Journal of Water Resource and Protection, 2026, 18(11), 769-792
https://www.scirp.org/journal/jwarp
ISSN Online: 1945-3108
ISSN Print: 1945-3094

# Microbial, Heavy-Metal and Physico-Chemical Water Quality of the Udu River in the Vicinity of an Abattoir, Delta State, Nigeria

**Gbuvboro Anthonia Ejiroghene[1*], Ajimmy Ruth Angobrakumor[1], Monday Joshua[1], Onuabuchi Sherack Chisom[1], Oyamakin Oluwafemi Samuel[2]**

[1]Department of Environmental Management and Pollution, Faculty of Environmental Management, Nigeria Maritime University, Okerenkoko, Nigeria
[2]Biostatistics Unit, Department of Statistics, University of Ibadan, Ibadan, Nigeria
Email: *ganthonia3@gmail.com, ajimmyruth2015@gmail.com, mondayjoshua401@gmail.com, onuabuchichisom42@gmail.com, fm_oyamakin@yahoo.com

**How to cite this paper:** Ejiroghene, G.A., Angobrakumor, A.R., Joshua, M., Chisom, O.S. and Samuel, O.O. (2026) Microbial, Heavy-Metal and Physico-Chemical Water Quality of the Udu River in the Vicinity of an Abattoir, Delta State, Nigeria. *Journal of Water Resource and Protection*, **18**, 769-792.
https://doi.org/10.4236/jwarp.2026.1811038

**Received:** September 23, 2026
**Accepted:** November 16, 2026
**Published:** November 19, 2026

Copyright © 2026 by author(s) and Scientific Research Publishing Inc.
This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).
http://creativecommons.org/licenses/by/4.0/
Open Access

## Abstract

Wastewater from slaughterhouses can contaminate receiving waters and endanger aquatic and human health. This study assessed microbial, heavy-metal and physico-chemical water quality of the Udu River at six stations located upstream (A, B), within the discharge zone (C, D) and downstream (E, F) of an abattoir. Single grab samples were collected between 08:00 and 12:00 h on 28 March 2025 (dry season) for lead, nickel, cadmium and chromium by Flame Atomic Absorption Spectroscopy (FAAS), Model-Agilent 240FS AA, total coliforms (three-tube most-probable-number technique) and presumptive Salmonella (selective plating). Temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), BOD5 and COD were measured at five stations on 28 March and 22 May 2025 (rainy season). Data were screened for physical plausibility; spatial differences were tested with exact permutation tests, seasonal differences with paired tests, and water quality was classified with the CCME Water Quality Index and a one-out-all-out compliance rule. Total coliforms were detected at all stations (15 - 23 MPN/100 mL) and presumptive Salmonella at four stations (100 - 105 CFU/mL), including both upstream stations; MPN confidence limits overlapped at every station and no difference between river sections was detected (exact $p = 0.40$). Lead and cadmium were not detected (<0.001 mg/L), and nickel (0.001 - 0.004 mg/L, maximum at midstream station D) and chromium (≤0.004 mg/L, maximum at downstream station E) were far below WHO guideline values. All dry-season pH readings (11.53 - 14.8) were inconsistent with the measured conductivity and were excluded as instrument error; rainy-

season pH was 6.98 - 7.32. Temperature did not differ between the two visits (paired p = 0.74). DO was below 5 mg/L at all stations in May and BOD5 exceeded 5 mg/L at all stations on both dates. No correlation between physical parameters and contaminants remained significant after correction for multiple testing. Every station-visit was non-compliant with at least one criterion (CCME WQI 39 - 76; Poor at stations A, B, E and F in March), driven mainly by microbial contamination and oxygen demand. Because contamination was already present upstream, the data cannot quantify the contribution of the abattoir. Treatment of abattoir effluent, routine replicated monitoring and microbial source-tracking studies are recommended.

## Keywords

Tropical-System, Abattoir, Pollution, Monitoring, Management Practices

## 1. Introduction

Water resources are essential for maintaining life and promoting worldwide economic growth. Nevertheless, human-caused pollution including industrial release, agricultural runoff, and untreated effluent from numerous sources constantly jeopardizes the quality of water resources. Over two billion people rely on drinking water supplies that are tainted with feces, which can result in diseases caused by water such as, cholera and dysentery, making water contamination a major issue worldwide [1]. Both sustaining life and fostering global economic expansion depend on water resources. Nonetheless, the quality of water resources is continuously threatened by environmental contaminants, such as industrial discharges, agricultural runoff, and untreated wastewater from various sources. Water pollution is a huge global problem since people depend on drinking water that is contaminated with excrement, which can lead to water-borne illnesses [1].

Water pollution is a particularly serious problem in Africa, where it is made worse by poor infrastructure, governance, and policy frameworks, as well as restricted access to clean water. Agricultural runoff, industrial waste, and raw wastewater have severely contaminated many rivers and lakes throughout the continent, posing serious dangers to individuals as well as the state of the environment [2]. The biological waste, blood, lipids, pathogens, and other toxins found in slaughterhouse discharges, often pose a concern to public health and water quality when released improperly into bodies of water [3]. The African Development Bank [4] has emphasized the need for better wastewater treatment facilities. and greater governance to control water quality, pointing out that water contamination is a major barrier to attaining sustainability and the SDG goals, in Africa and meeting up with the world's blue future. These contaminants are putting more strain on rivers like the Nile, Congo, and Niger, demonstrating how pervasive the problem is throughout the continent. In order to confront the escalating ecological catastrophe, the African Development Bank [4] has acknowledged that water pollution is a significant barrier to

sustainable development in Africa and has called for investments in treatment plants for wastewater and capacity-building efforts.

The ubiquitous prevalence of water contamination on the continent is demonstrated by the increasing pressures these contaminants place on major waterbodies. Rapid urbanization, industrial growth, and subpar waste management techniques exacerbate Nigeria's water quality problems [5]. Nigeria, a nation of more than 200 million people, has serious problems with water pollution. Untreated wastewater from both household and industrial sources has significantly deteriorated many of the country's rivers, including the Benue, Ogun, and Kaduna [6]. In Nigeria, slaughter facilities are the primary cause of pollution, caused by wastewater since they discharge vast amounts of unprocessed waste that are essentially directed into neighbouring water bodies and frequently contain pathogenic germs. These waste products seriously endanger aquatic communities and public health if improperly managed [3]. Due to its distinct natural and socio-economic features, Delta State, which is part of Nigeria's Niger Delta area, is especially susceptible to water contamination. Many rivers, creeks, and estuaries in the area sustain residential water consumption, agriculture, and fishing. Furthermore, industrial releases, oil exploration activities, and raw wastewater, especially abattoir effluents, are posing a rising threat to these aquatic bodies [2]. According to [7], abattoir discharges exacerbate environmental and public health issues by contributing to the area's declining water quality. A vital water source in Delta State's Udu Local Government Area, the Udu River is becoming more and more contaminated by untreated abattoir effluents, which lowers the water's quality. The impact of this pollution on local ecosystems is highlighted by the problems that communities near the river experience, including disagreeable odour, discolouration, and loss of biodiversity [7].

The threats that wastewater poses to the environment and human health are made worse in many parts of Nigeria by the lack of contemporary waste management infrastructure, waste treatment facilities, and practices [3]. The threats the effluent poses to the ecosystem and human health are made worse by the lack of contemporary waste management infrastructure, waste treatment facilities, and practices in numerous areas of Nigeria [3]. According to [6] [8], polluted waters can disrupt fisheries, lower agricultural output, and raise the cost of water purification for metropolitan areas, all of which have a substantial socio-economic impact. The high biological load in slaughterhouse wastewater frequently causes heightened levels of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), as reported [9] [10]. Furthermore, pathogenic microorganisms like *Escherichia coli, Salmonella species*, *Listeria monocytogenes*, and *Clostridium,* which endanger aquatic ecosystems and human health, are frequently found in effluents along with nitrogen (from blood and protein breakdown) and phosphorus (from detergents and animal waste) [11].

Discharge from animal slaughter operations, carcass washing, and facility cleaning is an extremely complex mixture of organic and inorganic materials. Based on the size of activities and the hygienic measures used, its composition changes [12].

Abattoir discharge is a major source of contamination since it contributes to high levels of both chemical and biochemical oxygen demands (BOD and COD). The possibility of oxygen deficiency in adjacent receiving water bodies is highlighted by BOD values ranging from 800 to 8000 mg/L and COD values from 1200 to 12,000 mg/L in untreated effluents [9] [10]. Significant amounts of inappropriate nutrient flow from abattoir discharges cause eutrophication, which is typified by an algal bloom in aquatic environments [13] [14]. Abattoir effluent frequently contains trace amounts of heavy metals like copper, lead, zinc, and chromium. These metals can come from cleaning supplies, corroded equipment, or animal feed additives. Heavy metals can vary in levels, but their bio-accumulative nature poses a threat to aquatic creatures and food safety [15]. It is usual to see substantial amounts of suspended solids, such as undigested feed, hair, skin fragments, and bone fragments.

