value of 5.51, indicating acidic wastewater at that location. Total dissolved solids (TDS) were substantially elevated at both locations, with values of 3210 and 1400 mg/L at S1 and S2, respectively. Electrical conductivity (EC) was also high at both locations, measuring 6300 µS/cm at S1 and 5500 µS/cm at S2. Dissolved oxygen (DO) concentrations were low at both sites, with S1 recording 1.7 mg/L and S2 recording 0.4 mg/L. Biochemical oxygen demand (BOD) was markedly elevated, with values of 672 and 502 mg/L at S1 and S2, respectively. Nitrate concentrations were 64 and 56 mg/L at S1 and S2, respectively.

### Bacteriological characteristics of abattoir wastewater

The bacteriological analysis showed that abattoir wastewater from Agip Road generally had higher bacterial loads than samples from Sandfield/Iloabuchi Road (Table 2). The total heterotrophic bacterial (THB) count was $1.60 \times 10^7 \pm 9.17 \times 10^6$ CFU/mL at Agip Road, compared with $6.33 \times 10^6 \pm 3.51 \times 10^6$ CFU/mL at Sandfield/Iloabuchi Road. Similarly, the total coliform count (TCC) was higher at Agip Road ($5.00 \times 10^5 \pm 4.70 \times 10^5$ CFU/mL) than at Sandfield/Iloabuchi Road ($2.63 \times 10^5 \pm 3.96 \times 10^5$ CFU/mL). The total faecal coliform (TFC) count was also higher at Agip Road ($1.73 \times 10^4 \pm 1.62 \times 10^4$ CFU/mL) than at Sandfield/Iloabuchi Road ($5.00 \times 10^3 \pm 8.66 \times 10^3$ CFU/mL).

**Table 1.** Physicochemical characteristics of abattoir wastewater.

| Parameter | Unit | S1 | S2 |
|---|---|---|---|
| Temperature | °C | 28.2 | 28.5 |
| pH | – | 7.20 | 5.51 |
| Total dissolved solids | mg/L | 3210 | 1400 |
| Electrical conductivity | µS/cm | 6300 | 5500 |
| Dissolved oxygen | mg/L | 1.7 | 0.4 |
| Biochemical oxygen demand | mg/L | 672 | 502 |
| Nitrate | mg/L | 64 | 56 |

**Key:** S1 = Sandfield/Iloabuchi Road Abattoir; S2 = Agip Road Abattoir.

**Table 2.** Bacteriological counts of abattoir wastewater samples.

| Abattoir | Sandfield / Iloabuchi Road | Agip Road |
|---|---|---|
| THB (CFU/mL) | $6.33 \times 10^6 \pm 3.51 \times 10^6$ | $1.60 \times 10^7 \pm 9.17 \times 10^6$ |
| TCC (CFU/mL) | $2.63 \times 10^5 \pm 3.96 \times 10^5$ | $5.00 \times 10^5 \pm 4.70 \times 10^5$ |
| TFC (CFU/mL) | $5.00 \times 10^3 \pm 8.66 \times 10^3$ | $1.73 \times 10^4 \pm 1.62 \times 10^4$ |
| TPC (CFU/mL) | $0 \pm 0$ | $1.37 \times 10^4 \pm 2.28 \times 10^4$ |
| SSC (CFU/mL) | $8.33 \times 10^3 \pm 1.44 \times 10^4$ | $2.80 \times 10^4 \pm 3.21 \times 10^4$ |
| TSC (CFU/mL) | $1.33 \times 10^3 \pm 1.15 \times 10^3$ | $1.00 \times 10^3 \pm 1.73 \times 10^3$ |

**Key:** THB = Total heterotrophic bacteria; TCC = Total coliform count; TFC = Total faecal coliform; TPC = Total *Pseudomonas* count; SSC = Salmonella-Shigella count; TSC = Total staphylococcal count.

