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BIOENERGY FROM AQUACULTURE EFFLUENTS: EFFECTS ON WATER QUALITY AND BENTHIC FAUNA IN A CULTURE POND AT ORHOMURU- OROGUN, DELTA STATE

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Abstract

Aquaculture is a major global source of fish protein and continues to expand in Nigeria due to declining capture fisheries and rising population demand. However, intensive aquaculture releases effluents containing uneaten feed, faeces, fertilizers, and chemical residues that can degrade water and sediment quality. This study evaluated the one-year impact of aquaculture effluents on benthic macrofauna and water quality in a culture pond at Orhomuru-Orogun, Delta State, Nigeria, from March 2024 to February 2025. Monthly sampling was carried out at three stations: Inlet, Pond Centre, and Outlet, to assess spatial and seasonal variations. Water samples were analyzed for temperature, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), nitrate, phosphate, and total dissolved solids (TDS) following APHA (2017) procedures. Sediment samples were collected using an Ekman grab, sieved (500 µm), and preserved in 4% formalin with Rose Bengal for macrofauna identification. Statistical analyses using PAST 4.14 included One-way ANOVA, Pearson correlation, ANOSIM, and PERMANOVA. Significant ($p < 0.05$) spatial variations were observed in DO, BOD_5, nitrate, and phosphate, with the Outlet showing reduced DO (3.6 ± 0.4 mg/L) and elevated nutrients. Macrofaunal diversity decreased from Inlet to Outlet, where tolerant groups (Oligochaeta, Chironomidae) dominated and sensitive taxa (Ephemeroptera, Trichoptera) declined. PERMANOVA ($F = 16.98$, $p = 0.001$) and ANOSIM ($R = 0.978$, $p = 0.001$) confirmed strong differences among stations. Overall, aquaculture effluents significantly impaired water quality and altered benthic communities, highlighting the need for improved effluent control. The study contributes to sustainable aquaculture by providing baseline information on nutrient-rich wastes that can support waste reuse, nutrient recovery, and potential bioenergy applications.

Keywords: Aquaculture effluents, Benthic macrofauna, Water quality, Bioenergy, Orogun.

Introduction

Aquaculture contributes more than 50% of the global fish consumed annually, bridging the gap created by declining capture fisheries (FAO, 2023). In Nigeria, pond aquaculture has expanded rapidly, providing income and food security to millions of households (Oladimeji *et al*., 2021). However, intensive culture practices often result in the release of nutrient-laden effluents into surrounding ecosystems. These effluents, composed of uneaten feed, fish excreta, and fertilizers, can severely alter physicochemical and biological conditions of pond and receiving waters (Boyd *et al*., 2020 and Akinsulire *et al.,*2018).

Aquaculture effluents are now recognized not only as pollutants but also as potential agrowaste bioresources rich in nitrogen, phosphorus, and organic carbon that can be converted into biogas or compost (Musa *et al*., 2020 and Ahmad *et al*., 2022). Harnessing such effluents for bioenergy and nutrient recovery corresponds with the United Nations Sustainable Development Goals (SDGs 7 and 14) and Nigeria's circular economy objectives.

Benthic macrofauna, including annelids, insect larvae, crustaceans, and mollusks, are essential components of aquatic ecosystems (Ekelemu *et al.,* 2020). Because they are relatively immobile and respond directly to sediment and water-quality changes, they serve as effective bioindicators of pollution (Nkwoji *et al.,* 2023 and Lukhabi *et al.,* 2024). In nutrient-enriched environments, species composition typically shifts from diverse communities to dominance by tolerant taxa such as *Tubifex tubifex* and *Chironomus* sp., while sensitive taxa like *Ephemeroptera* and *Trichoptera* decline (Tampo *et al.,* 2021).

Despite the growing significance of aquaculture in Nigeria, few studies have examined within-pond ecological gradients or the relationship between effluent buildup and benthic community shifts. Previous investigations mostly focused on downstream water bodies rather than internal pond variations (Omoigberale *et al.*, 2020 and Adeogun *et al*., 2020).