Aquatic environments may be impacted by substantial amounts of suspended solids, such as undigested feed, hair, skin fragments, and bone fragments. These products contribute to sedimentation and turbidity in water bodies [12]. This significantly hinders the microbial breakdown of contaminants and the oxygen transport required for aquatic life [16]. Because blood and other organic wastes are present, the effluent is frequently dark red or brown. Additionally, when organic matter breaks down, especially under anaerobic conditions, it may release a pungent smell [17]. Discharge from abattoirs typically has a higher temperature since hot water is used for disinfecting and preparation. Cleaning products and the makeup of organic waste can affect the pH, which can vary from slightly acidic to alkaline [18]. In order to ensure responsible utilization of water resources and improve the health and quality of living of the local population, it is imperative that the Udu River's abattoir-related water contamination be addressed. In order to provide empirical support for well-informed policy interventions and effective water management techniques, this study intends to examine the effects of abattoir discharges on the Udu River. By concentrating on this particular body of water, the project aims to advance knowledge of water contamination in the Niger Delta and provide suggestions for reducing the detrimental impacts of slaughterhouse effluent on water quality. In order to ascertain the interaction between microbial load and heavy metals on the water quality of the Udu River system, this research evaluates the impact of abattoir wastewater on the physio-chemical parameters of the river.

## 2. Methodology

### 2.1. Study Area

Delta State is situated in Nigeria's South-South geopolitical zone, with latitudes of 5.45˚N to 6.45˚N and longitudes of 5.30˚E to 6.90˚E. It shares borders with the Atlantic Ocean to the west, Bayelsa State to the south, Anambra and Rivers States to the east, and Edo State to the north. The state's population is approximately 5.6 million. Delta State is a major participant in Nigeria's oil and gas industry due to its abundant natural resources, which include natural gas and crude oil. Large tracts of agricultural terrain, bodies of water, and industrial zones are also present

in the state. However, the Niger Delta ecosystem, which encompasses a large portion of the state, is marked by mangrove swamps, freshwater forests, and a network of rivers and creeks. These features are becoming more and more threatened by environmental degradation brought on by deforestation, industrial discharge, and oil exploration [19]. One important tributary of the Warri River, which empties into the Atlantic Ocean, is the Udu River. The river provides a variety of functions such as, domestic use, irrigation, and industrial operations, and flows through the Udu Local Government Area (LGA). Recent research indicates that the water quality has declined due to uncontrolled waste disposal from surrounding companies, wood industries and slaughterhouses, with elevated levels of microbiological pollutants, organic matter, and heavy metals. One prominent site close to the river is the Udu Bridge, which links Warri with Udu. Fishing and agriculture are two of the river's main sources of income for communities around that area, including, Ovwian, Aladja, and Ekete. Nevertheless, the river is now hazardous for residential and recreational usage due to rising pollution levels, which pose major dangers to human health and the ecosystem.

### 2.2. In-Situ Water Parameters Measurements

Temperature (˚C), pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured in situ with an IPC-Pen multifunction water-quality tester (Temp-pH-EC-TDS probe, Model P-3) at stations A-E on 28 March 2025 and 22 May 2025. The instrument was calibrated in the laboratory before field use, multipoint calibration method was used on the 25 march, 2025 at 800h, and EC (S/m). Salinity was below the display range of the instrument and is recorded as 'Nil'. Dissolved oxygen (DO) was measured calorimetrically following [20]. For biochemical oxygen demand (BOD5), samples were collected in 250 mL amber bottles and incubated in darkness at 20˚C for five days; chemical oxygen demand (COD) was determined via titration method in the laboratory [20].

### 2.3. Sample Collection

Sediment samples were collected with van veen grab into a Ziplock bag and Surface-water samples were collected in labelled, sterile 1-L plastic bottles at six stations along the Udu River (**Table 1**): two upstream of the abattoir discharge point (A, B), two in the discharge (midstream) zone (C, D) and two downstream (E, F) at 5.516 latitude and 5.784 longitude, with a direct inflow from source discharge point, of 50 meters apart from each sample stations respectively. Sampling was carried out between 08:00 and 12:00 h on 28 March 2025 (dry season) and 22 May 2025 (rainy season). Each station was sampled once per visit; no field or laboratory replicates were taken. Heavy-metals, total coliforms and *Salmonella* were analysed for in the March samples only (stations A - F); in-situ parameters were measured at stations A - E on both dates; DO, BOD5 and COD were determined for five sites on each date. The laboratory labelled the dry-season oxygen-demand sites 1 - 5; these are assumed to correspond to stations A - E. **Table 1** summarises the

data available for each station. Samples were transported to the laboratory immediately after collection.

**Table 1.** Sampling stations and data available (one grab sample per station per visit).

| Station | Section | Coordinates (field sheet) | Metals, coliform, Salmonella (28/03/2025) | In-situ parameters (28/03/2025) | In-situ parameters (22/05/2025) | DO, BOD5, COD site (dry/rainy) |
|---|---|---|---|---|---|---|
| A | Upstream | 5˚31'03"N, 5˚46'43"E | Yes | Yes | Yes | 1*/A |
| B | Upstream | 5˚31'04"N, 5˚47'19"E | Yes | Yes | Yes | 2*/B |
| C | Midstream | 5˚30'56"N, 5˚47'01"E† | Yes | Yes | Yes | 3*/C |
| D | Midstream | 5˚31'02"N, 5˚46'51"E | Yes | Yes | Yes | 4*/D |
| E | Downstream | 5˚30'56"N, 5˚47'01"E† | Yes | Yes | Yes | 5*/E |
| F | Downstream | Not recorded | Yes | No | No | - |

*Dry-season laboratory site numbers; correspondence with stations A - E assumed. †Identical coordinates were recorded for stations C and E 5.516 Latitude, 5.784 Longitude and 5.516 Latitude, 5.791 Longitude**.** No coordinates were recorded for station A in May.

### 2.4. Determination of Microbial Load and Heavy Metals in Abattoir Wastewater

Samples for heavy- metal analysis were collected in acid-washed, pre-labelled 1-L plastic containers, filtered through a 0.45 μm membrane to remove particulate matter and acidified with a few drops of concentrated nitric acid before transport to the laboratory (Thermosteel Nigeria Ltd, Warri; Lab Ref. TNL/2763-2768). The laboratory records the preservation method as ± 'Ambient' at 15˚C and 30˚C approximately [59˚F and 86˚F] respectively.

### 2.5. Laboratory Analysis

Lead, nickel, cadmium and chromium were determined by Flame Atomic Absorption Spectroscopy (FAAS), Model-Agilent 240FS AA following ASTM methods. Results below show the laboratory reporting limit (0.001 mg/L for Pb, Ni and Cd; 0.001 - 0.002 mg/L for Cr) are reported as '<' the limit and were not replaced by substituted values. Quality control comprised a method blank, duplicate and spike-recovery, batch TNL/2763-2768. Total coliforms were enumerated by the three-tube most-probable-number (MPN) technique with inocula of 10, 1 and 0.1 mL, in the medium; of Lauryl Tryptose Broth (LTB) at 35˚C - 37˚C which follows the isolate step. The results are expressed as MPN/100 mL with 95% confidence limits calculated by the likelihood-ratio method. Presumptive *Salmonella* was enumerated on Xylose Lysine Deoxycholate (XLD) agar, the dilution process is between 53.0 and 57.0 grams of dehydrated powder per 1 litre (1000mL) of distilled water with a plated volume of 15mL-20mL of molten agar per standard 90mm Petri ditch, in a time of 24 ± 3 hours and incubated at temperature as above, the laboratory reported counts as CFU/mL × $10^2$, which were multiplied by 100,

and plates without growth are reported as not detected (ND). In 800hr-1200hrs and at 35˚C - 37˚C for the microbiological analysis.

### 2.6. Quality Control

Flame Atomic Absorption Spectroscopy (FAAS) using the Agilent 240FS AA is a solution that contains all the reagents, solvents, and acids used in sample preparation, except the actual sample itself a method blank, duplicate and spike-recovery, a standard operational protocol.

### 2.7. Data Quality Screening

Before analysis, each in-situ value was screened for physical plausibility. A pH reading was rejected when it exceeded 14 or when the hydroxide concentration it implies, [$OH^-$] = 10^(pH − 14) mol/L, would require a conductivity more than ten times the measured EC. The minimum conductivity was calculated from the limiting molar conductivities of $OH^-$ (198.6 S $cm^2$ $mol^{-1}$) and $Na^+$ (50.1 S $cm^2$ $mol^{-1}$), which gives a conservative lower bound. The TDS/EC ratio was compared with the range expected for natural waters (0.55 - 0.75), and DO, BOD5 and COD were checked for internal consistency.

