Journal of Limnology and Freshwater Fisheries Research

http://www.limnofish.org

Influence of Municipal and Abattoir Effluents on Surface Water Quality and Biological Responses of Fish in the Benue River, Nigeria

Athanasius AENDE [1*], Orfega KWAGHVIHI[1], Donald TORSABO [1], Tivfa GBAIOR [1]

[1] Department of Fisheries and Aquaculture, Joseph Sarwuan Tarka University, Makurdi (Formally Federal University of Agriculture, Makurdi), Benue State, Nigeria

ABSTRACT

This study assessed surface water quality and biological responses of fish exposed to municipal and abattoir effluents discharged into the Benue River at Makurdi, Benue State, Nigeria (Latitude 7.733218° N, Longitude 8.546908° E). Most physicochemical parameters, including temperature (27.59 ± 1.40°C) and pH (7.17 ± 0.10), fell within NESREA (2011) limits, but ammonia nitrogen (0.50 ± 0.12 mg/L) exceeded the 0.05 mg/L permissible limit, while biological oxygen demand (4.03 ± 0.13 mg/L) surpassed the 3.0 mg/L limit, alongside significantly elevated ($p < 0.0001$) dissolved oxygen, total alkalinity, total hardness, and transparency, reflecting abattoir-driven pollution. Among fish species, *Clarias gariepinus* recorded the highest gonadosomatic index but the lowest condition factor, while *Oreochromis niloticus* showed the highest hepatosomatic index and, with *Coptodon zillii*, higher condition factors ($p < 0.05$). Haematological analysis revealed depressed haemoglobin (9.20 g/dl) and markedly elevated white blood cell counts (8753.70×10^9 cells/L; $p < 0.001$), indicating physiological stress. Liver enzymes (ALT, AST, ALP) and oxidative stress biomarkers (SOD, CAT, MDA, GPx, GR, LPO) varied significantly across seasons and species ($p < 0.001$), except glutathione (GSH), which remained stable. These findings confirm that abattoir and municipal waste degrade Benue River water quality and compromise fish physiological health, posing ecological and public health risks to communities dependent on the river.

Keywords: Water quality, morphology, biological indices, seasonal variation, Benue River.

ARTICLE INFO

RESEARCH ARTICLE

Received : 03.02.2026
Revised : 15.04.2026
Accepted : 12.06.2026
Published : 14.08.2026

DOI:10.17216/LimnoFish.1880957

*** CORRESPONDING AUTHOR**

aende.athanasius@uam.edu.ng
Phone : +2349094645515

How to Cite
Aende A., Kwaghvihi O., Torsabo D., Gbaior T. 2026. Influence of Municipal and Abattoir Effluents on Surface Water Quality and Biological Responses of Fish in the Benue River, Nigeria. LimnoFish. 12(2): 64-80. doi: 10.17216/LimnoFish.1880957

Introduction

The aquatic environment provides diverse habitats and clean water that are essential for aquatic organisms, wildlife, and human use. Among freshwater systems, rivers are the most critical resource for humans; however, they are also the most vulnerable to pollution owing to their accessibility for waste disposal (Mishra, 2023). Water pollution occurs when the physical, chemical, thermal, or biological characteristics of water are altered by waste inputs, thereby reducing water quality and negatively impacting both aquatic life and human benefits. The growing problem of water contamination is largely attributed to untreated sewage, industrial effluents, and agricultural runoff (Madhav et al., 2019).

Freshwater ecosystems are increasingly threatened by multiple stressors, including temperature fluctuations, nutrient enrichment, acidity, habitat destruction, species invasion, and chemical inputs (Tahir et al., 2021). Rapid industrialization, agricultural intensification, chemical use, urbanization, and population growth have been identified as key drivers of declining water quality (Akhtar et al., 2021). These pressures degrade biodiversity and introduce significant health stressors for aquatic organisms and humans (Ogidi & Akpan, 2022). Therefore, preserving the ecological integrity and functional dynamics of rivers is a major environmental challenge of this century (Jungwirth et al., 2002).

Fish are particularly susceptible to pollution because they are directly dependent on aquatic systems. Pollutants may enter fish through contaminated food, direct water uptake, or permeable membranes such as the gills and skin (Abdel-Kader & Mourad, 2020). Once absorbed, contaminants are metabolized and accumulate in tissues and organs in the body. Haematological and serological markers are widely used to evaluate the physiological and pathological conditions of fish, as they reflect infections and stress induced by pollutants (Tahir et al., 2021). One major outcome of pollutant exposure is oxidative stress, which is caused by the overproduction of reactive oxygen species (ROS) that disrupt cellular homeostasis (Menon et al., 2023).

Biochemical markers such as Alanine Aminotransferase (ALT), Aspartate Aminotransferase (AST), and Alkaline Phosphatase (ALP) serve as indicators of tissue injury, disease, or environmental stress (Muliari et al., 2020). Alongside these, alterations in oxygen-carrying capacity and haematological indices provide critical tools for assessing fish health and detecting pollution impacts (Chen & Luo, 2023)

In Nigeria, the Benue River is of great ecological, agricultural, and economic importance, particularly in Makurdi, the capital of Benue State. However, the river is increasingly affected by industrial effluents and domestic waste along its course, resulting in a significant water quality degradation (Anhwange et al., 2012; Jokam Nenkam et al., 2022). It is a widespread occurrence resulting from the release of untreated liquid and solid waste from industrial and municipal sources (Awgchew et al., 2015). Consequently, this study was carried out to assess the state of the Benue River and to evaluate the impacts of abattoir effluents and municipal discharges on water quality using NESREA (2011) permissible limit of surface water quality for fisheries and recreation quality criteria standard, and the physiological well-being of fish in the river, with particular focus on haematological and biochemical biomarkers as measures of anthropogenic pollution.

Materials and Methods

Study Site

The River Benue abattoir site (figure 1) is located at Latitude 7.733218° N, Longitude 8.546908° E, MSL 65.44m, and Alt. Ellipsoid 86.90m along the riverbank. Makurdi is the capital of Benue State. The hydrological regime is characterized by high discharge between August and early October and reduced flow from December to April, corresponding to a seven-month wet season with a mean annual rainfall of 1,200–2,000 mm (Akaahan et al., 2014).

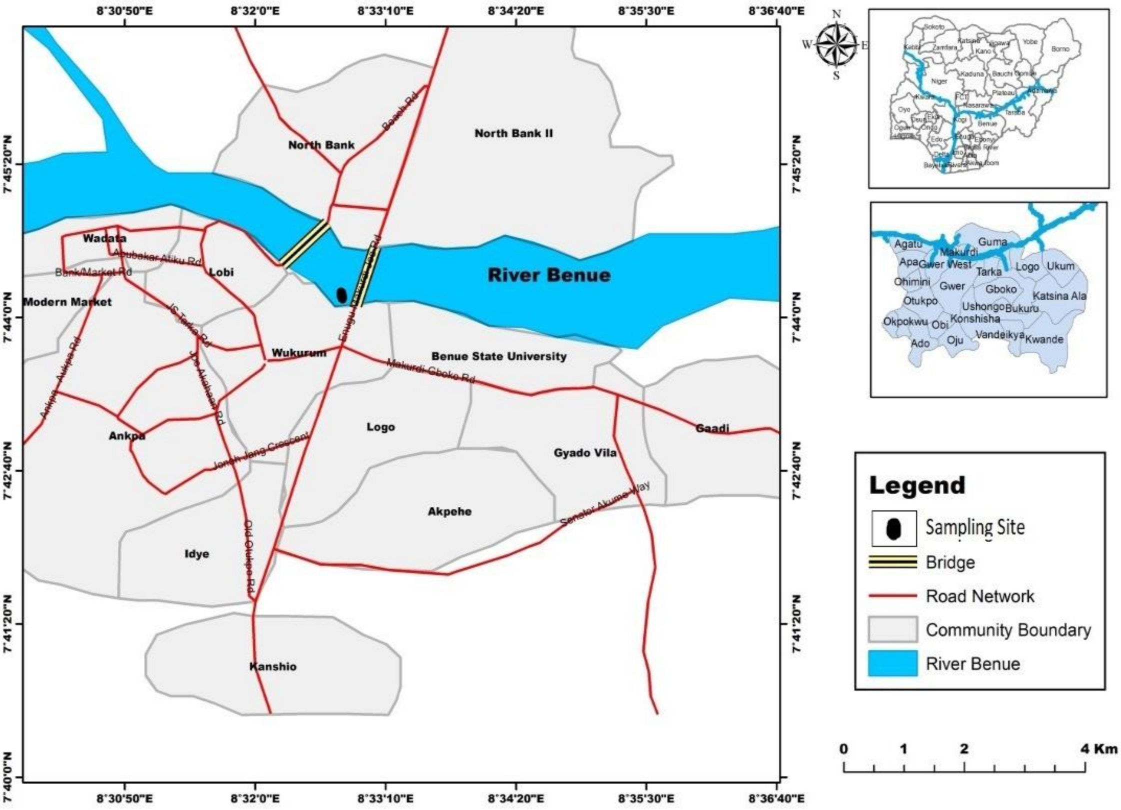

Figure 1. Abattoir sampling site in Makurdi on the Benue River

Water Sample Collection and Analysis.