This study therefore investigates the impact of aquaculture effluents on water quality and benthic fauna in an earthen pond at Orhomuru - Orogun, Delta State, Nigeria, while exploring their bioenergy potential. The findings are relevant to both environmental monitoring and sustainable aquaculture practices.

General Aim

To evaluate the effects of aquaculture effluents on water quality and benthic fauna in a culture pond at Orhomuru, Orogun and identify their bioenergy potential.

Specific Objectives

i. to assess spatial and seasonal variations in key physicochemical parameters,
ii. to determine the composition and abundance of benthic macrofauna in different stations.
iii. to evaluate relationships between water quality and benthic-fauna diversity using SPSS and PAST software.
iv. to explore possibilities for converting aquaculture effluents into renewable bioenergy resources.

Materials and Methodology

Study Area

The study was conducted in a culture pond at Ororomi stream, Orhomuru - Orogun (5°41'23.532" N, 6°04'41.9988" E), Delta State, Nigeria. The pond receives inflow from a small stream and drains into nearby wetlands. The area is humid tropical, with annual rainfall around 2,400 mm and mean temperature between 27-30°C.

Sampling Design

Monthly sampling was carried out between March 2024 and February 2025 at three stations:

Station 1 (Inlet): water inflow point, low effluent accumulation

Station 2 (Centre): main culture zone

Station 3 (Outlet): discharge point with high effluent concentration

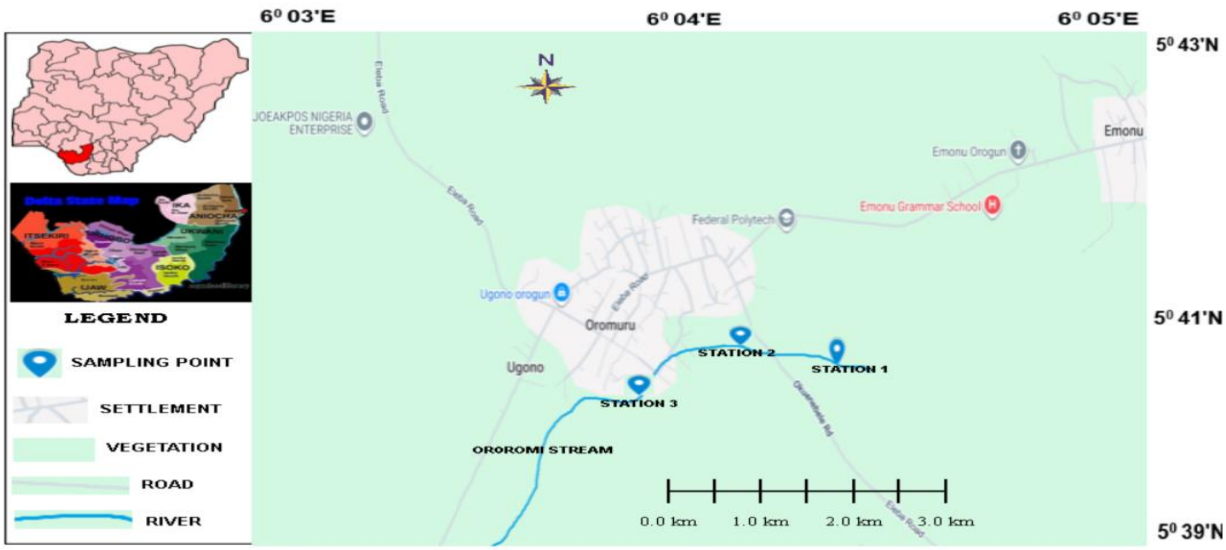

Figure1: Map of study stations

Physico-chemical Analysis of Water
Physicochemical parameters were analyzed following standard APHA (2017) procedures. Water temperature was measured in situ at each sampling station using a calibrated mercury thermometer. The remaining parameters such as pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), nitrate, phosphate, and total dissolved solids (TDS), were analyzed in the laboratory using standard methods.

Benthic-Fauna Sampling
Sediments were collected using an Ekman grab (225 cm²), sieved through 500 µm mesh, stained with Rose Bengal, and preserved in 4% formalin. Identification followed Ekelemu *et al.,* (2020).

