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Integrated assessment of abattoir effluent impacts on water quality and public health risk in Agbarho municipality, Delta state, Nigeria

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Abstract
Abattoir effluents are known sources of organic and microbial pollution that compromise both surface and groundwater quality, yet site-specific impacts remain underexplored in parts of Delta State. This study evaluated the effect of abattoir wastewater on water quality in Agbarho, Nigeria. Six sampling points were investigated: three along the receiving river (AGR1-AGR3) and three boreholes at increasing distances from the discharge point (AB1-AB3). Physicochemical and microbiological parameters were analyzed in triplicate and benchmarked against WHO, SON, and NESREA standards. Results revealed severe deterioration of surface waters, particularly at the discharge point (AGR2), where turbidity (14.85 NTU), BOD (4.22 mg/L), fecal coliforms (2.26×10^3 cfu/mL), and *E. coli* (15.50 MPN/100 mL) exceeded guideline limits by up to threefold for turbidity and more than fifteenfold for microbial indicators. Although groundwater samples analyzed were within both international and local regulatory limits, AB1, the nearest borehole, showed ionic enrichment (EC 259.55 μS/cm, TDS 130.45 mg/L) and detectable coliforms, suggesting early infiltration. Statistical analysis confirmed significantly higher turbidity, BOD, and microbial loads in surface waters compared with groundwater ($p<0.05$). Exceedance factor analysis identified turbidity, BOD, and microbial indicators as the dominant risks. These findings highlight a dual concern: immediate health hazards from surface water use and progressive groundwater vulnerability. It is recommended that untreated effluent discharge be discontinued and replaced with primary treatment units and low-cost biological systems, while boreholes are reinforced through sanitary safeguards, setback assessments, and routine monitoring.

Keywords: Abattoir effluent, Fecal coliforms, physicochemical quality, groundwater contamination, Agbarho River, Niger Delta, environmental health, waterborne disease

1. Introduction
Access to clean water is a cornerstone of public health and sustainable development, yet it remains under threat from rising anthropogenic pollution in developing regions. In sub-Saharan Africa, the unregulated discharge of abattoir effluents is an overlooked but critical driver of water quality degradation. These wastewaters, typically rich in blood, fats, excreta, and microbial pathogens, are often released untreated into the environment, posing serious ecological and health risks (Nwachukwu *et al.*, 2020; WHO, 2017) [13, 22].

In Nigeria's Niger Delta, this challenge is intensified by high rainfall, shallow aquifers, and weak enforcement of environmental regulations. Agbarho, a peri-urban town in Delta State, exemplifies this vulnerability. Here, effluent from the central abattoir is discharged directly into the Agbarho River, a vital water source for surrounding communities. During the rainy season, rapid surface runoff and elevated water tables accelerate contaminant migration, promoting both horizontal dispersion in rivers and vertical infiltration into groundwater (Fatunsin *et al.*, 2023; Otokunefor & Obiukwu, 2017) [20].

While previous studies in Nigeria (e.g., Asibor *et al.*, 2020) [5] have reported either microbial or physicochemical pollution near abattoirs, few have conducted integrated, spatially resolved assessments that capture risks across both surface and groundwater domains. This gap limits understanding of the full extent of ecological and public health threats in abattoir-impacted communities.

To address this gap, the present study undertakes a dual-domain evaluation of water quality in Agbarho. Specifically, the objectives were to:

i) Characterize the physicochemical and microbiological quality of surface and groundwater at varying proximities to the abattoir discharge point.
ii) Compare measured values against national (SON, NESREA) and international (WHO) regulatory standards.
iii) Quantify exceedance factors for parameters above permissible limits to identify dominant risks.
iv) Evaluate potential environmental and public health implications and propose evidence-based interventions for sustainable abattoir effluent management.

2. Materials and Methods

2.1 Study Area

This study was conducted in Agbarho, a semi-urban town in Ughelli North Local Government Area, Delta State, Nigeria. Situated within the Niger Delta basin (latitudes 5.5830°N-5.5845°N, longitudes 5.8484°E-5.8499°E), Agbarho is characterized by shallow unconfined aquifers, high rainfall, and weak environmental enforcement structures. The town hosts a central abattoir that discharges untreated effluent directly into the Agbarho River, a major surface water source for domestic and agricultural use.