### 2.8. Statistical Analysis

Because there was one sample per station and two stations per river section, spatial differences were tested with an exact permutation test of the one-way F statistic over all 90 distinct allocations of the six stations to three sections, with the Kruskal-Wallis test as a check; the smallest p-value attainable in this design is 0.067. Seasonal differences were tested on the five stations measured on both dates as matched pairs, using the paired t-test (with the 95% confidence interval of the mean difference) and the exact Wilcoxon signed-rank test (minimum attainable p = 0.0625). Associations were assessed with Pearson's r, its 95% confidence interval and Holm-adjusted p-values within each season [21], with Spearman's $\rho$ as a check; with n = 5, |r| must exceed 0.878 for $p < 0.05$ before adjustment. Censored metal values were excluded from correlations, lead and cadmium (never detected) were not analysed statistically, and dry-season pH was excluded throughout. Analyses were carried out in R version 4.3.3 at $\alpha = 0.05$.

### 2.9. Water Quality Classification

Water quality was classified in two complementary ways against the criteria in **Table 2**. (a) The CCME Water Quality Index [22]: WQI = 100 − √($F1^2$ + $F2^2$ + $F3^2$)/1.732, where F1 (scope) is the percentage of variables failing their criterion, F2 (frequency) is the percentage of individual tests failing, and F3 (amplitude) = nse/(0.01·nse + 0.01), with nse the sum of excursions divided by the number of tests; excursion = (value/criterion) − 1 for maximum criteria and (criterion/value) − 1 for minimum criteria. Categories are Excellent (95 - 100), Good (80 - 94), Fair (65 - 79), Marginal (45 - 64) and Poor (0 - 44). (b) A one-out-all-out rule, under

which a station-visit is non-compliant if any assessed parameter fails its criterion. No weights were used. A variable not measured at a station-visit was omitted, not imputed, and the number of variables assessed is reported; an index was not computed with fewer than four variables. A result below the reporting limit was counted as compliant when the limit was below the criterion. Microbial criteria were set at the detection limit of the method (3 MPN/100 mL for the three-tube series; 1 CFU/mL for *Salmonella*), so any detection fails. Temperature and EC have no applicable criterion for ambient river water and were not scored. Because metals and microbes were not measured in May, dry- and rainy-season indices are based on different variables and are not compared with each other.

**Table 2.** Criteria used for water quality classification.

| Variable | Criterion | Unit | Basis |
|---|---|---|---|
| pH | 6.5 - 8.5 | - | WHO/NESREA range |
| DO | ≥5 | mg/L | Manuscript **Table 11** |
| BOD | ≤5 | mg/L | Manuscript **Table 11** |
| COD | ≤20 | mg/L | Manuscript **Table 11** |
| TDS | ≤500 | mg/L | US EPA secondary (**Table 11**) |
| Lead | ≤0.01 | mg/L | WHO GDWQ |
| Nickel | ≤0.07 | mg/L | WHO GDWQ |
| Cadmium | ≤0.003 | mg/L | WHO GDWQ |
| Chromium | ≤0.05 | mg/L | WHO GDWQ |
| Coliform | ≤3 | MPN/100 mL | Absence; 3 = 3-tube MPN detection limit |
| Salmonella | ≤1 | CFU/mL | Absence; 1 CFU/mL operational limit |

The WHO Guidelines for Drinking-water Quality set no values for DO, BOD5 or COD; the values shown are those adopted in the original manuscript [National Environmental (Surface and Groundwater Quality Control) Regulation, 2011(S.I No 22 of 2011), established under the National Environmental Standards and Regulations Enforced Agency (NESREA) Act of 2007].

## 3. Results

### 3.1. The Abattoir Site

**Figure 1** shows the sampling stations across the Udu River gradient ecosystem in Delta State; which reveals the interplay between microbial loads and heavy-metal contamination in freshwater surrounding, creating a complex, compounding ecological stress. The Abattoir is an open-sided concrete and timber structure built at the water's edge with its slaughter slab extending to the riverbank as shown in (**Figure 2**). No true effluent collection sport, screening or treatment facilities were observed. Carcases are dressed on the slab and offal is washed

directly in the river as shown in (Figure 3), so blood, gut contents, wash-water and solid residues enter the river system untreated [17]. Floating aquatic vegetation and timber rafts around station C and D; as shown in (Figure 2), located in this discharge zone, with A and B upstream and E and F downstream, suggest sluggish flow at this point, which may favour local accumulation of organic material, In addition, when organic matter According to [11]. Indigenous and

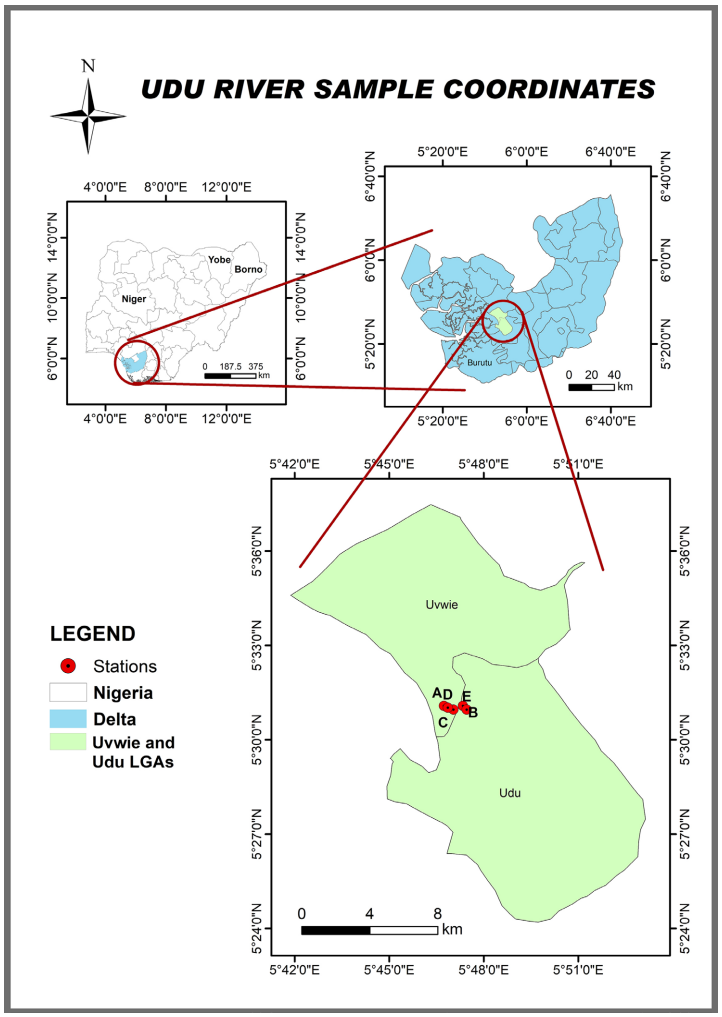



Figure 1. Map showing the sampling stations in Udu River, Delta State.



Figure 2. The typical view of the Udu River abattoir.



Figure 3. Butchered carcasses being washed into the Udu River system.

introduced aerobic microbes reproduce exponentially to decompose organic matter break down, especially under anaerobic conditions, it may release pungent smell [17]. Conversely, heavy metal pollution restructures microbial communities, impairing key biogeochemical processes. Most abattoir's wastewater is extraordinarily rich in microbial biomass and organic substrate. When discharged into receiving waters like (rivers, streams, estuaries, or lagoon systems), the introduced microorganisms alongside the rapid bloom of indigenous aquatic microbes feeding on the nutrients surge instigate severe biological, chemical and structural disruptions in aquatic ecosystem. Microorganisms act both as mediators of heavy-metal toxicity and as direct drivers of water quality degradation; causing localized biodiversity loss. Representative culture plates from the river samples are shown in **Figure 4**. Colonies presumptively identified as *Escherichia coli* (**Figure 4(a)**) and colonies on *Salmonella-Shigella* agar presumptively identified as *Salmonella* (**Figure 4(b)**) were isolated. These identifications were not confirmed biochemically or serologically.



(a) *Escherichia coli* (b) *Salmonella shigella*

Figure 4. Representative culture plates from Udu River water samples. (a) Colonies presumptive for *Escherichia coli*; (b) Colonies on *Salmonella-Shigella* agar presumptive for Salmonella.

## 3.2. Data Quality

All five dry-season pH readings failed the plausibility screen (**Table 3**, **Figure 5**).