Statistical Analyses
Data were processed with SPSS v25 and PAST v4.14. One-way ANOVA tested spatial differences ($\alpha = 0.05$); Pearson correlation measured relationships between DO, BOD_5, and diversity indices; PERMANOVA and ANOSIM analyzed community separation. Diversity indices were computed using Shannon (H′) and Simpson (1-D) equations.

Results

Water-Quality Characteristics

Table i: Mean ± SD values of physicochemical parameters (One-Way ANOVA)

Parameter	Inlet	Centre	Outlet	F-value	p- value
Water temperature (°C)	27.2 ± 0.4	27.8 ± 0.6	28.1 ± 0.5	4.82	**0.021**
pH	7.5 ± 0.2	7.0 ± 0.3	6.6 ± 0.3	6.34	**0.009**
DO (mg L^{-1})	6.0 ± 0.5	4.8 ± 0.4	3.6 ± 0.4	12.43	**0.001**
BOD_5 (mg L^{-1})	2.8 ± 0.4	4.5 ± 0.6	5.9 ± 0.7	11.22	**0.002**

Nitrate ($mg\ L^{-1}$)	1.7 ± 0.2	2.6 ± 0.3	3.4 ± 0.3	9.54	**0.003**
Phosphate ($mg\ L^{-1}$)	0.38 ± 0.04	0.60 ± 0.07	0.84 ± 0.08	8.71	**0.004**
TDS ($mg\ L^{-1}$)	162 ± 12	184 ± 14	201 ±18	7.86	**0.005**

Significant at $p < 0.05$

Table ii: Benthic Fauna Composition

Taxa	**Species**	**Inlet**	**Centre**	**Outlet**	**Total**
Oligochaeta	*Tubifex tubifex*	96	148	166	410
Chironomidae	*Chironomus sp*	68	104	122	294
Bivalvia	*Corbicula fluminea*	34	44	22	100
Gastropoda	*Physa acuta*	28	38	18	84
Ephemeroptera	*Caenis sp*	20	14	8	42
Trichoptera	*Hydropsyche sp.*	14	10	6	30
Crustacea	*Caridina africana*	16	8	10	34
Total		276	366	352	994

Diversity Indices and Multivariate Statistics

Table iii: Diversity indices

Station	Taxa (S)	Individuals (n)	Shannon (H′)	Simpson (1–D)	Evenness (J′)	F-value	p-value
Inlet	7	276	1.92	0.79	0.79	**-----**	**-----**
Centre	7	366	1.67	0.73	0.71	**-----**	**-----**
Outlet	7	352	1.41	0.65	0.66	**------**	**------**
PERMANOVA	-----	-----	-----	------	-----	16.98	**0.001**
ANOSIM (R)	------	-----	-------	-------	------	0.978	**0.001**

Significant at $p< 0.05$

Pollution-Tolerance Classification and Ecological Indication of Benthic Taxa Recorded in a culture pond at Orhomuru, Orogun

The identified macrofaunal groups from a culture pond at Orhomuru - Orogun displayed varying levels of tolerance to organic enrichment and oxygen depletion, providing insights into the ecological condition of the pond. The distribution pattern followed a distinct pollution gradient from the Inlet (cleaner, oxygenated zone) to the Outlet (organically enriched, oxygen-deficient zone).

Table iv: Pollution-Tolerance Classification and Ecological Indication of Benthic Taxa

Taxon	Species	Groups	Pollution tolerance level	Ecological indications	References
Oligochaeta	*Tubifex tubifex*	Segmented worm	Highly tolerant	Dominant in organically enriched and oxygen-poor sediments; typical indicator of severe organic pollution and high BOD_5. Survive under near-anoxic conditions	Boyd *et al*., 2020.
Chironomidae	*Chironomus sp*	Midge larvae	Moderately tolerance	Thrive in low-oxygen, nutrient-rich ponds. Possess hemoglobin-like pigments enabling survival under hypoxia. High abundance reflects organic enrichment and partial eutrophication.	Feio *et al.,* 2022 and Musa *et al.,* 2020
Bivalvia	*Corbicula fluminea*	Mullusk (clam)	Moderately sensitive	Filter-feeder; present in moderate organic conditions, declines with high turbidity or nutrient stress. Indicates fair water quality.	Ekelemu *et al*., 2020.
Gastropoda	*Physca acuta*	Snail	Moderately tolerant	Common in nutrient-enriched, but not anoxic waters; reflects intermediate water quality and moderate organic load	Feio *et a*l., 2022.