The total *Pseudomonas* count (TPC) was not detected at Sandfield/Iloabuchi Road ($0 \pm 0$ CFU/mL) but was recorded at $1.37 \times 10^4 \pm 2.28 \times 10^4$ CFU/mL at Agip Road. The Salmonella-Shigella count (SSC) was also

higher at Agip Road ($2.80 \times 10^4 \pm 3.21 \times 10^4$ CFU/mL) than at Sandfield/Iloabuchi Road ($8.33 \times 10^3 \pm 1.44 \times 10^4$ CFU/mL). In contrast, the total staphylococcal count (TSC) was slightly higher at Sandfield/Iloabuchi Road ($1.33 \times 10^3 \pm 1.15 \times 10^3$ CFU/mL) than at Agip Road ($1.00 \times 10^3 \pm 1.73 \times 10^3$ CFU/mL).

## Identification of bacterial isolates

Fifteen bacterial isolates were recovered from the abattoir wastewater samples and characterized using colonial morphology, cellular morphology, Gram reaction, motility, and biochemical tests (Table 3). Based on the observed characteristics and biochemical profiles, the isolates were assigned to probable members of ten bacterial taxa: *Bacillus* sp., *Serratia* sp., *Chromobacterium* sp., *Pseudomonas* sp., *Micrococcus* sp., *Staphylococcus* sp., *Escherichia coli*, *Klebsiella* sp., *Salmonella* sp., and *Shigella* sp.

The isolates comprised both Gram-positive and Gram-negative bacteria. Gram-positive isolates included probable *Bacillus* sp., *Micrococcus* sp., and *Staphylococcus* sp., whereas Gram-negative isolates included probable *Serratia* sp., *Chromobacterium* sp., *Pseudomonas* sp., *Escherichia coli*, *Klebsiella* sp., *Salmonella* sp., and *Shigella* sp. The recovery of these diverse bacterial taxa indicates a heterogeneous bacterial population in the abattoir wastewater.

**Table 3.** Probable bacterial isolates identified from abattoir wastewater.

| S/N | Isolate code | Probable bacterial identity |
|---|---|---|
| 1 | N1 | *Bacillus* sp. |
| 2 | N2 | *Serratia* sp. |
| 3 | N3 | *Chromobacterium* sp. |
| 4 | N4 | *Pseudomonas* sp. |
| 5 | N5 | *Bacillus* sp. |
| 6 | N6 | *Micrococcus* sp. |
| 7 | N7 | *Bacillus* sp. |
| 8 | MS1 | *Staphylococcus* sp. |
| 9 | MS2 | *Staphylococcus* sp. |
| 10 | C1 | *Pseudomonas* sp. |
| 11 | M1 | *Escherichia coli* |
| 12 | M2 | *Klebsiella* sp. |
| 13 | E1 | *Escherichia coli* |
| 14 | S1 | *Salmonella* sp. |
| 15 | S2 | *Shigella* sp. |

## Growth of bacterial isolates in mineral salt medium

The growth performance of the bacterial isolates in mineral salt medium, measured as optical density (OD), is presented in Table 4. The OD values ranged from 0.621 to 1.678, demonstrating differences in the growth responses of the isolates under the mineral salt medium conditions. The highest OD was recorded for *Pseudomonas* sp. (1.678), followed by another *Pseudomonas* sp. isolate (1.647), whereas the lowest OD values were recorded for *Escherichia coli* isolates, at 0.621 and 0.674.

The *Bacillus* sp. isolates recorded OD values of 1.524, 1.451, and 1.023. Other isolates recorded intermediate values, including *Serratia* sp. (1.367), *Chromobacterium* sp. (1.299), *Micrococcus* sp. (1.234), *Salmonella* sp. (0.921), *Staphylococcus* sp. (0.824 and 0.651), *Shigella* sp. (0.822), and *Klebsiella* sp. (0.812). The relatively high OD values recorded for *Pseudomonas* sp. and some *Bacillus* sp. isolates provided the basis for their subsequent use in the wastewater treatment experiment.