2.2 Sampling Design and Site Description

Sampling was conducted in June 2025 during the rainy season, a period of increased effluent runoff and groundwater recharge. A total of six sampling sites were selected to reflect a spatial gradient of exposure to abattoir effluent:

i) Surface Water (Agbarho River)

- AGR1-Upstream control (~95 m from effluent discharge)
- AGR2-Abattoir discharge point (0 m)
- AGR3-Downstream (~100 m from effluent discharge)

ii) Groundwater (Residential Boreholes):

- AB1-Closest borehole (~39 m from effluent discharge)
- AB2-Mid-distance borehole (~69 m)
- AB3-Farthest borehole (~82 m)

Table 1: Sampling Locations, Coordinates, and Proximity

Sample Code	Site Description	Latitude (N)	Longitude (E)	Distance from AGR2
AGR1	River Upstream (Control)	5.584457	5.848476	~95 m
AGR2	Discharge Point	5.583716	5.848832	0 m
AGR3	River Downstream	5.583070	5.849053	~100 m
AB1	Closest Borehole	5.583718	5.849223	~39 m
AB2	Mid-distance Borehole	5.583698	5.849534	~69 m
AB3	Farthest Borehole	5.583564	5.849866	~82 m

All coordinates were acquired using handheld GPS and later verified against updated GIS data (WGS84 coordinate system). Site selection was based on proximity to the abattoir, accessibility, and relevance to community water use.

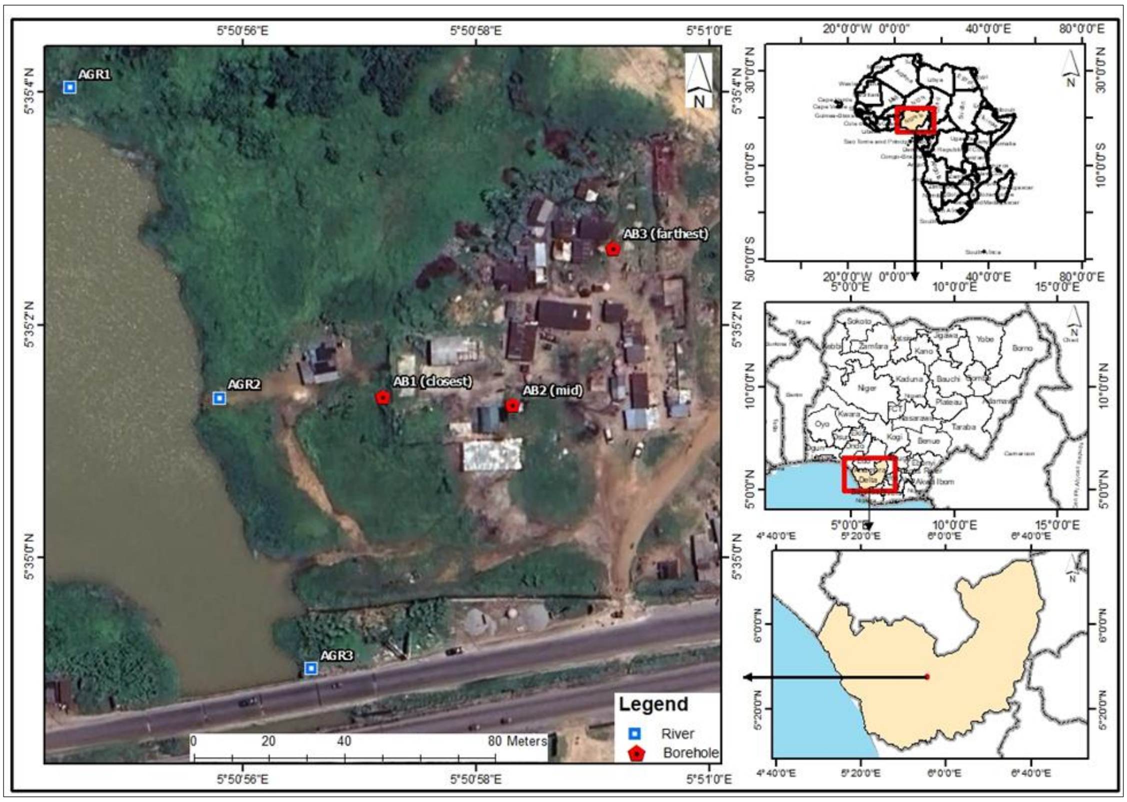

Fig 1: Spatial distribution of sampling sites (AGR1-3 surface water and AB1-3 groundwater) in Agbarho, Delta State, showing proximity to the abattoir effluent discharge point.