Sampling was conducted at randomly selected locations in water within the abattoir effluent-discharged site, and each parameter was measured in triplicate to generate mean values. Water was collected at a depth of 20 cm using 250 mL glass bottles fitted with cork stoppers and protected from sunlight to prevent alteration. On-site measurements of temperature (°C), conductivity (mS), total dissolved solids (mS/cm), and pH were recorded with a Hanna multiparameter meter (Model HI9813-6), while dissolved oxygen (DO) was measured using an Iuzmar meter (Model UMR-9100). Water transparency was assessed using a calibrated Secchi disk (cm). The 250 mL BOD water samples were analyzed for ammonia, nitrite, carbon dioxide, chloride, and biological oxygen demand (mg/L) following Winkler's method, as described by Rice et al. (2012).

Fish Sample Collection

The sampled fish species are *Clarias gariepinus* (Burchell, 1822), *Coptodon zillii* (Gervais, 1847), and *Oreochromis niloticus* (Linnaeus, 1758). A total of 30 individuals were sampled from each species every month. Three species were included in the study, resulting in a monthly sample size of 90 individuals. Sampling was conducted over a period of six months, giving a cumulative sample size of 540 individuals for the entire study spanning January to March for the dry season and June to August for the rainy season of 2025 (Morphometric). Collections were carried out in similar months for fish specimens, which were sourced directly at the study location with the aid of artisanal fishers using their various selective fishing gears and identified using the estimating fisheries reference point from the catch and resilience fish identification key by Froese et al. (2017). Blood samples were drawn using 2mm syringes and transferred into tubes containing EDTA and plain sampling tubes. All samples were kept on ice and transported to Q.A. Diagnostics Laboratory for laboratory analyses.

Fish Haematological Analysis

Collected blood samples from the experimental fish were examined for haematological indices, which are Red Blood Cell (RBC) count, White Blood Cell (WBC) count, Haemoglobin (Hgb) level, Haematocrit (Hct), Mean Corpuscular Haemoglobin (MCH), Mean Corpuscular Volume (MCV), and Mean Corpuscular Haemoglobin Concentration (MCHC), by means of an automated haematology analyzer (Sysmex RKX-21N) following the method described by Amaeze et al. (2020).

Fish Biochemical Analysis

Blood samples in sterile plain tubes were analyzed for liver enzymes, including Aspartate Aminotransferase (AST), Alanine Aminotransferase (ALT), and alkaline phosphatase (ALP), using reagent enzyme assay kits (Randox) as described by Abdel-Kader & Mourad (2020).

Tissue biochemical markers, including Superoxide Dismutase (SOD) and Lipid Peroxidation (LPO), were quantified using standardized assay protocols as reported by Sharma et al. (1972) and Mansou et al. (2023). Malondialdehyde (MDA), Glutathione S-transferase (GST), Reduced Glutathione (GSH), Glutathione peroxidase (GPx), and Glutathione Reductase (Glucocorticoid Receptor) were measured using Bioxytech (LOPO – 596 kit) as illustrated by Kumar et al. (2017).

Morphometric Measurement

The standard length of the fish was measured using a meter rule, while the total body and liver weights were determined using a sensitive digital balance (Model: ATOM A123). These measurements were used to compute morphometric indices, namely the hepatosomatic index (HSI), gonadosomatic index (GSI), and condition factor (CF), following the method described by Ogili et al. (2021).

Statistical Analysis

Data were analyzed using the Statistical Package for Social Sciences (SPSS version 20.00, IBM Corporation, Armonk, USA) and Paleontological Statistics (PAST version 3.2). Physicochemical and Physiological parameters were analyzed using the Mann–Whitney U test.

Results

Physicochemical Properties of the Benue River

The mean physicochemical parameters of the Benue River at the abattoir site, compared against NESREA (2011) permissible limits, are presented in Table 1. Mean pH (7.17 ± 0.10), temperature (26.54 ± 0.20°C), total dissolved solids (77.28 ± 5.23 mg/l), conductivity (154.67 ± 10.49 µs/cm), dissolved carbon dioxide (11.67 ± 0.39 mg/l), and chloride (14.89 ± 0.52 mg/l) all fell within NESREA permissible limits ($p > 0.05$). In contrast, dissolved oxygen (6.52 ± 0.22 mg/l), biological oxygen demand (4.04 ± 0.13 mg/l), total hardness (24.28 ± 0.65 mg/l), total alkalinity (14.17 ± 0.56 mg/l), and transparency (44.72 ± 0.41 cm) were all significantly higher than recommended limits ($p < 0.0001$). Ammonia nitrogen (0.50 ± 0.11 mg/l) exceeded the NESREA limit of 0.05 mg/l, although this difference was not statistically significant ($p = 1.00$). also biological oxygen demand (4.03 ± 0.13 mg/L) surpassed the 3.0 mg/L limit, alongside significantly elevated ($p < 0.0001$).

Table 1. Mean physicochemical parameters of the Benue River and NESREA permissible limit

Parameters	River water	*P*	NESREA (2011)
pH	7.17 ± 0.10	0.152	6.5 – 8.5
Temp. (°C)	26.54 ± 0.20	0.265	20 – 33
TDS (mg/l)	77.28 ± 5.23	0.279	500
Cond. (μs/cm)	154.67 ± 10.49	0.279	Nil
DO (mg/l)	6.52 ± 0.22	< 0.0001	6.0
BOD (mg/l)	4.04 ± 0.13	< 0.0001	3.0
CO_2 (mg/l)	11.67 ± 0.39	0.424	30.0
T. Hard. (mg/l)	24.28 ± 0.65	< 0.0001	180
T. Akal. (mg/l)	14.17 ± 0.56	< 0.0001	40.0
Amm. Nit. (mg/l)	0.50 ± 0.11	1	0.05
Chloride (mg/l)	14.89 ± 0.52	0.346	300
Transp. (cm)	44.72 ± 0.41	< 0.0001	Nil

Values are shown as mean ± SEM, but p-values from the Mann-Whitney U test. Temp. = temperature, Cond. = conductivity, T. Hard = total hardness, Amm. Nit = Ammonia nitrogen, Transp. = transparency. The Mean ammonia nitrogen concentration was considered using 0 for values less than 1.

Seasonal comparisons of the physicochemical parameters are presented in Table 2. Temperature was significantly higher in the dry season (27.59 ± 1.40°C) than in the rainy season (25.96 ± 0.67°C) ($p < 0.0001$), while biological oxygen demand was significantly higher in the rainy season (4.73 ± 0.47 mg/l) compared with the dry season (4.03 ± 0.52 mg/l) ($p < 0.0001$). All other parameters, including pH, total dissolved solids, conductivity, dissolved oxygen, carbon dioxide, total hardness, total alkalinity, ammonia nitrogen, chloride, and transparency, showed no statistically significant seasonal differences ($p > 0.05$).

Table 2. Seasonal physicochemical properties of the Benue River.

Parameters	Season		
	Dry	Rainy	*P*
pH	7.21 ± 0.49	7.27 ± 0.30	0.962
Temp. (°C)	27.59 ± 1.40	25.96 ± 0.67	< 0.0001
TDS (mg/l)	85.61 ± 32.64	179.22 ± 6.42	0.987
Cond. (μs/cm)	171.39 ± 65.54	179.22 ± 6.42	0.987
DO (mg/l)	7.09 ± 1.12	7.87 ± 1.20	0.0847
BOD (mg/l)	4.03 ± 0.52	4.73 ± 0.47	<0.0001
CO_2 (mg/l)	11.56 ± 1.01	12.72 ± 2.85	0.4619
T. Hard. (mg/l)	29.44 ± 8.33	32.78 ± 8.27	0.1182
T. Akal. (mg/l)	15.22 ± 2.26	16.28 ± 2.65	0.0907
Am. Nit. (mg/l)	0.33 ± 0.49	0.67 ± 0.49	0.0907
Cl^- (mg/l)	16.61 ± 1.94	15.94 ± 2.75	0.5010
Transp. (cm)	35.83 ± 9.67	34.56 ± 10.21	0.3231

Values shown as mean ± SD, but p-values are from the Mann-Whitney U test.

