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Evaluation of quality and health indicators in *Oreochromis Niloticus*: A comparative study of different sources

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Abstract

This study evaluated the physicochemical properties, hematological indices, proximate composition, and microbial profile of smoked *Oreochromis niloticus* sourced from dammed and undammed water bodies in Benue State, Nigeria, across wet (August/September 2025) and dry (January/February 2026) seasons. Results showed minor variations in pH, temperature, dissolved oxygen, and total dissolved solids, with consistently higher values in the dam. Electrical conductivity and biochemical oxygen demand differed significantly between sites, indicating variations in water quality. Hematological analysis revealed significantly higher white blood cell count, mean corpuscular hemoglobin, and mean corpuscular hemoglobin concentration in the dam fish. In contrast, red blood cell count and hematocrit were higher in river fish. Hemoglobin concentration and mean corpuscular volume showed no significant differences. Proximate analysis indicated higher levels of protein, fat, fiber, ash, and moisture in river fish compared to dam samples. Microbial assessment identified similar isolates in both sources; however, *Bacillus spp* and *Pseudomonas species* were detected only in the dam fish. These findings suggest mild physiological responses to environmental stressors, potentially linked to anthropogenic activities and pollution. The study highlights the need for improved water quality management, hygienic fish-handling practices, and continuous environmental monitoring to safeguard fish health and the sustainability of aquatic ecosystems.

Keywords: Benue cement dam, Buruku river, Haematology, Microbial load, Physicochemical parameters, Proximate analysis, Seasonal variations.

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Contents

Contribution of this paper to the literature

This study demonstrates how environmental conditions and human activities influence water quality, fish health, nutritional composition, and microbial safety in Oreochromis niloticus from dammed and river systems. The observed physiological, biochemical, and microbial differences highlight the impact of pollution and habitat variation on fish quality and potential public health risks. These findings emphasize the importance of effective water management, pollution control, and hygienic handling practices to ensure sustainable fisheries and food safety.

1. Introduction

Water quality has become a major concern for humanity in recent years; unlike other environmental components, water is irreplaceable. The water cycle forms the fundamental basis of both life processes and economic activities [1]. Water-soluble contaminants originating from industrial effluent, municipal discharges, agricultural soil leaching, and atmospheric inputs are quickly transported into natural water bodies. These pollutants break down or evaporate, while others combine to form insoluble compounds that settle out and become part of the sediment to pollute water [2]. A dam is a structure built across a flowing body of water to block, regulate, or slow its movement, often resulting in the formation of a reservoir, lake, or impoundment. The use of dams to harness rivers is an ancient practice found worldwide, and it has expanded significantly over time [3]. Dams provide numerous societal benefits that have also presented serious risks if they fail, and they may also affect the water quality of the streams on which they are constructed. Maintaining high water quality is vital for the health of streams, as excessively high temperatures and insufficient oxygen levels can significantly damage essential aquatic life [4]. Rivers, as freshwater ecosystems, are among the most vital resources for human use, yet they are highly susceptible to pollution because they are easily accessed for waste disposal [5]. Water pollution arises when waste materials alter the physical, chemical, thermal, or biological properties of water, leading to a decline in its quality and adverse effects on aquatic organisms as well as human use [6].

Physicochemical characteristics are crucial for evaluating water before its uses (i.e., drinking, household, agricultural, or industrial purposes); these measurements provide a clear understanding of its condition and suitability for safeguarding natural ecosystems [7]. Dam construction physically modifies and triggers chemical changes within the reservoir, affecting overall water quality. Consequently, these changes have ecological effects on downstream rivers and connected wetlands [8]. Freshwater ecosystems are progressively under pressure from various stressors, such as temperature changes, nutrient loading, acidification, habitat degradation, invasive species, and chemical pollution [9].