2.3 Sample Collection and Handling
Water samples were collected in triplicate from each site using sterilized 1 L HDPE bottles for physicochemical analysis and 250 mL sterile polypropylene bottles for microbiological testing. Borehole samples were collected after 3-5 minutes of flushing to ensure representativeness, while surface water was sampled at ~30 cm depth to avoid floating debris.

Samples were immediately stored in ice-packed coolers (4 °C) and transported to the Environmental Management and Toxicology Laboratory, Effurun, Delta State, for analysis within 6 hours. Preservation protocols followed APHA (2017) guidelines.

BOD samples were stored in amber bottles, while samples for COD (not reported here) were acidified appropriately.

2.4 Physicochemical Analysis

Table 2: Physicochemical parameters analysis, methods and instruments.

Parameter	Method	Instrument
pH	Potentiometry	Hanna HI98107 digital meter
EC	Conductometry	Horiba U-50
TDS	Gravimetric drying	Oven-dried at 103-105 °C
Turbidity	Nephelometric	Hach 2100Q turbidimeter
DO	Modified Winkler	Manual titration
BOD_5	DO difference (5 days)	Incubation + Winkler titration

All measurements were conducted in triplicate, and results recorded as Mean ± Standard Deviation (SD).

2.5 Microbiological Analysis
Microbial quality of water was determined using:

i) Fecal Coliform Count (FCC): Membrane filtration (0.45 µm cellulose nitrate), cultured on M-FC agar at 44.5 °C for 24 h; results expressed as cfu/mL $\times 10^3$.

ii) *Escherichia coli*: Most Probable Number (MPN) method; serial dilutions in MacConkey broth incubated at 37 °C for 48 h, followed by confirmatory EMB agar growth; results expressed as MPN/100 mL.

Standards were compared with WHO (2017) [22], NESREA (2011) [12], and SON (2007) [21] guidelines for drinking water.

2.6 Quality Control and Statistical Analysis
i) Analytical blanks and replicates were used to ensure accuracy.
ii) Daily calibration of instruments with certified standards.
iii) Only analytical-grade reagents were used.

Statistical analysis was carried out using SPSS v25.0. Independent sample t-tests compared surface vs. groundwater quality, with significance set at $p \leq 0.05$. Data is presented in tables and bar charts with error bars.

2.7 Ethical Considerations
Ethical approval was obtained from the Departmental Research and Ethics Committee, Federal University of Petroleum Resources, Effurun. Verbal informed consent was secured from borehole owners prior to sampling. Community leaders were engaged, and confidentiality of site identities was preserved.

3. Results
The results for the physicochemical and microbiological quality of water samples from surface and groundwater sources in Agbarho are presented here. Data are expressed as Mean±Standard Deviation (SD) from triplicate determinations. Results are compared with World Health Organization (WHO, 2017) [22], Standards Organization of Nigeria (SON, 2007) [21], and NESREA (2011) [12] guidelines.

3.1 Physicochemical Parameters
The physicochemical properties of water samples are shown in Table 3.

Table 3: Physicochemical Parameters of Water Samples (Mean ± SD)

Parameter	AGR1	AGR2	AGR3	AB1 (Closest)	AB2 (Mid)	AB3 (Farthest)
pH	6.85±0.05	6.79±0.01	6.91±0.01	5.78±0.03	6.22±0.02	6.82±0.02
EC (µS/cm)	134.00±1.00	183.50±0.50	167.50±0.50	259.55±0.05	165.75±0.05	95.60±0.10
TDS (mg/L)	65.60±0.11	92.45±0.06	84.35±0.06	130.45±0.05	81.75±0.05	47.25±0.05
Turbidity (NTU)	6.35±0.05	14.85±0.06	10.25±0.06	3.65±0.05	3.65±0.05	2.95±0.05
DO (mg/L)	6.15±0.01	6.06±0.01	6.11±0.01	5.36±0.01	5.66±0.01	5.95±0.01
BOD (mg/L)	4.21±0.01	4.15±0.01	4.19±0.01	0.00±0.00	4.13±0.01	4.11±0.01

Surface waters, particularly AGR2 (discharge point), showed markedly higher turbidity and BOD than groundwater sources. However, AB1 (closest borehole) recorded abnormal ionic enrichment (highest EC and TDS).