Morphometric Indices of Fish Species in the Benue River

Morphometric indices, including the gonadosomatic index (GSI), hepatosomatic index (HSI), and condition factor (CF), differed significantly among the three fish species sampled ($p < 0.05$) (Figure 2A - 2C). *Clarias gariepinus* exhibited a significantly higher GSI than both *Oreochromis niloticus* and *Coptodon zillii* (Figure 2A), with the difference exceeding threefold, while

C. zillii and *O. niloticus* showed comparable GSI values. The HSI differed significantly among all three species, with the highest value recorded in *O. niloticus* and the lowest in *C. zillii* (Figure 2B). Conversely, *C. gariepinus* recorded the lowest condition factor, whereas *O. niloticus* and *C. zillii* exhibited condition factor values more than three times higher (Figure 2C).

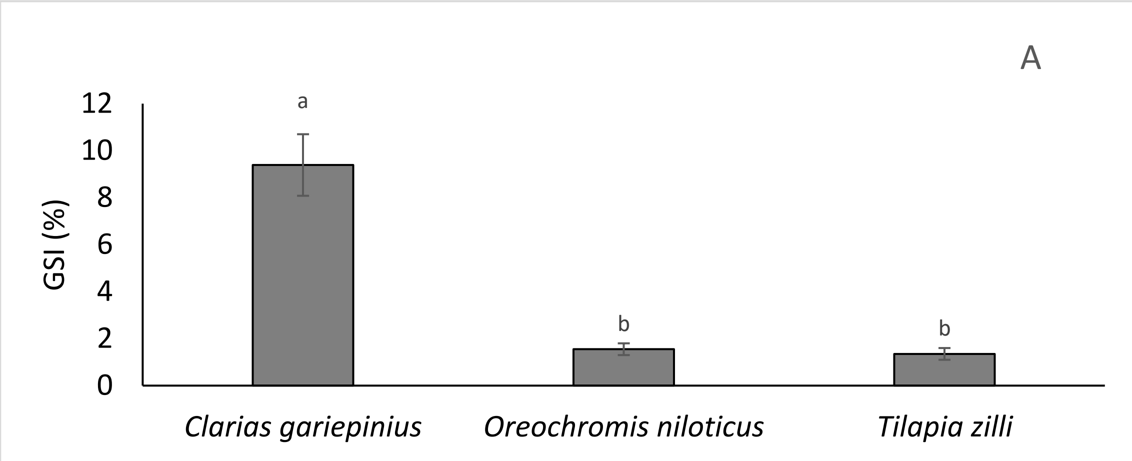

Figure 2A. Gonadosomatic index of the selected fish species in Benue River. Bars with different alphabet labels were significantly different ($p < 0.05$)

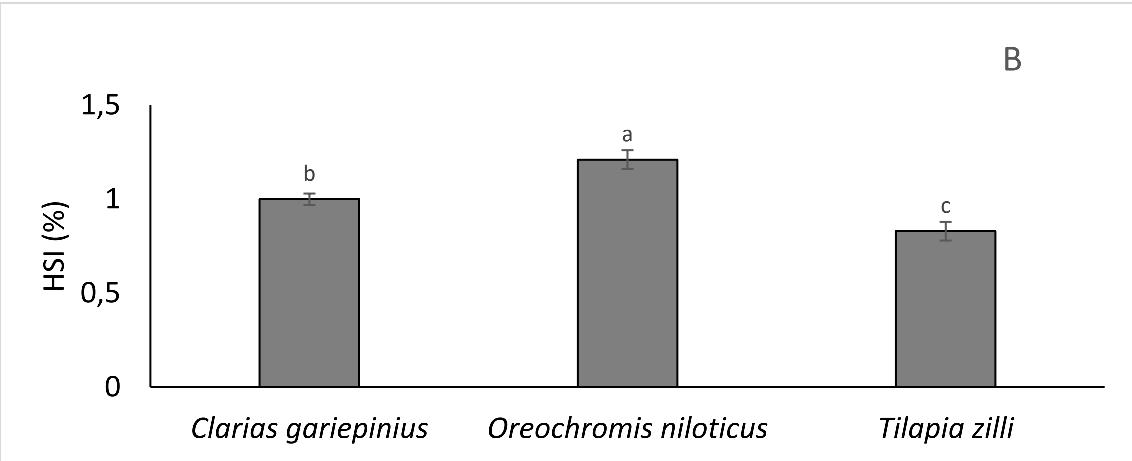

Figure 2B. Hepatosomatic index of the selected fish species in Benue River. Bars with different alphabet labels were significantly different ($p < 0.05$)

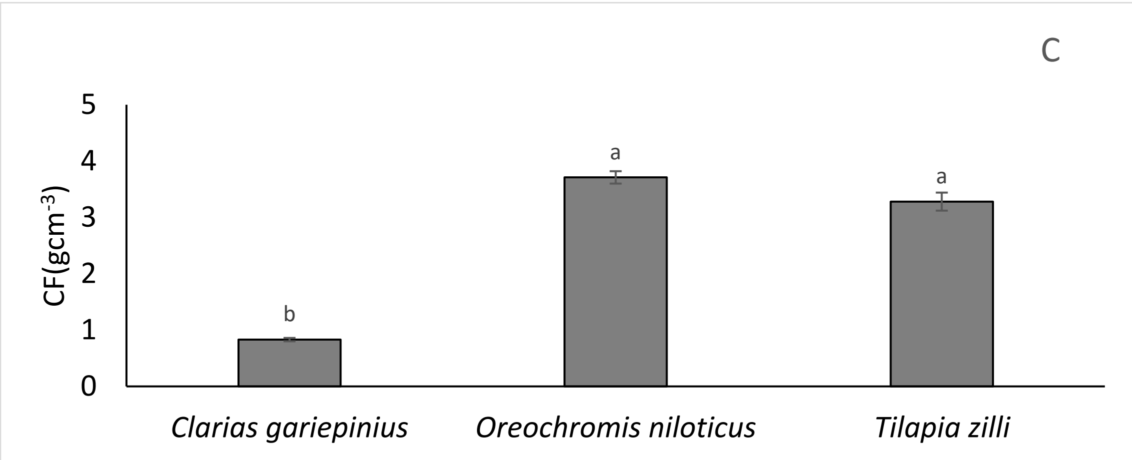

Figure 2C: Condition factor index of the selected fish species in the Benue River. Bars with different alphabet labels were significantly different ($p < 0.05$)

Haematological Status of Fish in the Benue River

Mean haematological values of fish in the Benue River are presented in Table 3. Haemoglobin (Hb) concentration (9.10 g/dl) was significantly below the optimal range ($p = 0.021$), while white blood cell (WBC) count (8753.70×10^9 cells/L) was markedly elevated ($p < 0.001$). Packed cell volume (PCV), red blood cell (RBC) count, mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), and mean corpuscular haemoglobin concentration (MCHC) did not differ significantly ($p > 0.05$).

Table 3. Haematological status of fish in the Benue River

Parameter	Mean values	*p*
Haematological		
PCV (%)	23.81 (23.47 – 24.13)	0.937
RBC (cells/L)	10.27 (10.18 – 10.39)	0.162
Hb (g/dl)	9.10 (10.11 – 10.29)	0.021
WBC (cells/L)	8753.70 (8413.67 – 8693.74)	< 0.001
MCV (fl)	23.43 (22.62 – 24.56)	0.634
MCH (pg)	9.91 (9.66 – 10.13)	0.709
MCHC (g/dl)	42.84 (40.65 – 45.02)	0.386

Values are mean ± SD. (95% confidence interval)

Table 4. Seasonal haematological changes of fish species in Benue River

Parameters	**Season**		
	Dry	Rainy	*P*
PCV (%)	26.07 ± 1.49	21.56 ± 2.76	< 0.0001
RBC (cells/L)	10.43 ± 0.38	10.02 ± 0.60	0.068
Hb (g/dl)	9.87 ± 0.61	10.37 ± 0.56	< 0.0001
WBC (cells/L)	9814.81 ± 1034.21	9350.00 ± 1536.32	< 0.0001
MCV (fl)	24.97 ± 1.43	21.62 ± 3.26	< 0.0001
MCH (pg)	9.48 ± 0.67	10.38 ± 0.82	< 0.0001
MCHC (g/dl)	38.01 ± 2.87	49.02 ± 7.85	< 0.0001

Values as mean (95% confidence interval)

Seasonal haematological profiles are presented in Table 4. PCV, WBC, and MCV were significantly higher in the dry season, whereas Hb, MCH, and MCHC were significantly elevated in the rainy season (all $p < 0.0001$).

Species-specific haematological values are presented in Table 5. Hb and PCV were significantly higher in *Clarias gariepinus* than in *Coptodon zillii* and *Oreochromis niloticus* ($p < 0.05$), while O. niloticus exhibited a significantly elevated WBC count relative to the other species. RBC, MCV, and MCH did not differ significantly among species.