Nile tilapia (*Oreochromis niloticus*) is a cichlid species indigenous to Africa. It has been widely cultured across diverse environmental conditions and remains a key aquaculture species globally, especially in tropical and subtropical regions [10]. *Oreochromis niloticus* has been considered one of the most common freshwater-bred fish species worldwide, especially in African households, because of their market value, hardiness, omnivorous diet, easy farm management, low trophic level, taste, tolerance to stress induced by handling, and ability to grow and reproduce in poor water quality [11, 12]. Fish, due to their close reliance on aquatic environments, are especially vulnerable to pollution. Contaminants can enter their bodies through polluted food, direct absorption from water, or across permeable surfaces like the gills and skin [13]. After uptake, these substances are processed and gradually build up in their tissues and organs. Many of these substances from water pollution are highly toxic, not only to fish but also to organisms that form part of their food chain [14]. In fish, blood serves as a distinct interface between the external surroundings and the internal system. Therefore, any physical or chemical alteration in the environment is reflected in changes to blood characteristics [15]. Hematological analysis is a vital tool in fish health management, enabling the early detection and effective treatment of health issues. Due to their close interaction with the environment, fish readily exhibit physical signs of changes in environmental conditions, whether physical or chemical [16]. The hematological profile of a fish reflects its physiological condition and overall health. When combined with other routine diagnostic techniques, it serves as a useful tool for detecting and evaluating stressors and diseases that may impair its performance [17].

Fish, being the major product of aquaculture, is an important source of protein for the teeming population in developing nations [18]. However, it is one of the most highly perishable food commodities in the tropics. Fish spoils easily after harvest due to the high tropical temperature, which accelerates the activities of bacteria, enzymes, and chemical oxidation of fat in the fish. However, processing and preservation of fish extends its shelf life either through moisture or pH reduction, thereby retarding microbial activity [19]. Furthermore, microbial activities in food samples are of great concern, as they can significantly affect food safety and shelf life. Microorganisms such as bacteria, yeasts, and molds can spoil food and cause foodborne illnesses. Fish smoking, which is the most common method of preservation, serves primarily as a tool to enhance the flavor and texture of fish, thus producing value-added products. Smoking usually extends the shelf life of fish due to the reduced moisture content and the effects of imparted phenolic compounds [20]. Comparing natural water bodies like rivers, such as the Buruku River, with man-made systems like the Benue Cement Dam, helps reveal differences in their physical, chemical, and biological characteristics, as well as how these factors influence fish and related research. Fish health is closely tied to blood condition, making hematological analysis important for understanding both genetic and physiological status. Since fish are a valuable protein source, maintaining good water quality is essential for safe consumption, as well as revealing the quality and safety of different food sources, as well as how human activities affect natural resources [21, 22]. Assessing the physicochemical properties, blood parameters, nutritional quality, and microbial analysis of smoked *Oreochromis niloticus* from different environments provides a clearer picture of their health status, composition, and microbial activity, while also highlighting potential risks associated with fish from these sources.

2. Materials and Methods

2.1. Experimental Sites

One sampling site is the Benue Cement Dam, formed by damming the Ahungwa and Oratsor streams to provide water for industrial activities associated with the cement plant in Benue State. It is situated about 2 km northwest of Yandev in Gboko Local Government Area, between longitudes 8°36′–8°45′E and latitudes 7°45′–8°00′N. The area ranges in elevation from 90 to 262 meters above sea level and drains into the Katsina-Ala River [23]. The second sampling site is located upstream along a tributary of the dam to the Buruku River (along part of the Benue River) in Buruku Local Government Area, positioned at latitude 7°28′3″N and longitude 9°12′14″E. Both areas have yearly rainfall of 900–1200 mm and separate wet (April–October) and dry (November–March) seasons.

Figure 1 illustrates sampling sites in Benue State.