3.2 Microbiological Parameters
The microbiological results are summarized in Table 4.

Table 4: Microbiological Parameters of Water Samples (Mean ± SD)

Sample Code	FCC (cfu/mL $\times 10^3$)	*E. coli* (MPN/100 mL)
AGR1	2.00±0.04	8.00±1.00
AGR2	2.26±0.07	15.50±1.50
AGR3	1.23±0.03	4.00±0.00
AB1 (Closest)	0.60±0.03	0.00±0.00
AB2 (Mid)	0.00±0.00	0.00±0.00
AB3 (Farthest)	0.00±0.00	0.00±0.00

Surface waters were heavily contaminated with fecal indicators, especially AGR2. Groundwater was generally safe, though AB1 (closest borehole) showed detectable coliforms.

3.3 Comparative Summary Table

To provide a clear overview, physicochemical and microbiological results were grouped into surface vs groundwater means, benchmarked against regulatory standards.

Table 5: Summary of Water Quality Parameters (Mean ± SD) vs Standards (SON/WHO/NESREA)

Parameter	Groundwater Mean (AB1-AB3)	Surface Water Mean (AGR1-AGR3)	Standard Guideline (WHO/SON/NESREA)	Exceedance Factor-Groundwater	Exceedance Factor-Surface Water
pH	6.27±0.52	6.85±0.06	6.5-8.5 (SON/WHO)	Below min	Within range
EC (µS/cm)	173.63±82.26	161.67±25.26	1000 (SON/WHO)	0.17	0.16
TDS (mg/L)	86.48±41.80	80.80±13.77	500 (SON/WHO)	0.17	0.16
Turbidity (NTU)	3.42±0.40	10.48±4.25	5 (SON/WHO)	0.68	2.10
DO (mg/L)	5.66±0.30	6.11±0.05	≥5 (WHO)	Complies	Complies
BOD (mg/L)	2.75±2.38	4.18±0.03	<3 (SON for surface waters)	0.92	1.39
FCC (cfu/mL $\times 10^3$)	0.20±0.29	1.83±0.44	0 (SON/WHO)	Exceeds	Exceeds
E. coli (MPN/100 mL)	0.00±0.00	9.17±5.50	0 (SON/WHO)	Absent	Exceeds

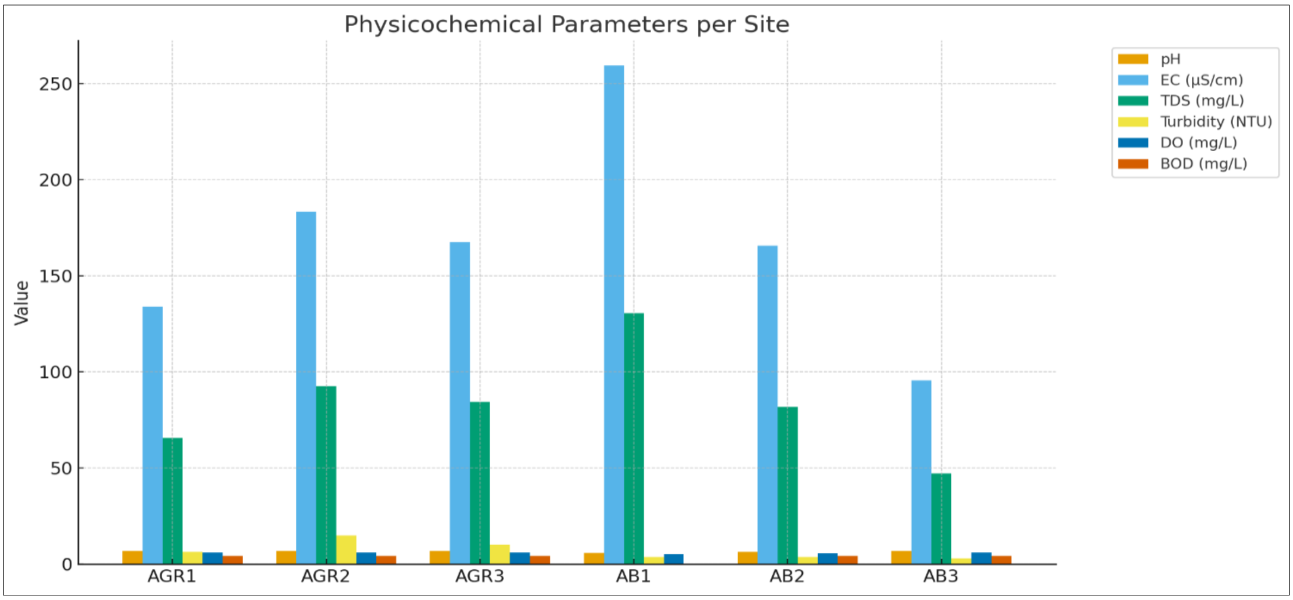

Fig 2: Grouped bar charts for physicochemical parameters of the water samples from Agbarho River and boreholes. Statistical comparison (t-test) showed that turbidity and BOD were significantly higher in surface water compared to groundwater ($p<0.05$), while pH, EC, TDS, and DO did not differ significantly ($p>0.05$).