Readings of 14.6 and 14.8 lie outside the 0 - 14 range of the meter, and the hydroxide concentrations implied by the five readings would require conductivities of 843 to 1.57 million µS/cm, 23 to 35,000 times the measured EC (36 - 47). These values were therefore excluded from all analyses. All rainy-season readings (6.98 - 7.32) passed. The TDS/EC ratio was 1.56 - 2.23 at nine of the ten station-visits, against 0.55 - 0.75 expected for natural waters, and 0.45 - 0.64 if the two columns are interchanged (Table 4), suggesting that the TDS and EC readings were transposed during transcription. In May, DO + BOD5 was 10.5 ± 0.05 mg/L at every station, and BOD5/COD ratios (0.67 - 0.93) were unusually high for river water (Table 5).

Table 3. Plausibility of the reported pH values.

| Station | Season | Reported pH | Measured EC | Implied [$OH^-$] (mol/L) | Minimum EC implied (µS/cm) | Implied ÷ measured | Decision |
|---|---|---|---|---|---|---|---|
| A | Dry | 14.8 | 45 | 6.3e+00 | 1,569,191 | 34,871× | Excluded |
| B | Dry | 14.6 | 43 | 4.0e+00 | 990,093 | 23,025× | Excluded |
| C | Dry | 11.53 | 36 | 3.4e−03 | 843 | 23× | Excluded |
| D | Dry | 14 | 47 | 1.0e+00 | 248,700 | 5291× | Excluded |
| E | Dry | 13.33 | 44 | 2.1e−01 | 53,171 | 1208× | Excluded |
| A | Rainy | 6.98 | 55 | 9.5e−08 | 0.02 | <0.01 | Retained |
| B | Rainy | 7.16 | 34 | 1.4e−07 | 0.04 | <0.01 | Retained |
| C | Rainy | 7.32 | 33 | 2.1e−07 | 0.05 | <0.01 | Retained |
| D | Rainy | 7.12 | 44 | 1.3e−07 | 0.03 | <0.01 | Retained |
| E | Rainy | 7.32 | 34 | 2.1e−07 | 0.05 | <0.01 | Retained |

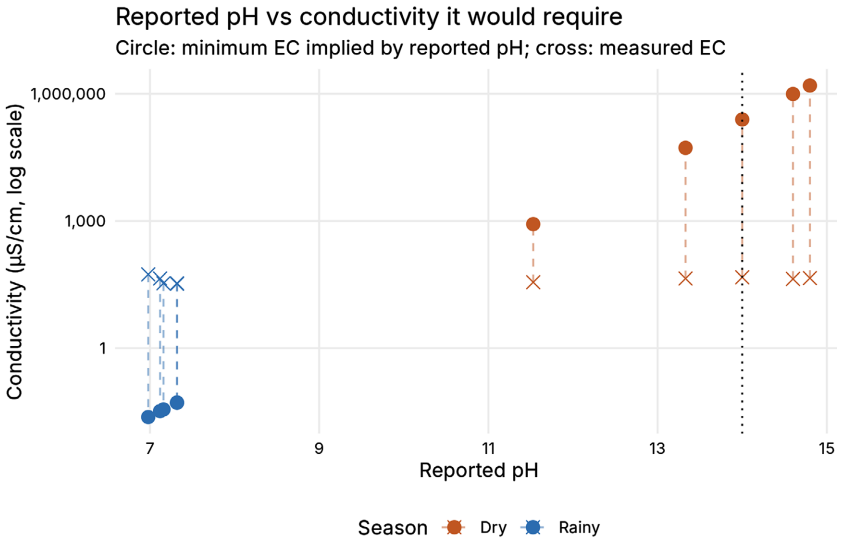



Figure 5. The Reported pH against the minimum conductivity it would require (circles) and the measured conductivity (crosses). Every dry-season reading would require a conductivity 23 to 35,000 times greater than was measured.

**Table 4.** Ratio of TDS to EC.

| Station | Season | TDS (mg/L) | EC | TDS/EC | EC/TDS (columns interchanged) |
|---|---|---|---|---|---|
| A | Dry | 84 | 45 | 1.87 | 0.54 |
| B | Dry | 86 | 43 | 2.00 | 0.50 |
| C | Dry | 70 | 36 | 1.94 | 0.51 |
| D | Dry | 105 | 47 | 2.23 | 0.45 |
| E | Dry | 34 | 44 | 0.77 | 1.29 |
| A | Rainy | 86 | 55 | 1.56 | 0.64 |
| B | Rainy | 70 | 34 | 2.06 | 0.49 |
| C | Rainy | 67 | 33 | 2.03 | 0.49 |
| D | Rainy | 93 | 44 | 2.11 | 0.47 |
| E | Rainy | 66 | 34 | 1.94 | 0.52 |

**Table 5.** Dissolved oxygen, BOD5 and COD (mg/L) with consistency checks.

| Site | Station* | Season | Date | Lab code | DO | BOD5 | COD | DO + BOD5 | BOD5/COD |
|---|---|---|---|---|---|---|---|---|---|
| 1 | A | Dry | 28/03/2025 | TNL/2785 | 5.41 | 6.1 | 7.30 | 11.51 | 0.84 |
| 2 | B | Dry | 28/03/2025 | TNL/2786 | 5.3 | 5.5 | 8.14 | 10.80 | 0.68 |
| 3 | C | Dry | 28/03/2025 | TNL/2787 | 5.35 | 5.3 | 7.91 | 10.65 | 0.67 |
| 4 | D | Dry | 28/03/2025 | TNL/2788 | 5.98 | 6.4 | 7.68 | 12.38 | 0.83 |
| 5 | E | Dry | 28/03/2025 | TNL/2789 | 5.78 | 6.1 | 7.68 | 11.88 | 0.79 |
| A | A | Rainy | 22/05/2025 | TNL/3970 | 4.13 | 6.4 | 7.68 | 10.53 | 0.83 |
| B | B | Rainy | 22/05/2025 | TNL/3971 | 3.72 | 6.8 | 7.30 | 10.52 | 0.93 |
| C | C | Rainy | 22/05/2025 | TNL/3972 | 4.27 | 6.3 | 7.30 | 10.57 | 0.86 |
| D | D | Rainy | 22/05/2025 | TNL/3973 | 3.38 | 7.1 | 8.45 | 10.48 | 0.84 |
| E | E | Rainy | 22/05/2025 | TNL/3974 | 3.48 | 7 | 8.06 | 10.48 | 0.87 |

*Dry-season sites 1 - 5 assumed to correspond to stations A - E.

### 3.3. Microbial Contamination

Total coliforms were detected at all six stations at 15 - 23 MPN/100 mL (Table 6). The 95% confidence limits of the MPN estimates were wide (4.9 - 90.8 MPN/100 mL for a value of 23) and overlapped at every station (Figure 6). Presumptive *Salmonella* was detected at upstream stations A and B (105 and 100 CFU/mL) and downstream stations E and F (100 and 102 CFU/mL) but not at midstream stations C and D. Any detection exceeds the WHO criterion for drinking water (none

detectable in 100 mL), so water at every station is unfit for drinking without treatment.

Table 6. Microbial results by station, 28 March 2025.

| Station | Section | Total coliform (MPN/100 mL) | MPN tube code (10/1/0.1 mL) | 95% confidence limits | Presumptive Salmonella (CFU/mL) |
|---|---|---|---|---|---|
| A | Upstream | 23 | 3-0-0 | 4.9 - 90.8 | 105 |
| B | Upstream | 23 | 3-0-0 | 4.9 - 90.8 | 100 |
| C | Midstream | 20 | 2-1-1 | 6 - 52.5 | ND |
| D | Midstream | 15 | 2-1-0 | 3.5 - 41.7 | ND |
| E | Downstream | 23 | 3-0-0 | 4.9 - 90.8 | 100 |
| F | Downstream | 20 | 2-1-1 | 6 - 52.5 | 102 |

ND = not detected. Salmonella counts were reported by the laboratory as CFU/mL × $10^2$ and are shown here in CFU/mL.

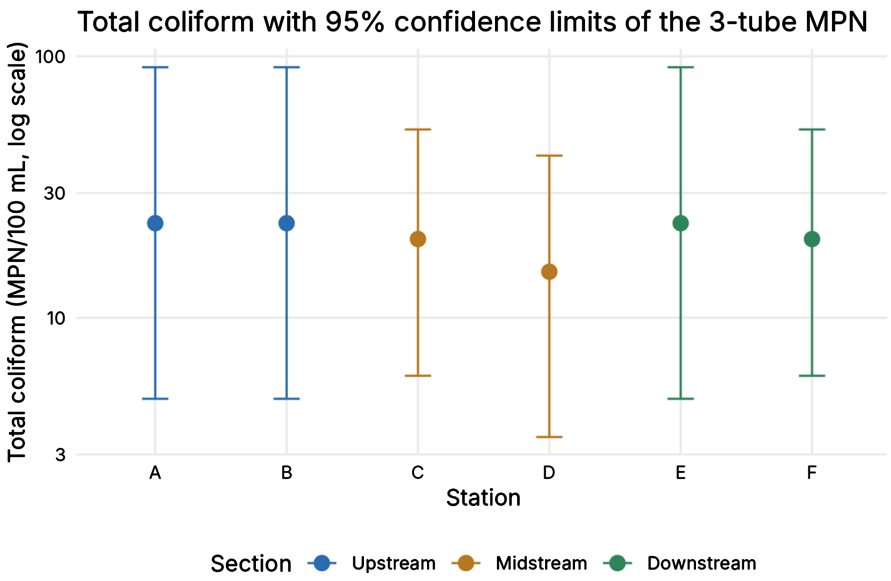



Figure 6. The total coliform at each station with the 95% confidence limits of the MPN estimate.