Ephemeroptera	*Caenis sp*	Nymph of mayflies	Sensitive	Require high dissolved oxygen; abundance limited to clean and well-oxygenated waters. Their decline indicates organic pollution.	Hauer and Resh, 2017.
Trichoptera	*Hydropsyche sp*	Caddisfly larva	Moderately sensitive	Prefer clean, flowing, oxygen-rich habitats; decline in polluted zones. Serve as reliable indicators of good water quality.	Feio *et al.,* 2022.
Crustacean	*Caridina Africana*	Shrimp	Moderately sensitive	Found in moderate to good water quality; reduction downstream reflects declining oxygen and increasing nutrient load	Ekelemu *et al.,*2020 and Musa *et al* 2020

Discussion

Benthic Macroinvertebrates as Bioindicators

The benthic macroinvertebrate community in Orhomuru - Orogun culture Pond revealed a clear pollution gradient. Highly tolerant taxa (*Tubifex tubifex* and *Chironomus sp*.) dominated the outlet, indicating strong organic pollution, low DO, and high BOD_5 (Omoigberale *et al.,* 2020, Tampo *et al*., 2021 and Musa *et al*., 2020). Moderately tolerant species (*Physa acuta, Corbicula fluminea, Caridina africana*) were present across all stations but declined downstream. According to (Ekelemu *et al*., 2020 and Agbam *et al*., 2025), this pattern reflects moderate organic loading and gradual eutrophication. Sensitive taxa (*Caenis* sp., *Hydropsyche* sp.) were restricted to the inlet with higher DO and lower BOD_5, confirming the studies conducted by (Nkwoji, *et al*., 2023 and Lukhabi *et al.,* 2024) stating their role as indicators of good water quality. These patterns support the study by (Boyd *et al.,* 2020 and Ahmad *et al*., 2022) which validate benthic macrofauna as reliable bioindicators of aquaculture effluent impacts

Physicochemical parameters mirrored these biological patterns. DO decreased and BOD_5, nitrate, phosphate, and TDS increased from inlet to outlet, indicating nutrient enrichment from feed residues and faecal deposition typical of semi-intensive aquaculture (Boyd *et al.,* 2020; Akinsulire, *et al.,* 2018). Elevated BOD_5 reflects microbial decomposition and sediment oxygen depletion (Omoigberale *et al*., 2020). Algal blooms at the outlet further confirm eutrophication caused by excess nutrients (Boyd *et al.,* 2020).

Statistical analyses reinforced these trends, with significant differences in water quality parameters among stations and clear benthic community separation in PERMANOVA and ANOSIM, consistent with global aquaculture studies (Musa *et al.,* 2020; Tampo *et al*.., 2021).

Beyond ecological assessment, pond effluents showed potential as recoverable agrowaste. Nutrient-rich sludge can be used for biogas production, composting, and soil amendment, while organic carbon supports anaerobic digestion and nutrient-rich microalgae cultivation for bioenergy. Agbam *et al.,* (2025) stated that nutrient-rich sludge can be used for biogas production, composting, and soil amendment, while organic carbon supports anaerobic digestion and nutrient-rich microalgae cultivation for bioenergy, Lukhabi *et al*., 2024). IoT-based sensors and machine-learning tools can further optimize feed, aeration, and nutrient recycling, promoting sustainable aquaculture practices by Ahmad *et al*., (2022).

In conclusion, aquaculture effluents in Orhomuru Orogun culture pond reduce biodiversity yet contain valuable recoverable nutrients. This integrated environmental impact and resource evaluation supports the theme "Agrowaste Bioenergy Resources for Scientific Advancement," highlighting opportunities to reduce ecological stress while enabling renewable-energy generation.

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