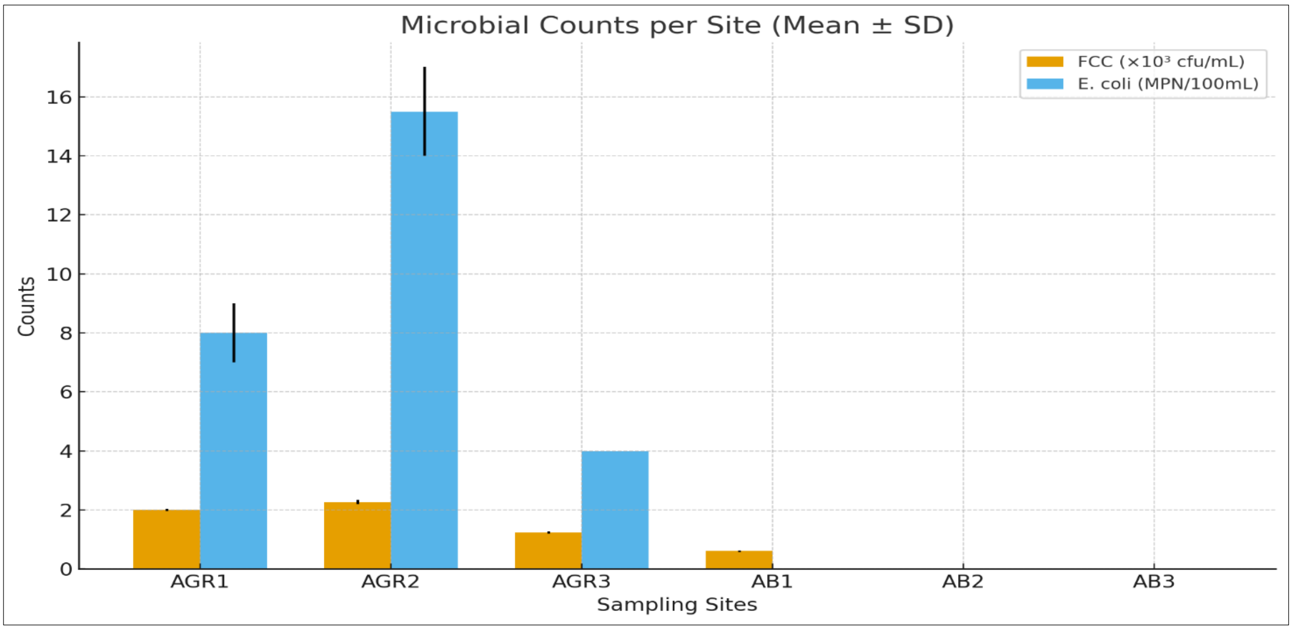

Fig 3: Microbial count per site (Mean ± SD). Both fecal coliform counts and *E. coli* were significantly higher in surface water than in groundwater ($p<0.001$), confirming surface water as the primary reservoir of microbial contamination.