**Table 4.** Growth pattern of bacterial isolates in mineral salt medium.

| S/N | Isolate | Optical density (OD) |
|---|---|---|
| 1 | *Bacillus* sp. | 1.524 |
| 2 | *Serratia* sp. | 1.367 |
| 3 | *Chromobacterium* sp. | 1.299 |
| 4 | *Pseudomonas* sp. | 1.678 |
| 5 | *Bacillus* sp. | 1.451 |
| 6 | *Micrococcus* sp. | 1.234 |
| 7 | *Bacillus* sp. | 1.023 |
| 8 | *Staphylococcus* sp. | 0.824 |
| 9 | *Staphylococcus* sp. | 0.651 |
| 10 | *Pseudomonas* sp. | 1.647 |
| 11 | *Escherichia coli* | 0.621 |
| 12 | *Klebsiella* sp. | 0.812 |
| 13 | *Escherichia coli* | 0.674 |
| 14 | *Salmonella* sp. | 0.921 |
| 15 | *Shigella* sp. | 0.822 |

## Changes in physicochemical characteristics during the treatment period

### *Changes in temperature*

Temperature remained relatively stable throughout the 21-day treatment period, with values ranging from 27.7 to 28.7°C (Table 5). The control increased slightly from 28.2°C on Day 0 to 28.3°C on Day 21. The *Pseudomonas* sp. treatment initially decreased from 28.2°C to 27.7°C on Day 7 before increasing to 28.3°C on Day 21. The *Bacillus* sp. treatment increased from 28.2°C to 28.5°C, whereas the consortium treatment increased from 28.2°C to 28.7°C.

### *Changes in pH*

The pH of the wastewater increased progressively in the bacterial treatments during the 21-day period (Table 6). The control increased from 7.10 on Day 0 to 7.20 on Day 21. The *Pseudomonas* sp. treatment increased from 7.11

**Table 5.** Changes in temperature of abattoir wastewater during treatment.

| Treatment | Day 0 (°C) | Day 7 (°C) | Day 14 (°C) | Day 21 (°C) |
|---|---|---|---|---|
| Control | 28.2 | 27.8 | 28.4 | 28.3 |
| *Pseudomonas* sp. | 28.2 | 27.7 | 28.4 | 28.3 |
| *Bacillus* sp. | 28.2 | 27.8 | 28.4 | 28.5 |
| Consortium | 28.2 | 27.8 | 28.4 | 28.7 |

**Table 6.** Changes in pH of abattoir wastewater during treatment.

| Treatment | Day 0 | Day 7 | Day 14 | Day 21 |
|---|---|---|---|---|
| Control | 7.10 | 7.21 | 7.20 | 7.20 |
| *Pseudomonas* sp. | 7.11 | 7.18 | 7.45 | 7.60 |
| *Bacillus* sp. | 7.23 | 7.20 | 7.50 | 7.70 |
| Consortium | 7.12 | 7.25 | 7.55 | 7.70 |

to 7.60, while the *Bacillus* sp. treatment increased from 7.23 to 7.70. The consortium treatment increased from 7.12 to 7.70. Thus, the greatest increase in pH was observed in the *Bacillus* sp. and consortium treatments.

### *Changes in total dissolved solids*

TDS showed different patterns among the treatments (Table 7). The control decreased marginally from 3210 mg/L on Day 0 to 3200 mg/L on Day 21, corresponding to a removal efficiency of 0.31%. The *Pseudomonas* sp. treatment showed a substantial decrease from 3210 to 2356 mg/L, representing a removal efficiency of 26.67%. In contrast, the *Bacillus* sp. treatment increased from 3209 to 3823 mg/L, corresponding to a calculated change of −19.13%, indicating a net increase rather than removal. The consortium treatment decreased from 3211 to 3101 mg/L, giving a removal efficiency of 3.43%. Among the bacterial treatments, *Pseudomonas* sp. produced the greatest reduction in TDS.