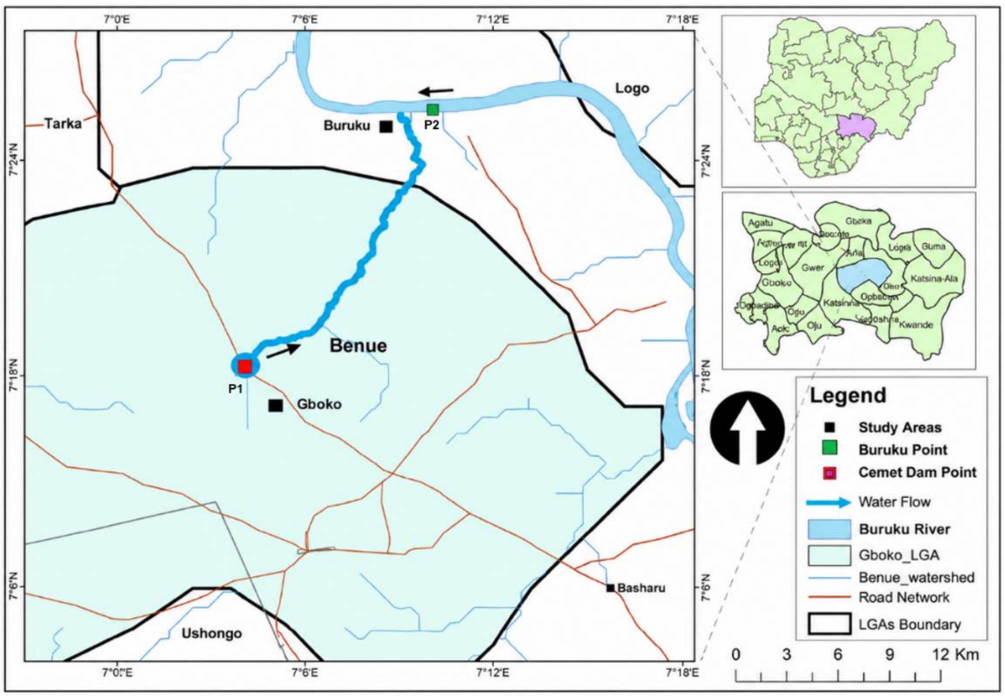

Figure 1. Map of Benue showing Sampling Sites.

2.2. Sample Collection and Preparation

Water and blood samples were collected weekly over four months (August-September and January-February), covering both rainy and dry seasons. Water samples from each site were analyzed on-site, then stored in reagent bottles, preserved, and transported to the Fisheries Department Laboratory at Joseph Sarwuan Tarka University for further analysis.

Blood samples were drawn from Oreochromis niloticus using a 2 ml syringe, transferred into EDTA bottles, preserved in ice packs, and taken to Q & Laboratory in Makurdi, Benue State, for analysis.

A total of 20 *O. niloticus* specimens were obtained from fisherfolk at the landing sites, with 10 fish from each location. Sampling was conducted once per season for both the Benue Cement Dam and the Buruku River. The fish were transported on ice to the Fisheries Department processing unit at Joseph Sarwuan Tarka University, where they were washed, gutted, and smoked in a drum kiln at a consistent temperature of 70 ± 5°C for 24 hours.

2.3. Physicochemical Analyses

Water samples were analyzed in situ using a Hanna HI9813-6 Multi-Parameter Checker to measure temperature (°C), conductivity (mS), total dissolved solids (mg/L), and pH. Dissolved oxygen (DO) concentration was measured using the Iuzmar UMR-9100 Dissolved Oxygen Meter. Additionally, for the determination of biological oxygen demand (BOD), water samples were collected in 250 mL Biological Oxygen Demand (BOD) bottles and preserved for subsequent laboratory analysis conducted following the ALPHA standard procedure as illustrated by Montaña et al. [24].

2.4. Hematological Analysis

The collected blood samples from the experimental fish were analyzed for White Blood Cells (WBC), Red Blood Cells (RBC), Hemoglobin (HGB), Hematocrit (HCT), Mean Corpuscular Volume (MCV), Mean Corpuscular Hemoglobin (MCH), and Mean Corpuscular Hemoglobin Concentration (MCHC). These hematological parameters were determined using an automated hematology analyzer (Sysmex KX-21N Automated Hematology Analyzer), following the procedure described by Amaeze et al. [25].

2.5. Proximate Analysis

The smoke-drying process was closely monitored, and the drying time adjusted to obtain the required moisture content and appropriate texture in the dried fish products. Periodic sampling and evaluation were carried out to track the drying progress and assess quality characteristics throughout the process. After the drying process was completed, the nutritional composition of the dried fish samples was determined using the description by Jim et al. [26] on the standard procedures of the Association of Official Analytical Chemists (AOAC).

2.6. Microbial Analysis

The *O. niloticus* fish obtained were stored at room temperature in the laboratory in a box for eight weeks under consistent conditions, after which they were subjected to microbial analysis and characterization following the methods described by Majumdar et al. [19].