Table 5. Haematological status of selected fish species in Benue River

Parameter	Fish species	Mean Values
PCV (%)	*Clarias gariepinus*	25.38 (24.82 – 25.96)***
	Coptodon zillii	22.73 (22.15 – 23.30)*
	Oreochromis niloticus	23.29 (22.70 – 23.85)**
RBC (cells/L)	*Clarias gariepinus*	10.28 (10.09 – 10.45)
	Coptodon zillii	10.27 (10.10 – 10.46)
	Oreochromis niloticus	10.31 (10.12 – 10.48)
Hb (g/dl)	*Clarias gariepinus*	10.24 (10.08 – 10.39)***
	Coptodon zillii	10.22 (10.06 – 10.36)**
	Oreochromis niloticus	10.13 (9.99 – 10.30)*
WBC (cells/L)	*Clarias gariepinus*	8072.22 (7829.67 – 8314.78)**
	Coptodon zillii	8711.11 (8468.56 – 8953.66)*
	Oreochromis niloticus	8877.78 (8635.23 – 9120.33)***
MCV (fl)	*Clarias gariepinus*	22.23 (20.86 – 23.58)
	Coptodon zillii	24.47 (23.10 – 25.82)
	Oreochromis niloticus	23.64 (22.28 – 24.99)
MCH (pg)	*Clarias gariepinus*	9.72 (9.32 – 10.15)
	Coptodon zillii	9.98 (9.58 – 10.41)
	Oreochromis niloticus	9.97 (9.54 – 10.38)
MCHC (g/dl)	*Clarias gariepinus*	44.87 (41.15 – 48.60)
	Coptodon zillii	41.13 (37.42 – 44.86)
	Oreochromis niloticus	42.49 (38.76 – 46.20)

*Values are mean (95% confidence interval). *Significant difference from counterpart species in the river (p < 0.05).*

Liver Enzyme Status of Fish in the Benue River

Seasonal liver enzyme activities are presented in Table 6 and Figure 3. Aspartate aminotransferase (AST) was significantly elevated in both the dry season (41.93 ± 3.72 U/L) and rainy season (41.78 ± 4.51 U/L) (both $p < 0.0001$). Alanine aminotransferase (ALT) was significantly elevated in the dry season (39.59 ± 4.29 U/L, $p < 0.0001$) but not in the rainy season (37.33 ± 6.05 U/L, $p = 0.113$). Alkaline phosphatase (ALP) was significantly elevated in both seasons, with the highest mean recorded in the rainy season (62.89 ± 6.20 U/L, $p < 0.0001$) compared with the dry season (60.04 ± 6.00 U/L, $p < 0.0001$).

Table 6. Mean of seasonal liver enzyme changes of fish species in the Benue River

Parameters	Season	Values	P
AST (U/L)	Dry	41.93 ± 3.72	< 0.0001
	Rainy	41.78 ± 4.51	< 0.0001
ALT (U/L)	Dry	39.59 ± 4.29	< 0.0001
	Rainy	37.33 ± 6.05	0.113
ALP (U/L)	Dry	60.04 ± 6.00	< 0.0001
	Rainy	62.89 ± 6.20	< 0.0001

Values as mean (95% confidence interval)

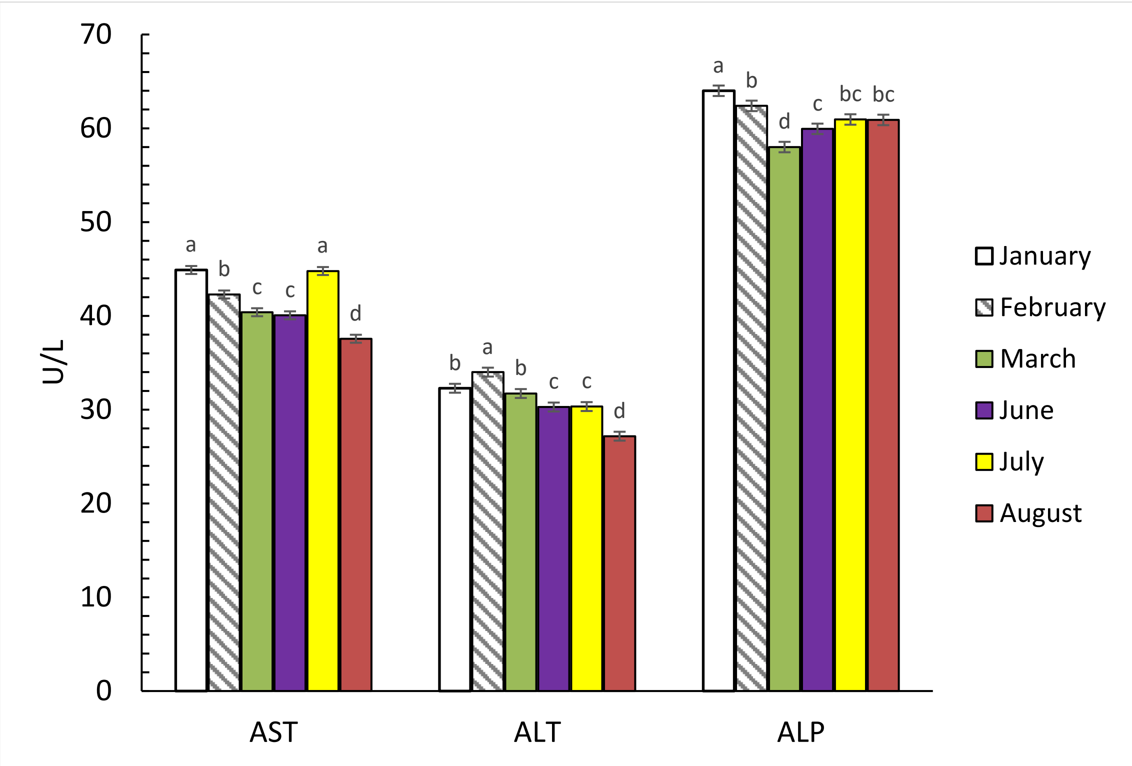

Figure 3. Month-by-month fluctuations in Liver Enzyme AST, ALT, and ALP. Bars with different letter labels were significantly different ($p < 0.05$)

Oxidative Stress Biomarker Status of Fish in the Benue River

Mean oxidative stress biomarker values are presented in Table 7. Catalase (CAT), superoxide dismutase (SOD), malondialdehyde (MDA), glutathione peroxidase (GPx), glutathione reductase (GR), and lipid peroxidation (LPO) were all significantly elevated ($p < 0.001$).

Table 7. Oxidative stress biomarkers of fish species in Benue River

Parameter	Mean Values	*p*
SOD (mg/dl)	10.22 (10.01 – 10.40)	< 0.001
CAT (mg/dl)	4.62 (4.49 – 4.78)	< 0.001
MDA (mg/dl)	2.67 (2.46 – 2.85)	< 0.001
GSH (µmol/L**)**	6.21 (6.04 – 6.37)	0.758
GPx (µmol/L**)**	7.58 (7.39 – 7.75)	< 0.001
LPO (µmol/L**)**	22.27 (22.02 – 22.54)	< 0.001
GR (µmol/L**)**	14.09 (13.88 – 14.27)	< 0.001

Values are mean (95% confidence interval).

Seasonal variation in oxidative stress biomarkers is presented in Table 8. SOD, CAT, MDA, GPx, and LPO were significantly elevated in both seasons ($p < 0.0001$). GR was significant in the dry season ($p = 0.002$) and highly significant in the rainy season ($p < 0.0001$). GSH showed no significant seasonal variation (dry: $p = 0.976$; rainy: $p = 0.683$).

Table 8. Seasonal oxidative stress changes in fish species of the Benue River

Parameters	Season	Mean Values	*P*
SOD (mg/dl)	Dry	7.80 ± 0.90	< 0.0001
	Rainy	8.22 ± 0.95	< 0.0001
CAT (mg/dl)	Dry	1.98 ± 0.59	< 0.0001
	Rainy	2.02 ± 0.71	< 0.0001
MDA (mg/dl)	Dry	6.10 ± 0.83	< 0.0001
	Rainy	6.86 ± 1.00	< 0.0001
GSH (µmol/L)	Dry	6.31 ± 1.56	< 0.976
	Rainy	6.15 ± 0.38	0.683
GPx (µmol/L)	Dry	9.68 ± 0.92	< 0.0001
	Rainy	9.53 ± 0.81	< 0.0001
LPO (µmol/L)	Dry	19.06 ± 1.22	< 0.0001
	Rainy	18.87 ± 1.53	< 0.0001
GR (**µmol/L**)	Dry	14.12 ± 1.04	0.002
	Rainy	12.07 ± 1.26	< 0.0001

Values are mean ± SD. (with 95% confidence interval).

Species-specific oxidative stress biomarker values are presented in Table 9. Significant differences ($p < 0.05$) were observed among species for SOD, CAT, GSH, LPO, and GR. MDA and GSH varied significantly within Clarias gariepinus, while GPx showed no significant variation among species. No significant differences in GSH or MDA were recorded for Oreochromis niloticus and Coptodon zillii.