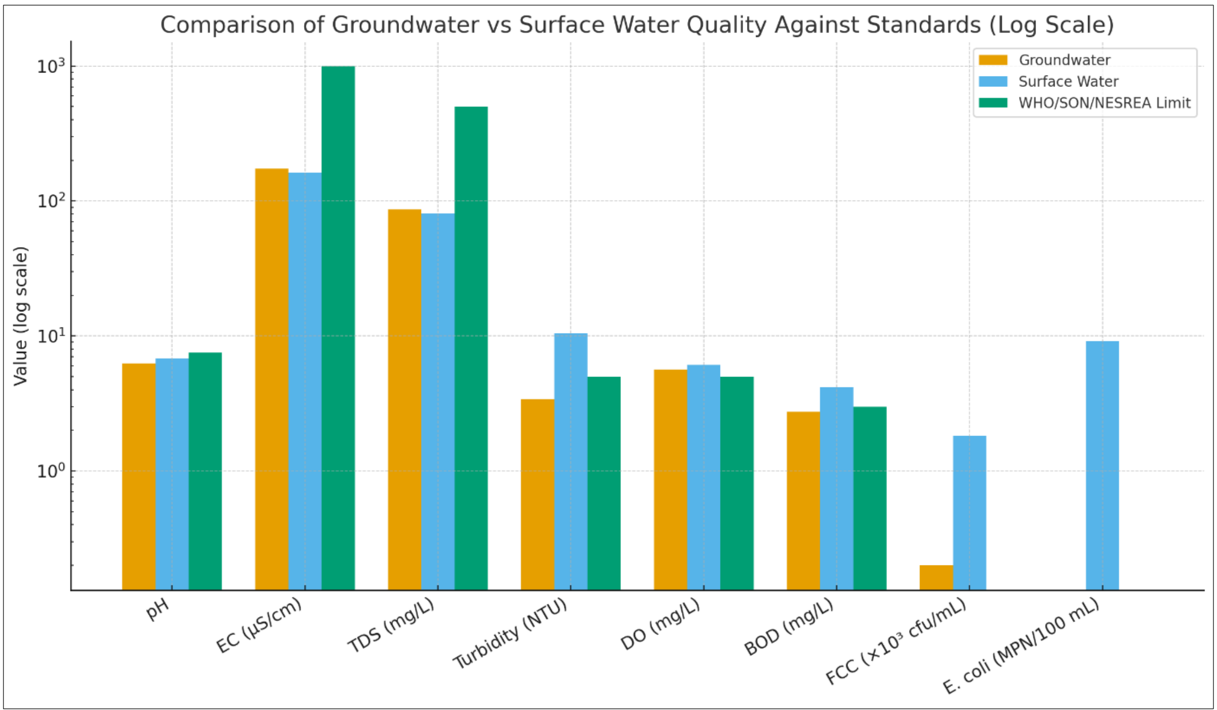

Fig 4: Comparative analysis of surface and groundwater mean values against WHO/NESREA/SON guideline limits.

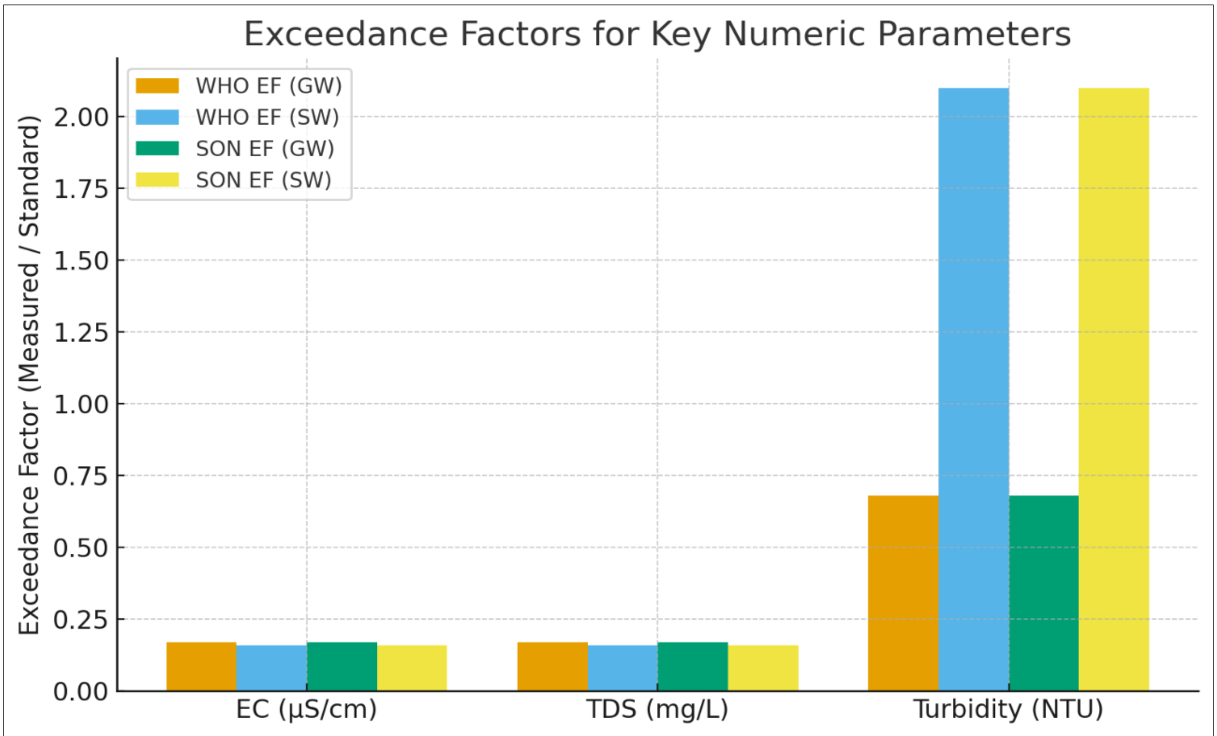

Fig 5: Exceedance factors for key Parameters

4. Discussion

4.1 Physicochemical Parameters

Physicochemical properties provide critical insight into both the quality of surface and groundwater around the Agbarho abattoir and their potential health and ecological consequences. Results are expressed as Mean ± SD (n = 3). Group comparisons were analyzed with Welch's t-test at $p<0.05$. Exceedance factors (EF = measured ÷ permissible limit) were used to quantify regulatory breaches.