2.7. Data Analysis

The data collected were analyzed using Excel and the SPSS statistical program and subjected to analysis of the t-test for differences in water samples and blood parameters. Data for proximate composition and microbial analysis of smoked samples were subjected to analysis of variance (ANOVA), and means were separated using least significant difference (LSD).

3. Results

The pH values of the dam and river were similar, with the dam slightly higher (7.5) than the river (7.45), though the difference was not statistically significant. Electrical conductivity was much higher in the dam (131.73 µs/cm) than in the river (78.50 µs/cm), indicating a significant variation between the two. All sites recorded the same temperature range, with the dam at 28.20°C and the river at 28.13°C. Total dissolved solids were slightly lower in the dam (34.2 mg/l) compared to the river (38.00 mg/l). Dissolved oxygen levels were higher in the dam (3.72 mg/l) than in the river (3.00 mg/l), whereas biochemical oxygen demand was notably higher in the river (1.00 mg/l) than in the dam (0.20 mg/l), suggesting greater organic pollution in the river.

Table 1. Water quality parameters of Benue cement dam and Buruku river.

Parameter	Source		t-value	p-value
	Dam	River		
pH	7.50 ± 0.12	7.45 ± 0.43	0.11	0.92
EC (µs/cm)	131.73 ± 3.7**	78.50 ± 3.7*	10.19	0.00
Temp (°C)	28.20 ± 0.32	28.13 ± 0.4	0.05	0.96
TDS (mg/l)	34.2 ± 1.7	38.00 ± 1.7	-0.22	0.84
DO (mg/l)	3.72 ± 1.0	3.00 ± 0.09	0.70	0.54
BOD (mg/l)	0.20 ± 0.06*	1.00 ± 0.09**	7.41	0.00

Note: Indicates statistical difference ** $p < 0.05$, * $p < 0.1$.

White blood cells (WBC), mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC) were significantly higher in fish from the dam (24.48 cells/µL, 240 pg, and 298 g/dL) compared to those from the river (18.49 cells/µL, 62.5 pg, and 138.8 g/dL). In contrast, red blood cells (RBC) and hematocrit (HCT) were significantly higher in river fish (10.13 cells/µL and 13.3%) than in dam fish (8.11 cells/µL and 9.1%). However, hemoglobin (HGB) and mean corpuscular volume (MCV) showed no significant difference between fish from the two water bodies.

Table 2. Hematological from Benue cement dam and Buruku river.

Parameters	Source		t-value	p-value
	Dam specimen	River specimen		
WBC (cells/µL)	24.48 ± 0.17**	18.49 ± 0.11*	7.17	0.00
RBC (cells/µL)	8.11 ± 0.07*	10.13 ± 0.07**	1.75	0.00
HGB (g/dL)	6.69 ± 3.3	6.59 ± 0.25	0.04	0.97
HCT (%)	9.1 ± 9.4*	13.3 ± 6.6**	5.33	0.95
MCV (g/dL)	77.3 ± 27	81.0 ± 25	-0.10	0.92
MCH (pg)	240 ± 180**	62.5 ± 20*	8.98	0.00
MCHC (g/dL)	298 ± 243**	138.8 ± 42*	10.65	0.00

Note: Indicates statistical significance ** $p < 0.05$, * $p < 0.1$.

Proximate analysis showed that fish from the Buruku River contained higher levels of crude protein, lipid, and ash (62.94%, 8.32%, and 13.95%, respectively). In contrast, fish from the Benue Cement Dam had higher moisture and nitrogen-free extract (NFE) values, at 5.05% and 27.00%, respectively.

Table 3 presents Oreochromis niloticus carcass proximate analysis from Benue Cement Dam and Buruku River, irrespective of season.

Table 3. Mean proximate analysis of *Oreochromis niloticus* fish carcass from Benue cement dam and Buruku river irrespective of season.