### *Changes in electrical conductivity*

Electrical conductivity decreased slightly in the bacterial treatments but remained unchanged in the control (Table 8). The control remained at 6300 µS/cm throughout the experimental period, corresponding to 0% removal. The *Pseudomonas* sp. treatment decreased from 6300 to 6234 µS/cm, representing 1.05% removal. The *Bacillus* sp. treatment decreased from 6301 to 6201 µS/cm, corresponding to 1.59% removal, while the consortium treatment decreased from 6300 to 6119 µS/cm, representing the highest EC removal of 2.87%.

### *Changes in biochemical oxygen demand*

BOD decreased during the treatment period, with the greatest reduction occurring in the consortium treatment (Table 9). The control decreased from 711 to 708 mg/L, corresponding to 0.42% removal. The *Pseudomonas* sp. treatment decreased from 713 to 703 mg/L, giving 1.40% removal. The *Bacillus* sp. treatment decreased from 709 to 691 mg/L, corresponding to 2.54% removal. The consortium treatment recorded the largest reduction, from 721 to 682 mg/L, equivalent to 5.41% removal.

### *Changes in nitrate concentration*

Nitrate concentrations decreased progressively during treatment, with the greatest reduction occurring in the consortium treatment (Table 10). The control decreased from 65 to 63 mg/L, corresponding to 3.08% removal. The *Pseudomonas* sp. treatment decreased from 66 to 58 mg/L, giving a removal efficiency of 12.12%. The *Bacillus* sp. treatment decreased from 66 to 56 mg/L, corresponding to 15.15% removal. The consortium treatment showed the greatest reduction, decreasing from 66 to 53 mg/L and achieving 19.70% removal.

**Table 7.** Changes in total dissolved solids during treatment.

| Treatment | Day 0 (mg/L) | Day 7 (mg/L) | Day 14 (mg/L) | Day 21 (mg/L) | Removal efficiency (%) |
|---|---|---|---|---|---|
| Control | 3210 | 3208 | 3203 | 3200 | 0.31 |
| *Pseudomonas* sp. | 3210 | 3211 | 3012 | 2356 | 26.67 |
| *Bacillus* sp. | 3209 | 3185 | 3218 | 3823 | −19.13 |
| Consortium | 3211 | 3209 | 3198 | 3101 | 3.43 |

Removal efficiency = [(Day 0 − Day 21)/Day 0] × 100. Negative value indicates an increase in concentration.

**Table 8.** Changes in electrical conductivity during treatment.

| Treatment | Day 0 (µS/cm) | Day 7 (µS/cm) | Day 14 (µS/cm) | Day 21 (µS/cm) | Removal efficiency (%) |
|---|---|---|---|---|---|
| Control | 6300 | 6300 | 6300 | 6300 | 0.00 |
| *Pseudomonas* sp. | 6300 | 6233 | 6231 | 6234 | 1.05 |
| *Bacillus* sp. | 6301 | 6291 | 6292 | 6201 | 1.59 |
| Consortium | 6300 | 6294 | 6287 | 6119 | 2.87 |

**Table 9.** Changes in biochemical oxygen demand during treatment.

| Treatment | Day 0 (mg/L) | Day 7 (mg/L) | Day 14 (mg/L) | Day 21 (mg/L) | Removal efficiency (%) |
|---|---|---|---|---|---|
| Control | 711 | 711 | 709 | 708 | 0.42 |
| *Pseudomonas* sp. | 713 | 710 | 707 | 703 | 1.40 |
| *Bacillus* sp. | 709 | 709 | 698 | 691 | 2.54 |
| Consortium | 721 | 718 | 711 | 682 | 5.41 |