Table 9. The Oxidative Stress Status of Selected Fish Species in the Benue River

Parameters	Fish Species	Values
SOD (mg/dl)	*Clarias gariepinus*	10.08 (9.75 – 10.42)*
	Coptodon zillii	10.21 (9.87 – 10.54)* *
	Oreochromis niloticus	10.32 (10.00 – 10.67)* **
CAT (mg/dl)	*Clarias gariepinus*	4.80 (4.55 – 5.06)* **
	Coptodon zillii	4.57 (4.31 – 4.82)* *
	Oreochromis niloticus	4.51 (4.26 – 4.77)*
MDA (mg/dl)	*Clarias gariepinus*	2.63 (2.28 – 2.96)
	Coptodon zillii	2.77 (2.44 – 3.12)
	Oreochromis niloticus	2.57 (2.22 – 2.91)
GSH (µmol/L)	*Clarias gariepinus*	6.52 (6.22 – 6.80)*
	Coptodon zillii	6.04 (5.76 – 6.34)
	Oreochromis niloticus	6.04 (5.76 – 6.34)
GPx (µmol/L**)**	*Clarias gariepinus*	7.54 (7.22 – 7.84)
	Coptodon zillii	7.63 (7.33 – 7.95)
	Oreochromis niloticus	7.53 (7.23 – 7.85)
LPO (µmol/L**)**	*Clarias gariepinus*	23.33 (22.29 – 23.79)* **
	Coptodon zillii	21.62 (21.16 – 22.06)*
	Oreochromis niloticus	21.88 (21.44 – 22.34)* *
GR (µmol/L**)**	*Clarias gariepinus*	14.73 (14.38 – 15.06)* **
	Coptodon zillii	13.64 (13.30 – 13.97)*
	Oreochromis niloticus	13.87 (13.54 – 14.21)* *

*Values are mean (95% confidence interval). *Significantly different from counterpart species in the river ($p < 0.05$)*

Discussions

The physicochemical characteristics of the Benue River at the abattoir site during the study period are presented (Table 1). Temperature (27.59 ± 1.40) was significantly higher ($p > 0.05$) during the dry season. Fluctuations in river water temperature are generally affected by seasonal conditions, geographical setting, sampling time, and the temperature of effluents released into rivers (Kebede et al., 2014). Variations in temperature influence water quality by altering conductivity and the solubility of dissolved gases, particularly oxygen and carbon dioxide, thereby increasing the risk of respiratory stress in aquatic organisms (Awgchew et al., 2015).

The elevated levels of biological oxygen demand (BOD), dissolved oxygen (DO), total alkalinity, total hardness, and transparency (Table 1), as well as the variations in other physicochemical properties of the Benue River, are consistent with the findings reported by Sharma and WalIa (2017), who reported higher levels of these parameters in the Satluj River, indicating that pollution was mainly attributed to siltation, domestic and municipal waste, industrial effluents, and surface runoff, all of which directly or indirectly affect water quality.

In general, the pH values remained within the acceptable limits established by the National Environmental Standards and Regulations Enforcement Agency (NESREA) (2011), although fluctuations were observed across the sampling months. Elevated pH levels may enhance the toxicity of certain pollutants, and because many aquatic organisms are highly sensitive to changes in pH, conditions that exceed their tolerance range can lead to declines in population abundance and shifts in species distribution and community composition (Awgchew et al., 2015). These changes can directly impact organism physiology, often leading to a weakened biological community dominated by a few pH-tolerant species.

The ammonia nitrogen concentration (0.50 ± 0.12) exceeded the NESREA permissible limit (0.05), likely due to abattoir discharge and municipal wastewater from Makurdi town, aligning with the observations of Yimer and Geberkidan (2020), who observed that ammonia levels exceeded the WHO permissible limit in the Awash River Basin. According to Moloantoa et al. (2022), in aquatic environments, nitrite (NO_2) can form through the deamination of ammonium nitrogen originating from nitrogenous compounds or untreated waste and is subsequently converted to nitrate by microbial activity. Ammonia (NH_3) serves as an indicator of potential bacterial contamination, sewage, and animal waste pollution (Yimer & Geberkidan, 2020), and becomes more toxic, which can adversely harm aquatic biota.

Monthly comparisons showed no significant differences ($p > 0.05$), and the variations did not follow a clear pattern. Seasonal analysis indicated higher temperatures in the dry season, whereas the biological oxygen demand (BOD) was greater during the rainy season. Both parameters differed significantly between seasons, with overall physicochemical values exhibiting considerable fluctuations (Table 2; $p > 0.05$)

The water exhibited relatively high biological oxygen demand (BOD) values (4.03 ± 0.13 mg L^{-1}), with the highest levels recorded during the rainy season (Tables 1 and 2). These values exceeded the maximum allowable limit of 3.0 mg L^{-1} established by the National Environmental Standards and Regulations Enforcement Agency (NESREA) (2011). Elevated biological oxygen demand (BOD) gives rise to a reduction of dissolved oxygen levels in aquatic environments, thereby limiting oxygen availability and impairing the decomposition of organic matter. The major contributors to BOD were likely biodegradable organic wastes originating from abattoir discharges and domestic waste entering the river system. These high BOD levels are consistent with the findings of Yimer and Geberkidan (2020), who attributed elevated BOD levels to the abundance of organic matter in water bodies. This may be associated with the accumulation of decomposing algal biomass and untreated industrial effluents, as noted by Jonathan et al. (2008), as well as the toxic effects of various chemical contaminants and heavy metals present in the aquatic environment.

Morphometrics of Fish Species in Benue River

Morphometric parameters varied among the fish species in the river. All three indices showed species-specific differences ($p < 0.05$; Figure 2A–C). *Clarias gariepinus* exhibited a significantly higher gonadosomatic index (GSI) than *Oreochromis niloticus* and *Coptodon zillii* (Figure 2A), with the difference exceeding threefold, while *C. Zillii* and *O. niloticus* showed comparable GSI values. The high gonadosomatic index (GSI) of *Clarias gariepinus* indicates strong adaptation to riverine conditions, supporting successful reproduction and establishment. Variations in reproductive stages and gonadal hormone levels among river-caught individuals likely enhance colonization, with *C. gariepinus* remaining more gravid than other species during the spent season due to fecundity increasing with body size, allometric growth patterns, and rainfall-driven spawning. This result agrees with the Findings of Singh et al. (2021) on morphometric traits and gonadal plasticity, which provided the first indication of invasion success in the African catfish (*Clarias gariepinus*) in the Ganga River.

The hepatosomatic index (HSI) showed significant variation among the species, with the highest value recorded in O. niloticus and the lowest in C. zillii (Figure 2B). This pattern was associated with elevated gonadosomatic index (GSI) values, which tended to coincide with lower HSI values. The HSI is commonly used as an indicator of energy storage in fish, reflecting the transfer of energy reserves from the liver to the gonads during reproductive development. A similar report by Abdel-Mohsen et al. (2017) indicated seasonal differences in the hepatosomatic index (HSI) and gonadosomatic index (GSI) of *Portunus pelagicus* along the Mediterranean coast of Alexandria, Egypt, indicating that the investigated sites experienced comparable environmental conditions. Gonadal development was sustained by energy mobilized from the liver, resulting in a corresponding decrease in the HSI. Variations in GSI and HSI among individuals of both species further suggest that the analyzed specimens were at different stages of gonadal maturation.

The condition factor reflects the overall well-being of fish within their habitat. It integrates biological and ecological influences, particularly feeding conditions. Food availability in aquatic systems is shaped by changes in water chemistry, which are driven by atmospheric and environmental variations (Agumassie, 2018). According to Jisr et al. (2018), fish with elevated K values were in a better condition than fish with lower K values with respect to their lengths. Therefore, *C. gariepinus*, which has the lowest condition factor, suggests that seasonal changes in food availability and quality, as well as fluctuations in water level, flow velocity, and temperature, influence its condition factor. Whereas *O. niloticus* and *C. zillii* exhibited higher values, which indicated higher body condition, this reflects what corresponds to the work by Agumassie (2018), fish with elevated K values were in a better condition than fish with lower K values with respect to their lengths. Therefore, *C. gariepinus*, which has the lowest condition factor, suggests that seasonal changes in food availability and quality, as well as fluctuations in water level, flow velocity, and temperature, influence its condition factor. Whereas *O. niloticus* and *C. zillii* exhibited higher values, indicating that higher body condition corresponded to the work by Teffera et al. (2019), who observed that water quality in Lake Chamo has deteriorated markedly due to poor land use practices, including fertilizer application, nutrient enrichment, and intensified agriculture. These activities degrade water quality and impose physiological stress on fish, adversely affecting their body conditions. Similarly, Tesfahun (2018) attributed intense anthropogenic pressure from shoreline farming, buffer-zone degradation, and industrial effluent discharges from textile, ceramic, and tannery industries in Ethiopian Rift Valley lakes such as Ziway, Langano, Hawassa, Koka, and Beseka, which affected the condition factor of fish.