Composition (%)	O. niloticus from the dam	O. niloticus from the river	P-Value
Crude protein	50.61±0.29	62.94±0.051	0.03
Lipid	6.16±0.14	8.32±0.18	0.069
Ash	11.36±0.13	13.95±0.06	0.036
Moisture	5.05±0.04	4.87±0.06	0.243
NFE	27.00±0.62	9.74±0.331	

The microbial analysis of smoked *O. niloticus* showed that fish from the dam had a total bacterial count of 1.5×10^4 cfu/g, with coliform counts around 1.2×10^1 cfu/g and fungal counts of 3.1×10^2 cfu/g. In comparison, fish from the Buruku River recorded higher values, with a total bacterial count of 2.7×10^4 cfu/g, coliform count of 1.7×10^1 cfu/g, and fungal count of 3.7×10^2 cfu/g. Overall, river samples consistently exhibited higher microbial loads, total bacteria, coliforms, and fungi, while dam samples had the lowest counts across all parameters.

Table 4. Mean microbial population from Buruku river and Benue cement dam irrespective of season.

Sample	TBC (cfu/g)	TCC (cfu/g)	TFC (cfu/g)
O. Niloticus from Dam	20500± 5500	14500±2500	340.0±30
O. Niloticus from the River	19500±5500	13500±2500	350.0±30
P-Value	0.909	0.804	0.836

Note: cfu/g = Colony-forming unit per gram, TBC = Total bacteria count, TCC = Total coliform counts, and TFC = Total fungal counts.

Description of microbial identification (Tables 5 and 6) based on morphological/biochemical characteristics of bacterial isolates and morphological characterization of fungal isolates. The microorganisms identified in this study comprised *Escherichia coli* (E. coli), *Micrococcus species*, *Salmonella spp*, *Staphylococcus aureus*, and *Pseudomonas*. Fungal isolates detected included *Aspergillus niger*, *Penicillium spp*, *Aspergillus flavus*, and *Mucor*. Biochemical characterization showed that all microbial isolates were present in the river samples of smoked fish from both sources. However, *Bacillus spp* and *Pseudomonas* were additionally detected in the dam samples but were absent in the river samples.

Table 5. Morphological and biochemical characteristics of bacterial isolates from Oreochromis niloticus in Buruku River and Benue Cement Dam, irrespective of season.

Sample code	Cell morphology test	Gram reaction test	Motility test	Catalase test	Coagulase test	Indole test	Citrate utilization test	Oxidase test	Possible organism
O. Niloticus Dam	Cocci	+ve	–	+	+	–	–	+	Staphylococcus aureus
	Cocci	+ve	–	+	–	–	–	–	Micrococcus spp.
	Cocci	+ve	+	+	–	–	–	–	Bacillus spp.
	Rods	–ve	+	+	–	+	–	–	E.coli
	Rods	–ve	+	–	–	–	+	–	Salmonella spp.
	Rods	–ve	+	+	–	+	–	–	pseudomonas
O. Niloticus From River	Cocci	+ve	–	+	+	–	–	+	Staphylococcus aureus
	Rods	–ve	+	+	–	+	–	–	E.coli
	Cocci	+ve	–	+	–	–	–	–	Micrococcus spp.
	Rods	–ve	+	–	–	–	+	–	Salmonella spp.

Table 6. Morphological characterization of fungal isolates of Orechromis niloticus from Buruku River and Benue cement dam, irrespective of season.

Sample code	Colony features	Microscopic description	Possible organisms
O. Niloticus From Dam	Green-grey with a white apron at the margin Yellowish mycelium Jet-black conidia	Conidiophore with vesicles Septate branching Branched conidia chains	Aspergillus fumigatus Penicillium spp. Aspergillus niger.
O. Niloticus From River	Jet-black conidia Yellow-green mycelium Whitish grey mycelium	Branded conidia in a chain Septate branching Sporangiophores branched	Aspergillus niger Gliocladium spp Mucor