### 3.4. Heavy Metals

Lead and cadmium were not detected at any station (<0.001 mg/L; Table 7). Nickel was detected at all stations (0.001 - 0.004 mg/L), with its maximum at midstream station D. Chromium was detected at five stations (0.001 - 0.004 mg/L), with its maximum at downstream station E and its lowest detected value at midstream station D (Figure 7). Every result, including the reporting limits, was below the WHO guideline values: the highest possible ratio to the guideline was ≤0.33 for cadmium and the highest detected ratio 0.08 for chromium. Metal contamination was therefore not a concern on the sampling date.

Table 7. Heavy-metal concentrations (mg/L), 28 March 2025.

| Station | Section | Lead | Nickel | Cadmium | Chromium |
|---|---|---|---|---|---|
| A | Upstream | <0.001 | 0.001 | <0.001 | 0.002 |
| B | Upstream | <0.001 | 0.001 | <0.001 | 0.002 |
| C | Midstream | <0.001 | 0.003 | <0.001 | 0.002 |
| D | Midstream | <0.001 | 0.004 | <0.001 | 0.001 |
| E | Downstream | <0.001 | 0.002 | <0.001 | 0.004 |
| F | Downstream | <0.001 | 0.003 | <0.001 | <0.002 |
| WHO guideline | | 0.01 | 0.07 | 0.003 | 0.05 |

'<' = below the laboratory reporting limit. The certificate prints the cadmium unit as '%' **[Authors to insert: laboratory confirmation that the unit is mg/L]**.

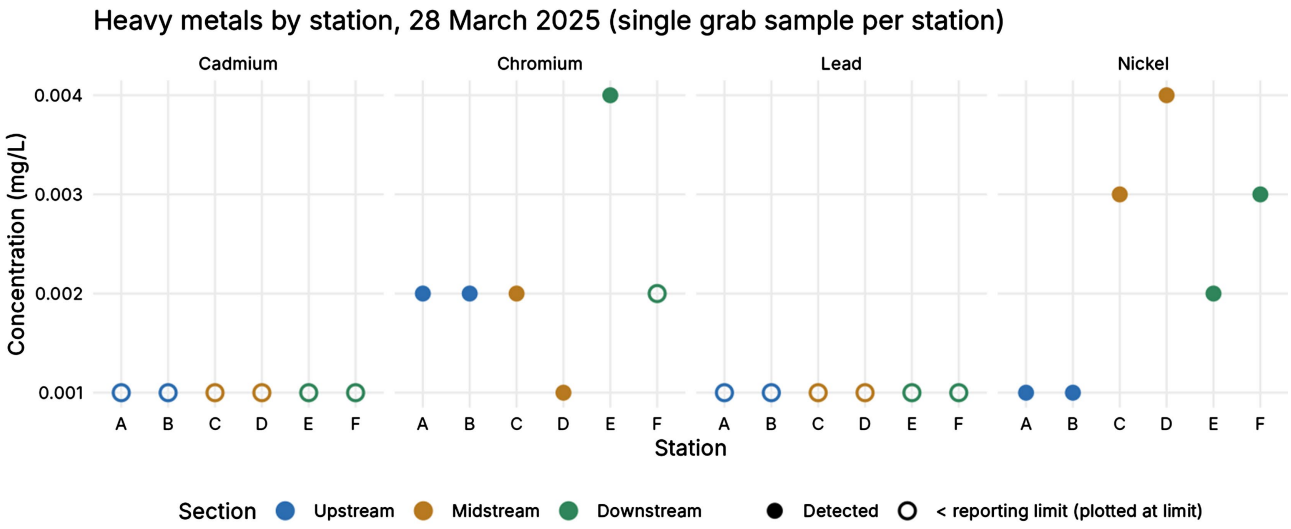



Figure 7. Heavy-metal concentrations by station. Open symbols are non-detects plotted at the reporting limit.

## 3.5. Physico-Chemical Parameters and Oxygen Demand

Table 8 gives the in-situ measurements and Table 5 the oxygen-demand results for both visits. Temperature did not differ between the March and May visits (mean difference 1.06˚C, 95% CI −7.32 to 9.44˚C; paired p = 0.74), nor did TDS (p = 0.95), EC (p = 0.45) or COD (p = 0.96) (Table 9), and changes between visits were inconsistent in direction across stations (Figure 8). DO was lower in May at every station (mean difference 1.77 mg/L; paired p = 0.004) and BOD5 higher (0.84 mg/L; paired p = 0.007), assuming dry-season sites 1 - 5 correspond to stations A - E; neither difference reached significance on the exact Wilcoxon test (p = 0.0625). DO was below 5 mg/L at all stations in May (3.38 - 4.27 mg/L), and BOD5 exceeded 5 mg/L at all stations on both dates (5.3 - 7.1 mg/L). COD (7.30 - 8.45 mg/L) remained below 20 mg/L and TDS (34 - 105 mg/L) below 500 mg/L throughout.

**Table 8.** In-situ physico-chemical parameters, stations A - E.

| Station | Season | Date | Temperature (˚C) | TDS (mg/L) | pH | EC | Salinity |
|---|---|---|---|---|---|---|---|
| A | Dry | 28/03/2025 | 38.2 | 84 | 14.8† | 45 | Nil |
| B | Dry | 28/03/2025 | 36.9 | 86 | 14.6† | 43 | Nil |
| C | Dry | 28/03/2025 | 29.2 | 70 | 11.53† | 36 | Nil |
| D | Dry | 28/03/2025 | 25.2 | 105 | 14† | 47 | Nil |
| E | Dry | 28/03/2025 | 29.0 | 34 | 13.33† | 44 | Nil |
| A | Rainy | 22/05/2025 | 29.8 | 86 | 6.98 | 55 | Nil |
| B | Rainy | 22/05/2025 | 29.3 | 70 | 7.16 | 34 | Nil |
| C | Rainy | 22/05/2025 | 30.4 | 67 | 7.32 | 33 | Nil |
| D | Rainy | 22/05/2025 | 32.5 | 93 | 7.12 | 44 | Nil |
| E | Rainy | 22/05/2025 | 31.2 | 66 | 7.32 | 34 | Nil |

†Excluded: fails the plausibility screen (Table 3). EC unit not stated on the field sheet **[Authors to insert: EC unit]**.

**Table 9.** Paired comparison between the dry- and rainy-season visits (stations A - E; difference = dry − rainy).

| Parameter | Dry mean (SD) | Rainy mean (SD) | Mean difference (95% CI) | Paired t | p (paired t) | p (exact Wilcoxon) |
|---|---|---|---|---|---|---|
| Temperature (˚C) | 31.7 (5.59) | 30.6 (1.26) | 1.06 (−7.32 to 9.44) | 0.35 | 0.743 | 0.812 |
| TDS (mg/L) | 75.8 (26.5) | 76.4 (12.3) | −0.6 (−24.1 to 22.9) | −0.07 | 0.947 | 0.812 |
| EC | 43 (4.18) | 40 (9.51) | 3 (−6.89 to 12.9) | 0.84 | 0.447 | 0.496 |
| DO (mg/L)* | 5.56 (0.3) | 3.8 (0.392) | 1.77 (0.953 to 2.58) | 6.03 | 0.004 | 0.062 |
| BOD5 (mg/L)* | 5.88 (0.46) | 6.72 (0.356) | −0.84 (−1.3 to −0.379) | −5.06 | 0.007 | 0.062 |
| COD (mg/L)* | 7.74 (0.312) | 7.76 (0.499) | −0.016 (−0.885 to 0.853) | −0.05 | 0.962 | 1.000 |

n = 5 pairs. *Assumes dry-season sites 1 - 5 correspond to stations A - E. pH is not compared because the dry-season readings were excluded. Minimum attainable exact Wilcoxon p = 0.0625.