**Table 10.** Changes in nitrate concentration during treatment.

| Treatment | Day 0 (mg/L) | Day 7 (mg/L) | Day 14 (mg/L) | Day 21 (mg/L) | Removal efficiency (%) |
|---|---|---|---|---|---|
| Control | 65 | 64 | 63 | 63 | 3.08 |
| *Pseudomonas* sp. | 66 | 63 | 61 | 58 | 12.12 |
| *Bacillus* sp. | 66 | 63 | 56 | 56 | 15.15 |
| Consortium | 66 | 62 | 58 | 53 | 19.70 |

### *Changes in phosphate concentration*

Phosphate concentrations remained unchanged in the control but decreased progressively in all bacterial treatments (Table 11). The control remained at 17.8 mg/L from Day 0 to Day 21, corresponding to 0% removal. The *Pseudomonas* sp. treatment decreased from 18.0 to 14.9 mg/L, giving a removal efficiency of 17.22%. The *Bacillus* sp. treatment decreased from 17.9 to 14.1 mg/L, corresponding to 21.23% removal. The consortium treatment produced the greatest reduction, from 17.8 to 12.2 mg/L, representing 31.46% removal. Thus, the consortium demonstrated the highest phosphate removal, followed by the *Bacillus* sp. and *Pseudomonas* sp. treatments.

### Removal efficiency of the bacterial treatments

The calculated Day 0–Day 21 removal efficiencies demonstrated that the bacterial treatments differed in their ability to reduce the measured wastewater parameters (Table 12).

**Table 11.** Changes in phosphate concentration during treatment.

| Treatment | Day 0 (mg/L) | Day 7 (mg/L) | Day 14 (mg/L) | Day 21 (mg/L) | Removal efficiency (%) |
|---|---|---|---|---|---|
| Control | 17.8 | 17.8 | 17.8 | 17.8 | 0.00 |
| *Pseudomonas* sp. | 18.0 | 17.6 | 16.8 | 14.9 | 17.22 |
| *Bacillus* sp. | 17.9 | 17.0 | 16.6 | 14.1 | 21.23 |
| Consortium | 17.8 | 17.3 | 16.4 | 12.2 | 31.46 |

**Table 12.** Overall Day 0–Day 21 removal efficiency of bacterial treatments.

| Parameter | Control (%) | *Pseudomonas* sp. (%) | *Bacillus* sp. (%) | Consortium (%) |
|---|---|---|---|---|
| TDS | 0.31 | 26.67 | −19.13 | 3.43 |
| EC | 0.00 | 1.05 | 1.59 | 2.87 |
| BOD | 0.42 | 1.40 | 2.54 | 5.41 |
| Nitrate | 3.08 | 12.12 | 15.15 | 19.70 |
| Phosphate | 0.00 | 17.22 | 21.23 | 31.46 |

Removal efficiency = [(initial concentration − final concentration)/initial concentration] × 100. Negative values indicate an increase in concentration.

*Pseudomonas* sp. produced the greatest reduction in TDS (26.67%), whereas the consortium produced the greatest reductions in EC (2.87%), BOD (5.41%), nitrate (19.70%), and phosphate (31.46%). *Bacillus* sp. achieved intermediate removal efficiencies for EC (1.59%), BOD (2.54%), nitrate (15.15%), and phosphate (21.23%).

Overall, the consortium demonstrated the broadest treatment performance across the parameters evaluated. Its greatest reduction was observed for phosphate, followed by nitrate, while the reductions in BOD and EC were comparatively modest. *Pseudomonas* sp. showed a particularly pronounced effect on TDS but relatively low reductions in BOD and EC. The *Bacillus* sp. treatment reduced BOD, nitrate, phosphate, and EC, although TDS increased during the treatment period.

## DISCUSSION

The physicochemical characteristics of the abattoir wastewater indicate a considerable organic and inorganic pollution burden. The relatively neutral condition observed at one sampling location, compared with the acidic condition at the other, suggests spatial differences in the composition of wastes entering the wastewater stream. Variations in the pH of abattoir wastewater may be associated with differences in the quantity and composition of animal tissues, blood, gastrointestinal contents, cleaning water, and other wastes discharged during slaughtering activities. Similar variability in the physicochemical quality of abattoir effluents has been reported by Atuanya et al. (2012), who observed considerable differences in effluent characteristics among government and private abattoirs in Benin City. Nasiru et al. (2016) also reported substantial physicochemical pollution in abattoir wastewater and attributed the observed characteristics to the release of animal wastes and wastes associated with slaughtering activities.