Haematological Status of Fish in Benue River

The haematological condition of fish in the Benue River was notably affected by environmental factors. Haemoglobin (Hb) levels (9.20 g/dl) were below the optimal range for the river fish species ($p < 0.05$), whereas white blood cell (WBC) counts (8753.70 $\times 10^9$ cells/L) were markedly higher ($p < 0.001$). Blood is a crucial indicator of overall health, and haematological parameters are mostly used to assess the physiological conditions of animals exposed to toxins. The observed reduction in Hb (Table 3) may compromise oxygen transport and increase the vulnerability of river fish. This finding corresponds with Ahmed et al. (2022), in their study on aquatic intoxication, they noted that reduced hemoglobin levels can trigger internal changes that compromise red blood cell membrane stability, increasing fragility, and potentially causing abnormal cell shapes (e.g., spherocytosis), shortened erythrocyte lifespan, and a reduced capacity to respond to chemical or drug-induced stress.The marked rise in white blood cell counts (Table 3) indicates tissue damage from infection, with cells proliferating to combat infection, heightened physiological stress, or pathological conditions such as leukemia. The findings are also similar to those of Habib et al. (2021), who reported that contaminated ions in aquatic environments can accumulate in fish tissues, leading to physiological disruptions reflected by increased white blood cell counts, which indicate tissue damage from infection, intense stress, and sometimes leukemia.

The seasonal haematological profile of fish in the Benue River (Table 4) revealed that PCV, Hb, WBC, MCV, MCH, and MCHC were significantly affected ($p < 0.001$). PCV, WBC, and MCV were higher during the dry season, whereas Hb, MCH, and MCHC were significantly elevated in the rainy season. These variations in blood parameters are attributed to environmental conditions, physiological dysfunctions, water quality, and stressors related to feeding habits, which influence energy levels, oxygen consumption, and metabolic processes. This claim is supported by Zhelev et al. (2016), who report that starvation or inadequate nutrition can lower the frequency of erythroblasts, resulting in a decline in neutrophil lineage cells and a reduced rate of oxygen utilization. Conversely, elevated levels of neutrophils and monocytes in fish from polluted habitats may reflect increased detoxification activity of cellular breakdown products and serve as indicators of physiological stress. These responses are often associated with infections and also parasitic infestations, which together affect immune competence and metabolic processes under different seasonal, environmental, and habitat conditions. Furthermore, Ahmed et al. (2020) stated that Differences in fish haematological parameters can be attributed to variations in internal physiological conditions, along with intrinsic factors like age, body size, sexual maturity, health, species and nutritional status, as well as environmental factors such as temperature, stress, seasonal changes, dissolved oxygen, water quality, habitat type (lotic or lentic), stocking density, photoperiod, sampling methods, and laboratory techniques.

Environmental conditions significantly influenced the haematological characteristics of the three fish species studied. Haemoglobin (Hb) concentration and packed cell volume (PCV) were significantly higher ($p < 0.05$) in Clarias gariepinus compared with *Coptodon zillii* and Oreochromis niloticus (Table 5). Conversely, O. niloticus exhibited a significantly elevated white blood cell (WBC) count, suggesting a physiological adaptation to the prevailing dry-season conditions. In general, WBC levels were markedly increased across all species ($p < 0.05$). Significant seasonal variations ($p < 0.05$) were also detected in PCV and Hb values within each species, reflecting changes in oxygen-carrying capacity, as well as in WBC counts, which are involved in immune defense and the mobilization of physiological resources required to maintain homeostasis. These findings are consistent with the observations reported by Zhelev et al. (2016), stating that Age significantly affects haemoglobin concentration, which tends to increase as fish grow, likely reflecting seasonal growth patterns. These changes are shaped by both environmental and genetic factors and represent coordinated adjustments in immune and circulatory systems to optimize physiological function, while variations in white blood cell counts indicate immune activation through heightened phagocytic activity in response to seasonal and environmental influences.

Liver Enzymes Status of Fish in Benue River

In the liver function tests, seasonal variations were observed in enzyme activities (Figure 3, Table 6). Alanine aminotransferase (ALT) levels were significantly higher in fish during the dry season (January), while aspartate aminotransferase (AST) and alkaline phosphatase (ALP) activities were notably affected across both seasons (February and August; $p < 0.001$). ALT showed relatively elevated levels during the dry season, whereas ALP reached its lowest point in March (Figure 3). The significant seasonal increases ($p < 0.001$) suggest possible infection or inflammation, indicating that the fish experienced physiological stress during the study period. These findings align with the report by Zheng et al. (2022), who reported that liver function in captive Chinese sturgeons is adversely affected by seasonal variations, with the highest levels of hepatic impairment observed. He also noted that the AST: ALT ratio serves as an invasive indicator of liver fibrosis and cirrhosis, where a ratio below 1 reflects healthy liver function, while a ratio above 1 indicates significant liver damage and impaired function.

Alkaline phosphatase (ALP) is a membrane-bound glycoprotein enzyme widely distributed in body tissues, responsible for catalyzing the hydrolysis of phosphomonoesters under alkaline conditions. It exists in four major isozyme forms depending on its tissue of origin and is classified as a metallophosphatase. ALP is regarded as an important biomarker of cellular physiological status(Banaee, 2020). Therefore. This aligns with Bojarski et al. (2025), who confirmed that increased ALP activity is often associated with impaired liver function, adding that toxicity-induced alterations in fish blood biochemical parameters are strongly influenced by both contaminant concentration and exposure duration. They further noted that organisms may exhibit varying sensitivity and response patterns, and that such biochemical changes can serve as reliable indicators of physiological stress or organ-specific dysfunction in fish.

Oxidative Biomarkers Status of Fish Species in Benue River

The mean values of oxidative stress biomarkers indicated that catalase (CAT), superoxide dismutase (SOD), malondialdehyde (MDA), glutathione peroxidase (GPx), glutathione reductase (GR), and lipid peroxidation (LPO) were highly significant ($p < 0.001$) in the river (Table 7). These biomarkers also exhibited strong seasonal variations, as SOD, CAT, MDA, GPx, LPO, and GR were all significantly affected across seasons in river fish ($p < 0.001$) (Table 8). All assessed oxidative stress biomarkers showed significant changes, except for reduced glutathione (GSH), which did not vary significantly ($p < 0.05$). In addition, GR during the dry season did not express a substantial difference ($p < 0.05$) in the river fish. Overall, the results suggest that oxidative stress responses in river fish were markedly influenced by seasonal conditions, with GSH the exception. Reactive oxygen species (ROS) are generated through various processes associated with environmental pollutants. Fish living in contaminated aquatic habitats are exposed to numerous oxygen radicals, which can cause oxidative damage to different biomolecules, including lipids and proteins. The actions of antioxidant enzymes and the amount of free radical scavengers are associated with various physiological and pathological states, including stress (Chaudhary et al., 2023). Stress is known to trigger a range of biochemical, physiological, and behavioral responses that disrupt normal body homeostasis. Moreover, the production of reactive oxygen species (ROS) in the blood compromises the antioxidant defense mechanisms required to counteract oxidative stress (Velkova-Jordanoska et al., 2008). The mean values and seasonal assessment of antioxidant biomarkers, including malondialdehyde (MDA), superoxide dismutase (SOD), reduced glutathione (GSH), glutathione peroxidase (GPx), and glutathione S-transferase (GST), showed significant ($p < 0.05$) increases (Tables 7 and 8). These findings are consistent with the observations reported by [Author(s)], Arojojoye et al. (2021), who similarly documented elevated antioxidant responses under comparable environmental conditions, which increase in the organs of fish collected from the Apata, Araromi, and Mahin rivers, to be attributed to pollution in these rivers, primarily resulting from oil spills and other industrial activities.

Glutathione S-transferase (GST) in the detoxification of environmental carcinogens, reactive nucleophiles, and epoxide intermediates. Additionally, Arojojoye et al. (2021) similarly reported a non-significant decrease ($p > 0.05$) in reduced glutathione (GSH) levels in the liver tissues of fish collected from the Benue River. Since pollutants are major contributors to oxidative stress, their presence in aquatic environments may lead to either an increase or a decrease in glutathione S-transferase (GST) and GSH levels, reflecting adaptive physiological responses to oxidative challenges. Habib et al. (2021) observed an induction of GST activity in fish livers following exposure to environmental contaminants.