### 3.6. Spatial Comparison

No parameter differed between river sections (Table 10). With two stations per section the smallest p-value the exact permutation test can produce is 0.067; the observed values were 0.13 for nickel, 0.80 for chromium and 0.40 for total coliform. Mean nickel was 0.0010, 0.0035 and 0.0025 mg/L, and mean total coliform 23.0, 17.5 and 21.5 MPN/100 mL, in the upstream, midstream and downstream sections respectively.

### 3.7. Correlation between Parameters

With five stations, $|r|$ must exceed 0.878 for $p < 0.05$, and confidence intervals spanned most of the range from −1 to 1 (Table 11). Three dry-season correlations had unadjusted $p < 0.05$ (temperature-nickel, $r = -0.93$; TDS-chromium, $r =$

−0.97; nickel-coliform, r = −0.92), as did two rainy-season correlations (temperature-COD, r = 0.89; pH-EC, r = −0.90), but none remained significant after Holm adjustment. The rainy-season DO-BOD5 correlation (r = −0.999) is an arithmetic consequence of the way BOD5 was derived (Table 5) and is not interpreted. Dry-season correlations involving pH are not reported because those readings were excluded.

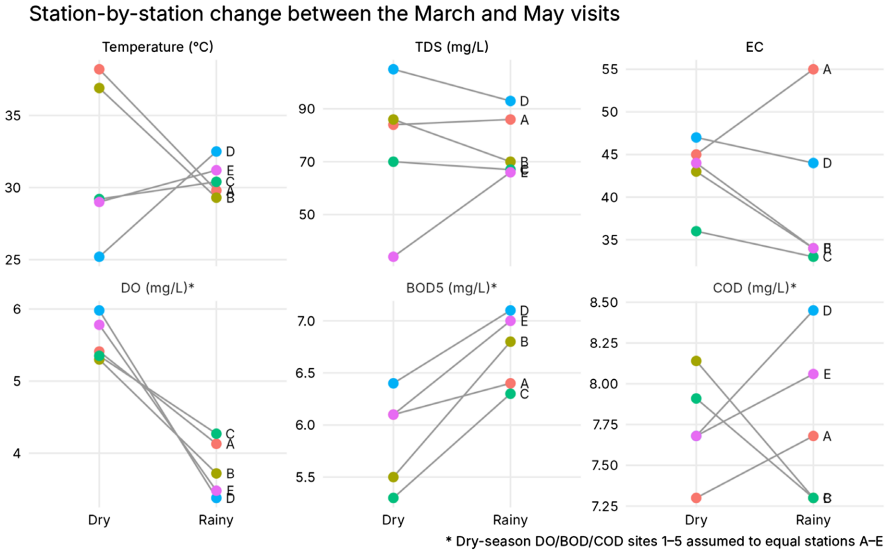



Figure 8. Station-by-station change between the March (dry) and May (rainy) visits.

Table 10. Comparison of river sections (two stations per section).

| Parameter | F | p (normal-theory ANOVA) | p (exact permutation) | p (Kruskal-Wallis) | Conclusion |
|---|---|---|---|---|---|
| Nickel (mg/L) | 9.50 | 0.050 | 0.133 | 0.115 | No detectable difference |
| Chromium (mg/L)‡ | 1.40 | 0.372 | 0.800 | 0.287 | No detectable difference |
| Total coliform (MPN/100 mL) | 2.85 | 0.202 | 0.400 | 0.167 | No detectable difference |

Minimum attainable exact p = 0.067. ‡Station F (<0.002 mg/L) entered at its reporting limit.

Table 11. Pearson correlations with 95% confidence intervals (n = 5 stations per season).

| Season | Pair | R | 95% CI | P | p (Holm) | Spearman $\rho$ |
|---|---|---|---|---|---|---|
| Dry | Temperature - Nickel | −0.93 | −1.00 to −0.28 | 0.021 | 0.415 | −0.87 |
| Dry | Temperature - Coliform | 0.76 | −0.37 to 0.98 | 0.135 | 1.000 | 0.67 |
| Dry | TDS - EC | 0.30 | −0.79 to 0.94 | 0.626 | 1.000 | 0.50 |
| Dry | TDS - Chromium | −0.97 | −1.00 to −0.63 | 0.006 | 0.117 | −0.89 |
| Dry | TDS - Coliform | −0.58 | −0.97 to 0.61 | 0.301 | 1.000 | −0.45 |
| Dry | Nickel - Coliform | −0.92 | −0.99 to −0.21 | 0.026 | 0.489 | −0.92 |

**Continued**

| | | | | | | |
|---|---|---|---|---|---|---|
| Dry | Chromium - Coliform | 0.67 | −0.52 to 0.97 | 0.219 | 1.000 | 0.75 |
| Rainy | Temperature - COD | 0.89 | 0.06 to 0.99 | 0.041 | 0.772 | 0.82 |
| Rainy | TDS - EC | 0.81 | −0.27 to 0.99 | 0.100 | 1.000 | 0.72 |
| Rainy | pH - EC | −0.90 | −0.99 to −0.09 | 0.037 | 0.746 | −0.92 |
| Rainy | DO - BOD5 | −1.00 | −1.00 to −0.99 | <0.001 | <0.001 | −1.00 § |
| Rainy | DO - COD | −0.76 | −0.98 to 0.38 | 0.139 | 1.000 | −0.82 |
| Rainy | BOD5 - COD | 0.74 | −0.41 to 0.98 | 0.150 | 1.000 | 0.82 |

Holm adjustment within season over all pairs tested. § Arithmetic artefact: DO + BOD5 was constant (10.5 mg/L) in May.

### 3.8. Water Quality Assessment and Rating

All eleven station-visits were non-compliant with at least one criterion (Table 12, Figure 9). In March, total coliform and BOD5 exceeded their criteria at every station where they were measured, and presumptive *Salmonella* at stations A, B, E and F; these four stations were rated Poor (CCME WQI 39 - 42) [22], and stations C and D, with coliforms but no Salmonella, were rated Fair (73 - 76). In May, DO and BOD5 failed at every station (Fair, 66 - 67), but microbes and metals were not measured, so the May index does not indicate microbial safety and is not comparable

Table 12. CCME water quality index and one-out-all-out compliance by station and season.

| Season | Station | Variables assessed | F1 (%) | F3 | CCME WQI | Category | Parameters failing | Compliance |
|---|---|---|---|---|---|---|---|---|
| Dry | A | 10 | 30 | 91.7 | 41.6 | Poor | BOD, Coliform, Salmonella | Non-compliant |
| Dry | B | 10 | 30 | 91.4 | 41.8 | Poor | BOD, Coliform, Salmonella | Non-compliant |
| Dry | C | 10 | 20 | 36.4 | 73.4 | Fair | BOD, Coliform | Non-compliant |
| Dry | D | 10 | 20 | 30 | 76.2 | Fair | BOD, Coliform | Non-compliant |
| Dry | E | 10 | 30 | 91.4 | 41.8 | Poor | BOD, Coliform, Salmonella | Non-compliant |
| Dry | F | 6 | 33.3 | 94.7 | 38.9 | Poor | Coliform, Salmonella | Non-compliant |
| Rainy | A | 5 | 40 | 8.9 | 66.9 | Fair | DO, BOD | Non-compliant |
| Rainy | B | 5 | 40 | 12.3 | 66.6 | Fair | DO, BOD | Non-compliant |
| Rainy | C | 5 | 40 | 7.9 | 67 | Fair | DO, BOD | Non-compliant |
| Rainy | D | 5 | 40 | 15.2 | 66.2 | Fair | DO, BOD | Non-compliant |
| Rainy | E | 5 | 40 | 14.3 | 66.3 | Fair | DO, BOD | Non-compliant |

F2 equals F1 because there was one sample per station-visit. Dry-season pH excluded. Dry- and rainy-season indices are based on different variables (Section on water quality classification) and should not be compared.

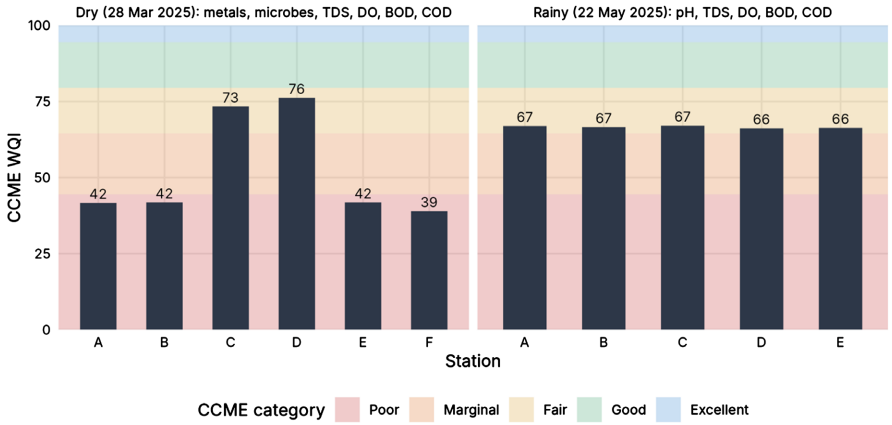



**Figure 9.** The CCME water quality index by station for each sampling visit, with category bands.

with March. Microbial contamination was the main driver of the classification: excluding the microbial variables would raise stations A - E in March to Good (89.6 - 89.8) and F to Excellent, whereas excluding the unmatched dry-season DO, BOD5 and COD values changed no category.