4. Discussion

The physicochemical analysis (Table 1) shows no statistically significant difference in pH between the dam and the river, although the dam recorded a slightly higher value. This variation may be linked to human activities such as industrial discharge or mining, which can introduce alkaline substances into water bodies. These findings are consistent with Khatri and Tyagi [27], who noted that natural processes such as rock weathering, evapotranspiration, wind deposition, soil leaching, runoff, and biological activities also contribute to changes in water pH and alkalinity. Electrical conductivity (EC) reflects the ability of water to conduct electrical current and is directly influenced by the concentration of dissolved ions. The dam recorded slightly higher conductivity than the river, likely due to the accumulation of dissolved minerals and salts under relatively stagnant conditions, whereas flowing river water tends to dilute or flush out these substances. This aligns with Boci et al. [28] and Aende et al. [23], who reported that increased levels of dissolved ions raise conductivity because ions carry electrical charges and move freely in water. There was no significant difference in temperature between the two water sources, although the dam was slightly warmer than the river. This is expected due to factors such as trapped particles and the relatively shallow depth of the dam, which allow for faster heating from increased sunlight exposure. In addition, the more stagnant nature of dam water enables it to absorb and retain heat more easily than flowing river water. This observation is consistent with Soomro et al. [29], who reported that discharge water tends to be warmer than natural river water. Total dissolved solids (TDS) were slightly higher in the dam than in the river, reflecting a greater concentration of dissolved substances. This is likely because dams retain water for longer periods, allowing solids to accumulate, whereas flowing rivers tend to dilute them. These solids originate from both natural processes and human activities around the dam. This agrees with Okunola et al. [30], who reported that dam solids can arise from sources such as industrial effluents, agriculture, construction, municipal waste, and urban runoff carried into the water body. Dissolved oxygen (DO) is the amount of oxygen present in water. The mean DO levels in both the dam and the river did not differ significantly during the study period. Dissolved oxygen is a key factor influencing fish growth and survival in tropical environments, along with their capacity to withstand low early-morning oxygen levels, and the ability to rapidly recover from the physiological stress caused by low dissolved oxygen can also enhance growth by prolonging feeding time [26]. However, greater fluctuations were observed in the dam, likely due to its slightly higher temperature, since warmer water holds less dissolved oxygen. Temperature changes in the dam can therefore influence DO levels, a finding consistent with Soomro et al. [29] and Li et al. [31] who reported that discharge water is typically warmer than natural river water. Biological Oxygen Demand (BOD) is a critical water quality parameter that measures the amount of dissolved oxygen consumed by microorganisms while decomposing organic matter present in water. There was a significant difference ($p<0.05$) between the Dam and River during the period of study with Dam showing 0.20 ± 0.06 compared to River with 1.00 ± 0.09 indicating high BOD in River which could result from domestic wastes, agricultural wastes, and livestock wastes are sources of organic pollutants around the river which is in agreement with Qadri and Faiq [32] which state that how much pollution occurs due to the ingress of organic matters into water bodies, Domestic wastes, agricultural wastes, and livestock wastes are sources of organic pollutants.

Hematological parameters (Table 2) show that white blood cell (WBC) counts differed significantly between fish from the dam and the river, with higher values recorded in the dam. This supports Prasad et al. [33], who suggested that elevated WBC levels may result from the fish's immune response to pollutants, leading to increased antibody production to maintain health. Red blood cell (RBC) counts also differed significantly ($p > 0.05$) between fish from the dam and the river, with lower values observed in the dam and higher values in the river. Exposure to pollutants or toxins can either trigger erythropoiesis as a compensatory mechanism or cause a decline in RBC levels. Heavy metal contamination in water can affect hematological parameters, and the observed variations in RBC counts in this study are likely linked to chronic exposure to pollutants, consistent with the findings of Sahiti et al. [34]. The difference in hemoglobin (HGB) levels between the dam and river was not statistically significant ($p > 0.05$), although dam fish exhibited slightly higher values. This may reflect an adaptive response to pollution or altered environmental conditions in the dam, prompting increased hemoglobin production to improve oxygen transport and support survival under more challenging conditions. This observation aligns with Dandi [35], who reported that hemoglobin levels are strongly influenced by environmental factors such as nutrient availability, oxygen levels, toxic substances, and other stressors. The difference ($p > 0.05$). The difference in hematocrit (HCT) between the dam and the river was statistically significant. Higher HCT levels in river fish compared to dam fish may result from environmental stressors, such as pollution, which can stimulate increased red blood cell production as a compensatory mechanism. Additionally, pollutants may directly affect fish physiology, leading to changes in hematocrit. These findings are consistent with Xu et al. [36]. Ahmed et al. [37] observed that hematocrit values are influenced by both the number and size of erythrocytes and can be affected by factors such as water quality, exposure to drugs, and certain infectious diseases. The study found significant differences in mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC) between fish from the dam and those from the river, with higher values observed in dam fish. These changes may be associated with swelling of red blood cells, which can reduce hemoglobin concentration within the RBCs. Variations in water conditions between the dam and river environments, such as differences in pollutants, oxygen levels, pH, diet, and exposure to contaminants or toxins, likely influence these hematological parameters. This aligns with Zutshi et al. [38], who attributed increases in MCV, MCH, and MCHC to reductions in RBC counts caused by contaminants, and also hematocrit (Hct) values caused a notable decline in MCH, MCV, and MCHC levels due to toxicity in water.