The pollutants likely triggered the production of superoxide anions, resulting in increased superoxide dismutase (SOD) activity as the enzyme acts to neutralize them by changing all of them into less harmful hydrogen peroxide (H_2O_2). Superoxide radicals are precursors to several highly reactive species, and their regulation by SOD is a crucial component of cellular defense mechanisms (Ramesh *et al*., 2018). Superoxide dismutase enzymatically removes toxic superoxide radicals, thereby protecting organisms from oxygen-related toxicity (Ponnampalam et al., 2022). Furthermore, antioxidant defense systems are known to be upregulated following pollutant exposure, indicating an adaptive response of species to environmental stressors.

When species-specific responses were examined, significant differences ($p < 0.05$) were found in oxidative stress biomarkers in the river (Table 9). Marked variations were observed in superoxide dismutase (SOD) and lipid peroxidation (LPO) among the studied fish species, as well as in malondialdehyde (MDA) and glutathione (GSH) levels in *Clarias gariepinus.* Conversely, glutathione peroxidase (GPx) activity showed no significant variation, and no notable changes in GSH or MDA were recorded for *Oreochromis niloticus* and *Coptodon zillii*. These differences likely indicate species-dependent capacities to regulate antioxidant enzymes in response to environmental stress, along with varying levels of pollutant exposure, possibly influenced by seasonal fluctuations in contaminants. Elevated antioxidant enzyme activity helps neutralize reactive oxygen species (ROS); however, oxidative stress arises when ROS production exceeds antioxidant defense. Lipid peroxidation (LPO) is a recognized indicator of environmental pollution, as xenobiotics and their metabolites induce oxidative stress by generating free radicals that damage membrane lipids, DNA, and proteins (Ogueji et al., 2020). Previous studies have shown that low pollutant levels can stimulate antioxidant enzyme activity, whereas higher concentrations may suppress or diminish these activities (Hongxing et al., 2021; Imtiaz et al., 2015; Mirghaed et al., 2020). Based on the seasonal and species-specific variations observed in antioxidant enzyme activities in these freshwater fish, the findings of this study indicate that contaminant-induced toxicity in the Benue River may have contributed to the negative effects recorded in the antioxidant status of organisms within this ecosystem.

Conclusion

This study demonstrates that the fish populations in the Benue River at the abattoir area are impacted by the alteration in water quality levels, physicochemical parameters, as indicated by NESREA (2011), surface water permissible level for fisheries standard, except for ammonia nitrogen, which exceeded the permissible limits, because it is receiving abattoir effluents within the Benue Basin, Nigeria. The findings of this study revealed significant interspecific variations in morphometric indices. *Clarias gariepinus* recorded a substantially higher gonadosomatic index, suggesting superior reproductive investment and adaptation, whereas *Oreochromis niloticus* possessed higher energy reserves, as indicated by its elevated hepatosomatic index. Furthermore, the significant alterations observed in both enzymatic and non-enzymatic antioxidant defense mechanisms serve as indicators of oxidative stress. Haematological parameters revealed suboptimal haemoglobin levels and elevated white blood cell counts, suggesting physiological stress and possible environmental perturbations in the river ecosystem. Seasonal variations significantly influenced blood profiles, liver enzyme activities, and metabolic processes, highlighting the role of environmental conditions and stressors in shaping fish health. Finally, pronounced fluctuations in oxidative stress biomarkers indicate that riverine fish are exposed to pollutant-induced stress, highlighting the need for continuous environmental monitoring and management while raising public health concerns for local communities reliant on the river, who may face increased risks of chronic degenerative conditions.

Acknowledgements

This study was supported by the Department of Fisheries and Aquaculture, Joseph Sarwuan Tarka University (Formally known as Federal University of Agriculture), Makurdi, Benue State, Nigeria.

References

Abdel-Kader, H. H., & Mourad, M. H. (2020). Trace elements exposure influences proximate body composition and antioxidant enzyme activities of the species tilapia and catfish in Burullus Lake—Egypt: human risk assessment for the consumers. *Environmental Science and Pollution Research*, *27*(35), 43670–43681. https://doi.org/10.1007/s11356-020-10207-2

Abdel-Mohsen, H. A., Atta, A. R. I., Moussa, F. I., El-Gendy, A. H., & M Abdou, H. A. (2017). Study on GSI and HSI of Portunus pelagicus at two polluted areas along the Coast of Alexandria, Egypt. *Journal of King Abdulaziz University: Marine Sciences*, *27*(2). https://doi.org/10.4197/Mar.27-6

Agumassie, T. (2018). Overview of length-weight relationship, condition factor and size at first maturity of Nile tilapia Oreochromis niloticus (L.) in different water bodies of Ethiopia: A review. *Greener Journal of Biological Sciences*, *8*(3), 021–028. http://doi.org/10.15580/GJBS.2018.3.060618077

Ahmed, I., Reshi, Q. M., & Fazio, F. (2020). The influence of the endogenous and exogenous factors on hematological parameters in different fish species: a review. *Aquaculture international*, *28*(3), 869–899. https://doi.org/10.1007/s10499-019-00501-3

Ahmed, I., Zakiya, A., & Fazio, F. (2022). Effects of aquatic heavy metal intoxication on the level of hematocrit and hemoglobin in fishes: a review. *Frontiers in Environmental Science*, *10*, 919204. https://doi.org/10.3389/fenvs.2022.919204

Akhtar, N., Syakir Ishak, M. I., Bhawani, S. A., & Umar, K. (2021). Various natural and anthropogenic factors responsible for water quality degradation: A review. *Water*, *13*(19), 2660. https://doi.org/10.3390/w13192660

Amaeze, N. H., Komolafe, B. O., Salako, A. F., Akagha, K. K., Briggs, T.-M. D., Olatinwo, O. O., & Femi, M. A. (2020). Comparative assessment of the acute toxicity, haematological and genotoxic effects of ten commonly used pesticides on the African Catfish, Clarias gariepinus Burchell 1822. *Heliyon*, *6*(8). https://doi.org/10.1016/j.heliyon.2020.e04768

Anhwange, B. A., Agbaji, E. B., & Gimba, E. C. (2012). Impact assessment of human activities and seasonal variation on River Benue, within Makurdi Metropolis. *International Journal of Science and Technology*, *2*(5), 248–254.

Arojojoye, O. A., Oyagbemi, A. A., Ola-Davies, O. E., Asaolu, R. O., Shittu, Z. O., & Hassan, B. A. (2021). Assessment of water quality of selected rivers in the Niger Delta region of Nigeria using biomarkers in Clarias gariepinus. *Environmental Science and Pollution Research*, *28*(18), 22936–22943. https://doi.org/10.1007/s11356-020-11879-6

Awgchew, H., Gebrekidan, H., & Molla, A. (2015). Effects of municipal and industrial discharges on the quality of Beressa river water, Debre Berhan, Ethiopia. *Journal of Ecology and The Natural Environment*, *7*(2), 23–28. https://doi.org/10.5897/JENE2015.0495

Banaee, M. (2020). Alkaline phosphatase activity as a biochemical biomarker in aqua-toxicological studies. *International Journal of Aquatic Biology*, *8*(2), 143–147. https://doi.org/10.22034/ijab.v8i2.880

Bojarski, B., Witeska, M., & Kondera, E. (2025). Blood Biochemical Biomarkers in Fish Toxicology—A Review. *Animals*, *15*(7), 965. https://doi.org/10.3390/ani15070965

Burchell, W. J. (1822). *Travels in the interior of Southern Africa. Volume 2*. London: Printed for Longman, Hurst, Rees, Orme, and Brown.

Chaudhary, P., Janmeda, P., Docea, A. O., Yeskaliyeva, B., Abdull Razis, A. F., Modu, B., Calina, D., & Sharifi-Rad, J. (2023). Oxidative stress, free radicals and antioxidants: potential crosstalk in the pathophysiology of human diseases. *Frontiers in chemistry*, *11*, 1158198.

Chen, H., & Luo, D. (2023). Application of haematology parameters for health management in fish farms. *Reviews in Aquaculture*, *15*(2), 704–737. https://doi.org/10.1111/raq.12753

Froese, R., Demirel, N., Coro, G., Kleisner, K. M., & Winker, H. (2017). Estimating fisheries reference points from catch and resilience. *Fish and Fisheries*, *18*(3), 506–526. https://doi.org/10.1111/faf.12190

Gervais, P. (1847). Sur les animaux vertébrés de l'Algerie envisagés sous le double rapport de la géographie zoologique et de la domestication.