## 4. Discussion of Findings

This study provides a screening assessment of the microbial, heavy-metal and physico-chemical quality of the Udu River upstream, within and downstream of an abattoir discharge on two sampling dates. The findings are interpreted below in the light of the single-sample design and the data-quality screening.

### 4.1. Physico-Chemical Parameters

#### 4.1.1. Temperature (˚C)

Water temperature did not differ between the March and May visits (mean 31.7˚C and 30.6˚C; paired $p = 0.74$; **Table 9**). The wide dry-season range (25.2˚C - 38.2˚C) was recorded on a single morning and most likely reflects differences in the time of measurement and exposure of the probe to direct sunlight rather than a seasonal effect; the value of 38.2˚C at station A is unusually high for a tidal river in the morning. Elevated temperatures lower oxygen solubility and can stress aquatic organisms in tropical rivers [23], but with one visit per season the present data cannot separate seasonal from day-to-day variation.

#### 4.1.2. pH

The dry-season pH readings (11.53 - 14.8) failed quality screening: values above 14 lies outside the range of the meter, and even the lowest reading would require a conductivity about 23 times greater than was measured (**Table 3**, **Figure 5**). They were therefore attributed to instrument malfunction or calibration error and excluded. Rainy-season pH (6.98 - 7.32) was near neutral and within the 6.5 - 8.5 range. No seasonal comparison of pH can be made from the present data.

#### 4.1.3. Total Dissolved Solids (TDS) and Electrical Conductivity (EC)

TDS (34 - 105 mg/L) and EC were low at all stations and well below the 500 mg/L criterion. Neither differed between visits (paired p = 0.95 and 0.45; **Table 9**), and their correlation was not significant in either season (**Table 11**). The TDS/EC ratios (about 2 at nine of ten station-visits) are far outside the range expected for natural waters and become about 0.5 if the two columns are interchanged (**Table 4**), suggesting a transcription error that should be resolved before these variables are interpreted further.

#### 4.1.4. Dissolved Oxygen Dynamics and Organic Pollution

DO was below the 5 mg/L criterion at all five stations in May (3.38 - 4.27 mg/L) and BOD5 exceeded 5 mg/L at all stations on both dates (5.3 - 7.1 mg/L), indicating organic loading along the reach, consistent with eutrophication dynamics [24]. If dry-season sites 1 - 5 correspond to stations A - E, DO was lower (by 1.77 mg/L; paired p = 0.004) and BOD5 higher (by 0.84 mg/L; paired p = 0.007) in May, although neither difference reached significance on the exact Wilcoxon test. The near-perfect negative correlation between DO and BOD5 in May (r = −0.999) is not interpreted ecologically, because DO + BOD5 was constant (10.5 mg/L) at every station, which indicates that BOD5 was derived from the same oxygen readings (**Table 5**) DO Initial and DO Final = Dilution P-factor. The sample were kept in a specialized airtight BOD bottle and placed in a dark incubator at 20˚C (68˚F) for exactly 5days to prevent photosynthesis from adding new oxygen in the Laboratory for the BOD5 test.

#### 4.1.5. Spatial Patterns and the Contribution of the Abattoir

No spatial gradient attributable to the abattoir was detected. Total coliforms were highest (23 MPN/100 mL) at both upstream stations, presumptive *Salmonella* was detected upstream at the same level as downstream, and the MPN confidence limits overlapped at every station (**Figure 6**); no parameter differed between river sections (exact permutation p ≥ 0.13; **Table 10**). Nickel was highest in the discharge zone and chromium downstream, but all metal concentrations were close to the reporting limits and below 10% of the guideline values. The presence of contamination upstream points to sources other than, or in addition to, the abattoir, such as domestic sewage, surface runoff and boat traffic, and possibly to tidal transport of the discharge upstream. With one sample per station and no effluent or flow measurements, the contribution of the abattoir cannot be quantified [25].

#### 4.1.6. Water Quality Risk Assessment and Compliance

All eleven station-visits were non-compliant with at least one criterion (**Table 12**). In March, coliforms and BOD5 exceeded their criteria at every station and presumptive *Salmonella* at stations A, B, E and F, giving Poor CCME [22]. ratings at these four stations (39 - 42) and Fair ratings at C and D (73 - 76). In May, DO and BOD5 failed at all stations (Fair, 66 - 67), but microbes and metals were not measured, so the May index cannot be compared with March and does not indicate microbial safety. Microbial contamination was the main driver of the classifica-

tion; without the microbial variables all March stations would have been rated Good or Excellent.

#### 4.1.7. Implications for Water Resource Management

The microbial contamination found along the whole reach, together with low DO and elevated BOD5, highlights the need for proactive management. Regular monitoring, enforcement of effluent-treatment regulations and establishment of riparian buffer zones are critical in mitigating pollution, and community sensitisation is needed to reduce nutrient and sediment runoff [26].

## 5. Study Limitations and Future Research

This study has important limitations. Each station was sampled once per season without replicates, so season is confounded with the day of sampling and statistical power is very low. No effluent sample, flow or tidal-stage measurements were taken, which prevents attribution of contamination to the abattoir and estimation of pollutant loads. Dry-season pH readings were invalid and the TDS and EC columns may have been transposed. Total coliforms are not specific to faecal pollution, *Salmonella* was presumptive, and sample-holding conditions for microbiology were not documented. Metals and microbes were measured in the dry season only. Future work should sample the effluent and paired stations above and below the outfall on several dates per season with duplicates, enumerate *E. coli* or thermotolerant coliforms with confirmed *Salmonella*, measure flow, and use microbial source tracking to separate abattoir inputs from human sewage. Biological indicators such as macroinvertebrate diversity and hydrological modelling would complement the physico-chemical assessment.

## 6. Recommendations

Based on the findings of this study, the following recommendations are proposed:

### 6.1. Immediate Interventions

**1) Implementation of Wastewater Treatment Systems:** All slaughterhouses that discharge into the Udu River are required to construct main and secondary treatment systems. To lower the organic load and get rid of pathogens, these systems should incorporate screening, sedimentation, biological treatment, and disinfection procedures.

**2) Regular Water Quality Monitoring:** Establish a monitoring programme with monthly sampling during the dry season and biweekly sampling during the rainy season that includes the abattoir effluent and stations above and below the outfall, replicate samples, *E. coli* and confirmed *Salmonella*, pH measured with documented calibration, and dissolved oxygen.

### 6.2. Medium-Term Strategies

**1) Regulatory Enforcement and Compliance:** bolster NESREA's and other

pertinent agencies' enforcement of current environmental standards. Regularly monitor slaughterhouses and penalize those who violate effluent discharge regulations.

**2) Community Health Protection Measures:** Public health recommendations alerting populations to the dangers of consuming untreated river water should be implemented right away. Establish water purification facilities at vital neighborhood access points and offer substitute clean water sources for household usage.

### 6.3. Long-Term Solutions

Create a thorough watershed management strategy that considers the Udu River basin's point and non-point sources of pollution. In order to lower the overall pollution load, this should involve riparian buffer zone creation, land use planning, and sustainable farming methods. When these suggestions are put into practice methodically, the Udu River's water quality will be greatly enhanced, public health will be safeguarded, and this essential water resource will be used sustainably for present and future generations.

## 7. Conclusion

This study assessed the microbial, heavy-metal and physico-chemical water quality of the Udu River upstream, within and downstream of an abattoir discharge. Lead and cadmium were not detected, and nickel and chromium were far below WHO guideline values, so metal contamination was not a concern on the sampling date. In contrast, total coliforms were detected at every station and presumptive *Salmonella* at four of six stations, including both upstream stations, so the water is unfit for drinking or domestic use without treatment along the whole sampled reach. DO was below 5 mg/L at all stations in May and BOD5 exceeded 5 mg/L on both dates, indicating organic loading, and all station-visits were non-compliant with at least one criterion. The dry-season pH readings were invalid, and no seasonal difference in temperature was found. Because contamination was already present upstream and no effluent or flow data were collected, the study could not quantify the contribution of the abattoir; a replicated, source-tracking design is needed for that. The results nevertheless support treatment of abattoir effluent, protection of downstream water users and routine monitoring of the river.