4.1.1 pH

Surface waters recorded a mean pH of 6.85±0.06, while groundwater was slightly more acidic (6.27±0.52; p = 0.1944). The lowest value occurred at AB1 (5.78), falling below the WHO/SON lower limit of 6.5 (EF = 0.89). Localized acidification at AB1 is consistent with oxidative breakdown of proteins and lipids in abattoir effluent, releasing organic acids. Similar findings were reported by Odipe *et al.* (2021) [15], where shallow aquifers impacted by slaughter effluent exhibited low acid-neutralizing capacity.

Acidic water enhances solubility of metals (Fe^{2+}, Pb^{2+}, Mn^{2+}), posing risks of chronic metal exposure. Acidic groundwater also corrodes pipes and can cause mucosal irritation in consumers (Olalekan *et al.*, 2020) [18].

4.1.2 Electrical Conductivity (EC)
Surface waters ranged 134-183.5 µS/cm (mean: 161.67±25.26), while groundwater varied more widely, 95.6-259.55 µS/cm (mean: 173.63±82.26; $p = 0.8289$). AB1 showed the highest EC (259.55 µS/cm), reflecting ionic loading, likely nitrate, ammonium, chloride, and sulfate species. All values were below the 1000 µS/cm limit (EF < 1). Comparable ionic enrichment near abattoirs has been reported in wells in Enugu (Ezeh & Chukwu, 2019) [10] and Delta State (Akpoveta *et al*., 2022) [3].

While current values are safe, ionic build-up can progress to salinization, unpleasant taste, and gastrointestinal distress when sulfate-rich. EC enrichment at AB1 highlights its vulnerability to infiltration.

4.1.3 Total Dissolved Solids (TDS)
Surface waters averaged 80.80±13.77 mg/L, while groundwater averaged 86.48±41.80 mg/L ($p = 0.8405$). The maximum occurred at AB1 (130.45 mg/L). All values were below the 500 mg/L guideline (EF < 1). TDS originates from protein degradation by-products, phosphate complexes, and salts from cleaning agents (Elemile *et al*., 2019) [7].

Although compliant, progressive increases may impair soil permeability when used for irrigation and contribute to aquifer salinity. Elevated TDS also reduces palatability of water. The trend at AB1 matches earlier reports of solute build-up in shallow wells close to abattoirs (Ogbonna *et al*., 2023) [16].

4.1.4 Turbidity
Surface waters were significantly more turbid (10.48±4.25 NTU) than groundwater (3.42±0.40 NTU; $p = 0.1013$). AGR2 (14.85 NTU) had the highest, almost three times the 5 NTU WHO threshold (EF = 2.97). Turbidity is driven by suspended colloids, organic macromolecules, and microbial aggregates from effluent discharge. Similar turbid elevations were observed in abattoir-impacted streams in Edo State (Ogbeibu & Erhirhi, 2021) [17].

High turbidity reduces light penetration, disrupting photosynthesis and altering aquatic food webs. More importantly, turbid water shelters pathogens, allowing longer survival and reducing disinfection efficiency (Nwachukwu *et al*., 2020) [13]. For consumers, turbid water is unaesthetic and increases risk of gastrointestinal infections.

4.1.5 Dissolved Oxygen (DO)
DO levels remained above the 5 mg/L guideline in all samples but were lower in groundwater (5.66±0.30) than surface water (6.11±0.05; $p = 0.1152$). AB1 recorded the lowest DO (5.36 mg/L). Declining DO near effluent exposure is attributable to organic decomposition and nitrification processes. Otokunefor & Obiukwu (2017) [20] similarly documented reduced DO in abattoir-fed groundwater systems.

Although compliant (EF < 1), sustained decline in DO promotes hypoxia, sediment nutrient release, and algal blooms. This threatens aquatic biodiversity and may impair self-purification capacity of the river.