Habib, S. S., Naz, S., Nawaz, S., Ameer, I., Khatoon, A., Rehman, H. U., Jawad, S. M., & Ali, H. (2021). Comparative analysis of hematological parameters of some farmed and wild fish species. *Pakistan Journal of Zoology, 54*(2), 591–598. https://dx.doi.org/10.17582/journal.pjz/20200124050118

Hongxing, G., Xiafei, L., Jialing, L., Zhenquan, C., Luoyu, G., Lei, L., Yuxuan, S., Zhiguo, D., & Min, W. (2021). Effects of acute ammonia exposure on antioxidant and detoxification metabolism in clam Cyclina sinensis. *Ecotoxicology and Environmental Safety, 211*, 111895. https://doi.org/10.1016/j.ecoenv.2021.111895

Imtiaz, M., Tu, S., Xie, Z., Han, D., Ashraf, M., & Rizwan, M. S. (2015). Growth, V uptake, and antioxidant enzymes responses of chickpea (Cicer arietinum L.) genotypes under vanadium stress. *Plant and Soil, 390*(1), 17–27. https://doi.org/10.1007/s11104-014-2341-0

Jisr, N., Younes, G., Sukhn, C., & El-Dakdouki, M. H. (2018). Length-weight relationships and relative condition factor of fish inhabiting the marine area of the Eastern Mediterranean city, Tripoli-Lebanon. *Egyptian Journal of Aquatic Research, 44*(4), 299–305. https://doi.org/10.1016/j.ejar.2018.11.004

Jokam Nenkam, T. L. L., Kringel, R., Fantong, W. Y., Nbendah, P., Fouépé Takoundjou, A., Elisabeth, Z., & Kamtchueng, B. T. (2022). Hydrochemistry of nutrients in groundwater under farmland in the Benue River Basin, North-Cameroon. *Environmental Earth Sciences, 81*(7), 209. https://doi.org/10.1007/s12665-021-10146-2

Jonathan, M. P., Srinivasalu, S., Thangadurai, N., Ayyamperumal, T., Armstrong-Altrin, J. S., & Ram-Mohan, V. (2008). Contamination of Uppanar River and coastal waters off Cuddalore, Southeast coast of India. *Environmental Geology, 53*(7), 1391–1404. https://doi.org/10.1007/s00254-007-0748-0

Jungwirth, M., Muhar, S., & Schmutz, S. (2002). Re-establishing and assessing ecological integrity in riverine landscapes. *Freshwater biology, 47*(4), 867–887.

Kebede, M. T., Nair, A. S., & Dawit, M. (2014). The impact of urban and rural land use types on water quality of Meki River in Sodo Wereda, Gurage zone, Snnprs, Euthopia. *Journal of Aquatic Biology and Fisheries, 2*, 376–389.

Kumar, N., Krishnani, K. K., Gupta, S. K., & Singh, N. P. (2017). Cellular stress and histopathological tools used as biomarkers in Oreochromis mossambicus for assessing metal contamination. *Environmental toxicology and pharmacology, 49*, 137–147. https://doi.org/10.1016/j.etap.2016.11.017

Madhav, S., Ahamad, A., Singh, A. K., Kushawaha, J., Chauhan, J. S., Sharma, S., & Singh, P. (2019). Water pollutants: sources and impact on the environment and human health. *Sensors in water pollutants monitoring: Role of material*, 43–62. https://doi.org/10.1007/978-981-15-0671-0_4

Mansou, A. T., Ashour, M., Ruiz, C. E., Kumar, N., & Esteban, M. A. (2023). Physiological performance of aquatic animals under farming-induced stress conditions. In (Vol. 14, pp. 1136611): Frontiers Media SA.

Menon, S. V., Kumar, A., Middha, S. K., Paital, B., Mathur, S., Johnson, R., Kademan, A., Usha, T., Hemavathi, K. N., & Dayal, S. (2023). Water physicochemical factors and oxidative stress physiology in fish, a review. *Frontiers in Environmental Science, 11*, 1240813.

Mirghaed, A. T., Paknejad, H., & Mirzargar, S. S. (2020). Hepatoprotective effects of dietary Artemisia (Artemisia annua) leaf extract on common carp (Cyprinus carpio) exposed to ambient ammonia. *Aquaculture, 527*, 735443.

Mishra, R. K. (2023). Fresh water availability and its global challenge. *British Journal of Multidisciplinary and Advanced Studies, 4*(3), 1–78.

Moloantoa, K. M., Khetsha, Z. P., Van Heerden, E., Castillo, J. C., & Cason, E. D. (2022). Nitrate water contamination from industrial activities and complete denitrification as a remediation option. *Water, 14*(5), 799.

Muliari, M., Zulfahmi, I., Akmal, Y., Karja, N. W. K., Nisa, C., Sumon, K. A., & Rahman, M. M. (2020). Toxicity of palm oil mill effluent on the early life stages of Nile tilapia (Oreochromis niloticus, Linnaeus 1758). *Environmental Science and Pollution Research, 27*(24), 30592–30599.

Ogidi, O. I., & Akpan, U. M. (2022). Aquatic biodiversity loss: impacts of pollution and anthropogenic activities and strategies for conservation. In *Biodiversity in Africa: potentials, threats and conservation* (pp. 421–448). Springer.

Ogili, F. I., Ali, D., Attamah, G. N., Aletan, U., Kelle, H. I., Chukwu, M. N., & Nwani, C. D. (2021). Morphometric, hematological and oxidative stress changes in Clarias gariepinus following sub-chronic exposure to tramadol. *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology, 248*, 109096.

Ogueji, E., Nwani, C., Mbah, C., Iheanacho, S., & Nweke, F. (2020). Oxidative stress, biochemical, lipid peroxidation, and antioxidant responses in Clarias gariepinus exposed to acute concentrations of ivermectin. *Environmental Science and Pollution Research, 27*(14), 16806–16815.

Ponnampalam, E. N., Kiani, A., Santhiravel, S., Holman, B. W. B., Lauridsen, C., & Dunshea, F. R. (2022). The importance of dietary antioxidants on oxidative stress, meat and milk production, and their preservative aspects in farm animals: Antioxidant action, animal health, and product quality—Invited review. *Animals, 12*(23), 3279.

Ramesh, M., Thilagavathi, T., Rathika, R., & Poopal, R. K. (2018). Antioxidant status, biochemical, and hematological responses in a cultivable fish Cirrhinus mrigala exposed to an aquaculture antibiotic Sulfamethazine. *Aquaculture, 491*, 10–19.

Rice, E. W., Bridgewater, L., & American Public Health, A. (2012). *Standard methods for the examination of water and wastewater* (Vol. 10). American public health association Washington, DC.

Sharma, N., & WalIa, Y. K. (2017). Water quality investigation by physicochemical parameters of Satluj River (Himachal Pradesh, India). *Magnesium*, *390*(190), 1368.

Sharma, S. C., Mukhtar, H., Sharma, S. K., & Murt, C. R. K. (1972). Lipid peroxide formation in experimental inflammation. *Biochemical Pharmacology*, *21*(8), 1210–1214.

Singh, A. K., Ansari, A., & Srivastava, S. C. (2021). Morpho-meristics, maturity stages, GSI and gonadal hormone plasticity of African catfish Clarias gariepinus (Burchell 1822) that invaded into the Ganga River, India. *The Journal of Basic and Applied Zoology*, *82*(1), 30.

Tahir, R., Ghaffar, A., Abbas, G., Turabi, T. H., Kausar, S., Xiaoxia, D., Naz, S., Jamil, H., Samra, R. S., & Abdelgayed, S. S. (2021). Pesticide induced hematological, biochemical and genotoxic changes in fish: a review. *Agrobiological records*, *3*, 41–57.

Teffera, F. E., Lemmens, P., Deriemaecker, A., Deckers, J., Bauer, H., Gamo, F. W., Brendonck, L., & De Meester, L. (2019). Why are Lake Abaya and Lake Chamo so different? A limnological comparison of two neighboring major Ethiopian Rift Valley lakes. *Hydrobiologia*, *829*(1), 113–124.

Tesfahun, A. (2018). Review in current problems of Ethiopian fishery: In case of human and natural associated impacts on water bodies. *Int. J. Fish. Aquat. Stud*, *6*(2), 94–99.

Velkova-Jordanoska, L., Kostoski, G., & Jordanoska, B. (2008). Antioxidative enzymes in fish as biochemical indicators of aquatic pollution. *Bulgarian Journal of Agricultural Science*, *14*(2), 235–237.

Yimer, Y. A., & Geberkidan, A. (2020). The pollution status of Awash River Basin (Ethiopia) using descriptive statistical techniques. *American Journal of Water Resources*, *8*(2), 56–68.

Zhelev, Z., Mollova, D., & Boyadziev, P. (2016). Morphological and hematological parameters of Carassius gibelio (Pisces: Cyprinidae) in conditions of anthropogenic pollution in Southern Bulgaria. Use of hematological parameters as biomarkers. *Trakia J. Sci*, *14*(1), 1–15.

Zheng, Y., Zhang, Y., Xie, Z., Shin, P. K. S., Xu, J., Fan, H., Zhuang, P., Hu, M., & Wang, Y. (2022). Seasonal changes of growth, immune parameters and liver function in wild Chinese Sturgeons under indoor conditions: implication for artificial rearing. *Frontiers in Physiology*, *13*, 894729.