## Acknowledgements

Sincere thanks to everyone who dedicated their time and effort toward reaching this milestone. We would especially like to acknowledge the expert guidance, analytical rigor, and help from Dr. Oyamakin, with data interpretation throughout this project.

## Author Contributions

Conceptualization: Gbuvboro A. E. and Ajimmy R. A. Methodology: Gbuvboro

A. E. and Ajimmy R. A. Software: Joshua M. and Onuabuchi S. C. Validation: Gbuvboro A. E. and Ajimmy R. A. Formal Analysis: Dr. Oyamakin O. S. Investigation: Joshua M. and Onuabuchi S. C. Resources: Joshua M.; Onuabuchi S. C. and Gbuvboro A. E. Data Curation: Dr. Oyamakin O. S. Writing—Original Draft Preparation: Gbuvboro A. E. and Dr. Oyamakin O. S. Writing—Review and Editing: Dr. Oyamakin O. S.; Gbuvboro A. E. and Ajimmy. A. Visualization: Dr. Oyamakin O. S. Supervision: Gbuvboro A. E. Project Administration: Dr. Oyamakin O. S.; Gbuvboro A. E. and Ajimmy A. Funding Acquisitions: Joshua. M.; Onuabuchi S. C. and Gbuvboro A. E.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

[1] World Health Organization and United Nations Children's Fund (2022) Progress on WASH in Health Care Facilities 2000-2021: Special Focus on WASH and Infection Prevention and Control. World Health Organization and United Nations Children's Fund (UNICEF). https://www.who.int/publications/i/item/9789240058699

[2] National Environmental Standards and Regulations Enforcement Agency (2011) National Environmental (Surface and Groundwater Quality Control) Regulations, S.I. No. 22. Federal Republic of Nigeria Official Gazette. http://faolex.fao.org/docs/pdf/nig145947.pdf

[3] Oladipo, O.O., Ilesanmi, T.M. and Olaleye, A.C. (2022) Environmental Impact of Abattoir Waste Discharge on the Quality of Water Body and Soil in Ado-Ekiti, Ekiti State. *Asian Journal of Biotechnology and Bioresource Technology*, **8**, 1-6. https://doi.org/10.9734/ajb2t/2022/v8i230120

[4] United Nations. Economic Commission for Africa, African Union Commission, African Development Bank and United Nations Development Programme (2022) Africa Sustainable Development Report 2022: Building Back Better from the Coronavirus Disease (COVID-19) While Advancing the Full Implementation of the 2030 Agenda for Sustainable Development. https://digitallibrary.un.org/record/4046861

[5] International Finance Corporation (2007) Environmental, Health, and Safety Guidelines for Meat Processing. World Bank Group. https://www.ifc.org/content/dam/ifc/doc/2000/2007-meat-processing-ehs-guidelines-en.pdf

[6] Edegbene, A.O., Arimoro, F.O. and Odume, O.N. (2020) Exploring the Distribution Patterns of Macroinvertebrate Signature Traits and Ecological Preferences and Their Responses to Urban and Agricultural Pollution in Selected Rivers in the Niger Delta Ecoregion, Nigeria. *Aquatic Ecology*, **54**, 553-573. https://doi.org/10.1007/s10452-020-09759-9

[7] Asonye, C.C., Okolie, N.P., Okenwa, E.E. and Iwuanyanwu, U.G. (2007) Some Phyco-Chemical Characteristics and Heavy Metal Profiles of Nigerian Rivers, Streams and Waterways. *African Journal of Biotechnology*, **6**, 617-624.

[8] European Commission (2005) Reference Document on Best Available Techniques in the Slaughterhouses and Animal By-Products Industries. European IPPC Bureau. https://bureau-industrial-transformation.jrc.ec.europa.eu/sites/default/files/2021-06/SA-BREF-20210629.pdf

[9] Masi, F., Rizzo, A. and Bresciani, R. (2018) Treatment of Wineries and Breweries Effluents Using Constructed Wetlands. In: Stefanakis, A.I., Ed., *Constructed Wetlands for Industrial Wastewater Treatment*, John Wiley & Sons, 95-104.

[10] Giwa, A., Yusuf, A., Balogun, H.A., Sambudi, N.S., Bilad, M.R., Adeyemi, I., *et al*. (2021) Recent Advances in Advanced Oxidation Processes for Removal of Contaminants from Water: A Comprehensive Review. *Process Safety and Environmental Protection*, **146**, 220-256. https://doi.org/10.1016/j.psep.2020.08.015

[11] Ra, J., Yoom, H., Son, H. and Lee, Y. (2020) Occurrence and Transformation of Gabapentin in Urban Water Quality Engineering: Rapid Formation of Nitrile from Amine during Drinking Water Chlorination. *Water Research*, **184**, Article 116123. https://doi.org/10.1016/j.watres.2020.116123

[12] Bustillo-Lecompte, C.F. and Mehrvar, M. (2015) Slaughterhouse Wastewater Characteristics, Treatment, and Management in the Meat Processing Industry: A Review on Trends and Advances. *Journal of Environmental Management*, **161**, 287-302. https://doi.org/10.1016/j.jenvman.2015.07.008

[13] Omole, D.O. and Longe, E.O. (2008) An Assessment of the Impact of Abattoir Effluents on River Illo, Ota, Nigeria. *Journal of Environmental Science and Technology*, **1**, 56-64. https://doi.org/10.3923/jest.2008.56.64

[14] Nguyen, T.T.T. and Waibel, M. (2021) Urban Heat Islands and Implications for Vietnam. In: Briesen, D. and Minh, P.Q., Eds., *Country Report Vietnam*: *Environmental Policy in Vietnam*, Thanh Nien Publishing House, 117-127. https://ussh.vnu.edu.vn/uploads/ussh/news/2021_10/annual-report-so-2-final.pdf

[15] Food Northwest (2020) Water and Wastewater Use in the Food Processing Industry. Food Northwest Organization. https://www.foodnorthwest.org/

[16] Lv, X., Wu, Y., Chen, G., Yu, L., Zhou, Y., Yu, Y., *et al*. (2022) The Strategy for Estrogen Receptor Mediated-Risk Assessment in Environmental Water: A Combination of Species Sensitivity Distributions and in Silico Approaches. *Environmental Pollution*, **309**, Article 119763. https://doi.org/10.1016/j.envpol.2022.119763

[17] Meat & Livestock Australia (2007) Water Use Efficiency in Meat Processing Plants (MLA Environmental Guidelines Series, Report No. ENV.007). Meat & Livestock Australia Limited.

[18] Adewoye, S.O. and Lateef, A. (2004) Assessment of the Microbiological Quality of Clarias Gariepinus Exposed to an Industrial Effluent in Nigeria. *The Environmentalist*, **24**, 249-254. https://doi.org/10.1007/s10669-005-1000-7

[19] United Nations Development Programme (2006) Niger Delta Human Development Report. https://hdr.undp.org/system/files/documents/nigeriahdrreport.pdf

[20] American Public Health Association, American Water Works Association and Water Environment Federation (2017) Standard Methods for the Examination of Water and Wastewater (23rd ed.). American Public Health Association. https://www.standardmethods.org/

[21] Holm, S. (1979) A Simple Sequentially Rejective Multiple Test Procedure. *Scandinavian Journal of Statistics*, **6**, 65-70.

[22] CCME (Canadian Council of Ministers of the Environment) (2001) Canadian Water Quality Guidelines for the Protection of Aquatic Life: CCME Water Quality Index 1.0, Technical Report. Canadian Council of Ministers of the Environment. https://unstats.un.org/unsd/envaccounting/ceea/archive/Water/CCME_Canada.PDF

[23] Anand, V., Oinam, B., Singh, S.K. and Wieprecht, S. (2025) Assessment of Freshwater

Ecosystem Health Condition Based on Fish Habitats Using a Holistic Modelling Approach. *Discover Water*, **5**, Article 11. https://doi.org/10.1007/s43832-025-00205-1

[24] Smith, V.H. and Schindler, D.W. (2009) Eutrophication Science: Where Do We Go from Here? *Trends in Ecology & Evolution*, **24**, 201-207. https://doi.org/10.1016/j.tree.2008.11.009

[25] Allan, J.D. (2004) Landscapes and Riverscapes: The Influence of Land Use on Stream Ecosystems. *Annual Review of Ecology, Evolution, and Systematics*, **35**, 257-284. https://doi.org/10.1146/annurev.ecolsys.35.120202.110122

[26] Pal, S.C., Chowdhuri, I., Das, B., Chakrabortty, R., Roy, P., Saha, A., *et al.* (2022) Threats of Climate Change and Land Use Patterns Enhance the Susceptibility of Future Floods in India. *Journal of Environmental Management*, **305**, Article 114317. https://doi.org/10.1016/j.jenvman.2021.114317