4.16 Biochemical Oxygen Demand (BOD)
Surface waters had significantly higher BOD (4.18±0.03 mg/L) than groundwater (2.75±2.38; $p = 0.4053$). AGR2 peaked at 4.22 mg/L, exceeding the ecological surface limit of 3 mg/L (EF = 1.39). High BOD indicates effluent-driven organic enrichment, consistent with blood, bile, and offal residues. Similar exceedances were reported in streams in Imo and Rivers States (Onuoha *et al*., 2022) [19]. Interestingly, AB1 showed zero BOD despite high EC/TDS, suggesting anoxic conditions suppressing aerobic metabolism or activity of sulfate-reducing bacteria, as described by Ogbonna *et al*. (2023) [16].

Elevated BOD implies strong oxygen demand, which can deplete DO and destabilize aquatic ecosystems. From a human health perspective, waters with high BOD often harbor microbial pathogens, aligning with the microbial results presented later.

4.2 Microbiological Parameters
4.2.1 Fecal Coliform Count (FCC)
Surface waters had high FCC (1.23-2.26 $\times 10^3$ cfu/mL), peaking at AGR2 (2.26 $\times 10^3$). AGR3 showed partial attenuation (1.23 $\times 10^3$) from dilution and die-off. All exceeded the 0 cfu/100 mL standard (EF > 20). Groundwater was compliant, except AB1 (0.60 $\times 10^3$), showing early infiltration. Similar patterns of borehole contamination near abattoirs were reported in Ughelli and Warri (Asibor *et al*., 2020; Adegoke *et al*., 2022) [5, 1].

FCC enrichment contributes to higher BOD, oxygen depletion, and eutrophication (Eze *et al*., 2023) [9]. Health-wise, presence of coliforms indicates potential co-occurrence of pathogens like *Salmonella* and *Shigella*, heightening risks of diarrhea, dysentery, and typhoid. AB1's contamination suggests its aquifer barrier has been breached, raising community health concerns.

4.2.2 *Escherichia coli*
E. coli was found in all surface samples, highest at AGR2 (15.50±1.50 MPN/100 mL), decreasing downstream (AGR1: 8.00; AGR3: 4.00). All exceeded the 0 MPN/100 mL guideline (EF > 15). Groundwater remained free of *E. coli*, showing natural filtration effectiveness. Comparable burdens were reported near abattoirs in Benue and Edo States (Alhassan *et al*., 2021; Ikhile & Ibhadode, 2023) [4, 11]. Persistence of *E. coli* in nutrient-rich, turbid waters indicates effluent as the primary contamination source. Health impacts include gastroenteritis, hemolytic uremic syndrome, and urinary tract infections (Afolabi *et al*., 2019; WHO, 2017) [2, 22]. Ecologically, high *E. coli* burdens alter microbial communities and increase sediment oxygen demand, as observed in Uyo and Asaba rivers (Effiong & Akpan, 2021; Enwemiwe *et al*., 2022) [6, 8].

5. Conclusion
This study has shown that abattoir effluent significantly deteriorates the quality of nearby surface waters while posing an emerging risk to groundwater resources in Agbarho. Surface waters recorded elevated turbidity (up to 14.85 NTU), BOD (4.22 mg/L), fecal coliforms (2.26 $\times 10^3$ cfu/mL), and *E. coli* (15.50 MPN/100 mL), all exceeding regulatory thresholds. Groundwater sources were generally within acceptable limits, but the closest borehole (AB1) exhibited abnormal ionic enrichment (EC 259.55 µS/cm, TDS 130.45 mg/L) and detectable coliforms, signaling early contamination. Statistical analysis confirmed significantly higher turbidity, BOD, and microbial loads in surface water compared to groundwater ($p < 0.05$). Exceedance factors

further highlighted that turbidity, BOD, FCC, and *E. coli* are the dominant parameters of concern. These results emphasize a dual risk: immediate health hazards from surface water use and the potential for progressive groundwater compromise.

To safeguard public health and aquatic ecosystems, it is recommended that direct discharge of untreated abattoir effluent be discontinued and replaced with primary treatment units such as screens, grit chambers, and grease traps, followed by low-cost biological systems like constructed wetlands or stabilization ponds for secondary treatment. Boreholes should be protected through sanitary improvements and hydrogeological assessments to determine safe setback distances, while regular monitoring of key indicators including turbidity, BOD, FCC, and *E. coli* should be institutionalized. Implementation of these measures will prevent further groundwater deterioration, reduce disease risks, and provide a model for sustainable abattoir wastewater management in Delta State and similar environments.

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