The elevated concentrations of total dissolved solids and electrical conductivity indicate that the wastewater contained substantial amounts of dissolved substances and ionic constituents. The measured values were several times higher than the recommended discharge limits, indicating considerable inputs of blood, animal tissues, manure, feed residues, salts, and other soluble materials from slaughtering activities. Such elevated dissolved-solid loads are environmentally important because they can alter the chemical characteristics of receiving waters, reduce water quality, and adversely affect aquatic organisms if discharged without adequate treatment. These findings agree with Nasiru et al. (2016), who associated elevated dissolved constituents with the substantial organic and inorganic wastes generated during slaughtering, and with Atuanya et al. (2012), who emphasized the environmental consequences of untreated abattoir effluents entering surface waters.

The exceptionally high $BOD_5$ values demonstrate that the wastewater contained a substantial biodegradable organic load. Abattoir wastewater commonly contains blood, proteins, fats, carbohydrates, faecal materials, and tissue residues, which provide substrates for microbial activity. Similar observations have been reported by Caixeta et al. (2002), who described slaughterhouse wastewater as highly biodegradable because of its elevated organic content, while Nafaranda et al. (2011) identified organic loading as an important consideration in slaughterhouse wastewater treatment. The persistence of high $BOD_5$ values therefore highlights the need for effective treatment before environmental discharge.

The nitrate concentrations indicate nutrient enrichment associated with the wastewater. Blood, animal tissues, urine, and faecal materials may contribute nitrogen-containing compounds to abattoir effluents. Although the nitrate concentrations exceeded recommended limits, their magnitude was lower than the pollution reflected by the $BOD_5$ values, suggesting that organic pollution was a major characteristic of the wastewater. Similar nutrient-related contamination has been reported by Atuanya et al. (2012), who emphasized that untreated abattoir effluents can contribute to nutrient loading in receiving water bodies.

The bacteriological findings demonstrate that the abattoir wastewater contained a high density and diverse population of microorganisms. The high heterotrophic bacterial population indicates that the wastewater provided favourable conditions for bacterial proliferation, probably because of the availability of organic materials such as blood, tissue residues, intestinal contents, animal faeces, and other slaughter wastes. These materials provide nutrients that can support substantial bacterial growth. Similar bacterial populations have been reported in abattoir wastewater and contaminated environments associated with slaughter facilities in Nigeria by Adesemoye et al. (2006).

The presence of total and faecal coliforms further indicates considerable sanitary and faecal contamination of the wastewater. The occurrence of faecal coliforms is consistent with abattoir operations, where intestinal contents, animal faeces, and other gastrointestinal materials may enter wastewater during slaughter and carcass processing. Such contamination may reflect inadequate containment and sanitary management of wastes generated within the slaughter environment. Komba et al. (2012) reported that poor sanitary practices during cattle slaughter can increase microbial contamination and potential zoonotic risks. Similarly, Ayoade and Olayioye (2016) associated microbiological contamination in Nigerian abattoirs with inadequate housekeeping and environmental sanitation.

The detection of *Pseudomonas*, Salmonella-Shigella groups, and staphylococci demonstrates the microbiological complexity of the wastewater and the occurrence of bacterial groups of environmental and public-health importance. *Pseudomonas* species are

widely distributed in aquatic and wastewater environments and can persist under diverse environmental conditions. The detection of Salmonella-Shigella groups is particularly important because members of these groups include enteric pathogens associated with gastrointestinal infections. Their occurrence in abattoir wastewater may therefore constitute an environmental and public-health concern, particularly where untreated effluent is discharged into surrounding water bodies, soil, or areas accessible to humans and livestock. The presence of staphylococci may reflect contamination associated with animal and human activities within the abattoir environment.

The variation in bacterial populations among the sampling locations suggests that microbial contamination differed spatially within the study area. Such variation may be associated with differences in slaughter activities, waste accumulation, wastewater flow, drainage conditions, and local sanitation practices. Locations receiving greater quantities of organic waste may provide more favourable conditions for bacterial proliferation and persistence. The coexistence of high heterotrophic bacterial populations, faecal indicator organisms, and potentially pathogenic bacterial groups indicates that untreated discharge could contribute to microbiological contamination of the surrounding environment. This reinforces the need for effective wastewater treatment and improved sanitary management of slaughterhouse wastes.

The bacterial diversity recovered from the wastewater reflects the mixed environmental and faecal-associated sources of microorganisms present in slaughterhouse environments. The identification of *Bacillus*, *Pseudomonas*, *Escherichia coli*, *Klebsiella*, *Salmonella*, *Shigella*, *Serratia*, *Chromobacterium*, *Micrococcus*, and *Staphylococcus* demonstrates that the wastewater supported diverse bacterial groups. Comparable bacterial diversity has been reported by Adesemoye et al. (2006) and Ogbomida et al. (2016), who similarly identified mixed bacterial communities in abattoir wastewater.

The frequent recovery of *Bacillus* species is noteworthy because members of this genus are commonly associated with soil, wastewater, and decomposing organic materials. Some *Bacillus* species have also been investigated for their ability to produce extracellular enzymes and utilize organic substrates. Sonune and Garode (2018) reported biodegradation potential among extracellular enzyme-producing *Bacillus* isolates recovered from wastewater environments. However, specific enzyme activities and degradation pathways were not determined in the present study. Therefore, the significance of the recovered *Bacillus* isolates should be interpreted in relation to their observed growth and treatment performance rather than through assumptions about particular biochemical mechanisms. The growth responses observed during screening demonstrated differences in the ability of the recovered isolates to grow under the test conditions. *Pseudomonas* exhibited the highest optical density, while *Bacillus* also demonstrated comparatively strong growth. In contrast, *Escherichia coli* showed the lowest growth response. The stronger growth of *Pseudomonas* and *Bacillus* provided a basis for selecting these isolates for the subsequent treatment experiment. However, optical density primarily reflects microbial growth under the conditions tested and does not, by itself, establish the extent or mechanism of pollutant degradation. The results therefore provide evidence of differential growth potential rather than definitive evidence of specific biodegradation pathways.

The bioremediation experiment demonstrated measurable changes in wastewater quality during the 21-day treatment period. Temperature remained relatively stable throughout the experiment, indicating that substantial temperature fluctuations did not occur. The progressive increase in pH observed in the bacterial treatments indicates a change in the chemical condition of the wastewater during treatment. However, because specific metabolic products were not measured, the precise processes responsible for the observed pH changes cannot be established from the present data.

The treatment responses differed among the bacterial treatments and the wastewater parameters examined. *Pseudomonas* sp. produced the greatest reduction in TDS, achieving approximately one-quarter removal of the initial dissolved-solid concentration. In contrast, the consortium produced a more modest reduction in TDS, while *Bacillus* sp. showed a net increase. The increase in TDS observed with *Bacillus* sp. indicates that dissolved-solid concentrations did not decrease uniformly during treatment. Since individual dissolved substances were not quantified, the specific reason for this increase cannot be established.

Electrical conductivity declined only modestly during treatment, with the consortium producing the greatest reduction among the bacterial treatments. The observed decrease represents a change in the overall ionic conductivity of the wastewater, although the specific ions responsible were not determined. Thus, the result demonstrates a reduction in measured conductivity rather than providing evidence of a particular mechanism of ionic removal.

$BOD_5$ decreased in all bacterial treatments, with the consortium producing the greatest reduction. This indicates an improvement in the measured biodegradable organic load during the treatment period. Nevertheless, the reduction remained modest relative to the extremely high initial $BOD_5$ concentration, demonstrating that the 21-day treatment period was insufficient to reduce the organic pollution to acceptable discharge levels. Similar observations have been reported by Caixeta et al. (2002) and Cao and Mehrvar (2011), who indicated that slaughterhouse wastewater may require sustained or integrated treatment approaches to achieve substantial reductions in organic pollution.

The bacterial treatments also produced different changes in nitrate concentration. The consortium produced the greatest reduction, followed by *Bacillus* sp. and *Pseudomonas* sp. These results demonstrate that nitrate concentrations decreased under the tested treatment conditions. However, ammonium, nitrite, total nitrogen, and dissolved oxygen were not measured; therefore, the specific processes responsible for the nitrate reduction cannot be determined. In particular, the observed nitrate reduction should not be interpreted as direct evidence of nitrification or denitrification. The persistence of nitrate above recommended discharge limits also indicates that the treatment was insufficient for complete nitrate removal.

Phosphate showed the greatest improvement among the measured nutrient parameters, with the consortium producing the largest reduction. Despite this improvement, phosphate remained above recommended limits after treatment. The result demonstrates a reduction in measured phosphate concentration but does not establish the specific mechanism responsible, because phosphorus fractions and processes such as biological uptake or precipitation were not directly investigated.

The comparative treatment results show that *Pseudomonas* sp. performed best for TDS reduction, whereas the consortium produced the greatest reductions in EC, $BOD_5$, nitrate, and phosphate. Thus, no single treatment produced the greatest reduction across all measured parameters. The comparatively broader improvement observed with the consortium may reflect differences in the performance of the inoculum under the experimental conditions. However, this interpretation should remain descriptive because the study did not investigate interactions among consortium members or specific metabolic pathways.

Importantly, the consortium contained probable *Escherichia coli*, *Klebsiella* spp., and *Salmonella* spp., which include organisms of public-health importance. Consequently, its superior physicochemical performance should not be interpreted as evidence of environmental suitability. The consortium was useful for demonstrating comparative treatment responses under controlled experimental conditions, but its composition limits its suitability as a practical bioremediation inoculum or for direct environmental application.

The results therefore provide preliminary evidence that indigenous *Pseudomonas* sp. and *Bacillus* sp. warrant further investigation as candidate organisms for abattoir wastewater treatment, while highlighting the need for safer and well-characterized microbial cultures in future bioremediation studies.

## CONCLUSION

This study demonstrated that the abattoir wastewater contained substantial physicochemical and bacteriological pollution, as indicated by elevated levels of TDS, EC, $BOD_5$, and nitrate, high bacterial counts, and the occurrence of faecal and potentially pathogenic bacterial groups, together with low DO concentrations. Fifteen bacterial isolates representing ten probable bacterial taxa were recovered, with *Pseudomonas* sp. and some *Bacillus* sp. isolates showing the strongest growth responses in mineral salt medium.

During the 21-day laboratory treatment, *Pseudomonas* sp. produced the greatest reduction in TDS, whereas the separately formulated bacterial consortium produced the greatest reductions in EC, $BOD_5$, nitrate, and phosphate. However, the observed reductions were incomplete, and several parameters remained elevated after treatment. Furthermore, the consortium comprised probable *Escherichia coli*, *Klebsiella* spp., and *Salmonella* spp.; consequently, it is not recommended for environmental bioremediation or direct application to wastewater.

The consortium results should therefore be regarded as comparative laboratory observations rather than evidence of environmental suitability. Future treatment development should focus on appropriately screened, well-characterized, and safer bacterial isolates, particularly *Pseudomonas* sp. and *Bacillus* sp., evaluated under suitable containment and biosafety conditions. Further studies should also assess treatment performance over longer periods and investigate the specific mechanisms underlying pollutant removal before practical environmental application is considered.

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