Proximate analysis of the Buruku River and Benue Cement Dam fish is essential for understanding their nutritional and biochemical characteristics. However, comprehensive data on specific nutrients such as carbohydrates, fats, proteins, fatty acids, amino acids, and minerals, especially in relation to sex and different body parts of fish, are still under investigation as adequate nutrients are required for effective growth and proper production of fish [39, 40]. The proximate analysis shows maximum moisture content for both samples, but more in the river fish. It also indicates that dam fish have higher nitrogen-free extract (NFE—energy) and moisture content. The protein, fats, ash, and lipids were higher for river samples. The protein accumulation needs of fish are affected by several factors, including their size, water temperature, feeding rate, the availability and quality of natural food sources, and the overall digestible energy content of the diet [41]. The retention of stable protein levels in smoked river fish indicates that controlled heat was applied during drying, preventing protein denaturation. In contrast, excessive heat can lead to protein loss through denaturation, while proper heat regulation helps preserve protein structure [42, 43]. Environmental factors, such as the feed intake ratio, remained largely unchanged, though fat accumulation increased, while factors such as fatty acid unsaturation, light exposure, and gut bacterial diversity are not yet fully understood. Ensuring suitable water quality is essential for aquatic life and fish health, with herbivorous species showing a closer association with stable conditions, as reflected in measurements like total length, lipid content, and fatty acid composition [44-47]. The elevated lipid levels observed in smoked river fish samples may be due to heat exposure and accelerated fat oxidation during the drying process. This finding is consistent with Akinneye et al. [48] and Rangasamy et al. [49], who reported that variations in fat content are influenced by the intensity of heat applied during preservation, which can promote lipid oxidation. The ash content was higher in the river than in the dam fish. Differences in fish nutritional composition may arise from variations in nutrient availability within the water body and the fish's ability to absorb and utilize essential nutrients from their habitat and diet. Larger reservoirs with lower pollution levels can enhance dry matter, protein, and ash content by reducing stocking density and competition for food. Additionally, *Oreochromis niloticus* prefers shallow waters, and the extensive shorelines of large water bodies provide ideal feeding areas that support its nutritional intake [26]. The ash content of fish samples showed the river with the greatest value, with variations influenced by environmental factors affecting the availability of proximate nutrients. This aligns with Shija et al. [50] stating that the differences in ash levels among smoked fish from various sources were also impacted by seasonal changes and processing methods. The moisture and NFE were higher in the dam fish sample. The energy content of these fish species was more strongly influenced by processing method, reflecting differences in the sources of catchability, which is visible in nutrient intake from their diet or environment and conversion rates. This is in accordance with Goswami and Manna [51], who indicated that energy and moisture levels may be affected by environmental and processing changes.

The proximate composition of fish varies and is influenced by factors such as species, season, temperature, size, developmental stage, and food or nutrient availability, all of which affect their nutritional components [40]. These factors highlight variations in composition across different processing methods, providing insights into how these methods impact the fish's nutritional value.

The findings of this study (Tables 4, 5, 6) indicated the microbial load, isolates, and their identifications. The results reveal no significant difference ($P > 0.05$) in the microbial load of fish collected from the two locations. This suggests that fish from both sites possess comparable microbial levels, which remain within the acceptable limits outlined in the microbiological quality guidelines for ready-to-eat foods by Meldrum et al. [52], Giannoglou et al. [53], and Muzzafar et al. [54]. Therefore, the fish obtained from these locations are considered safe for human consumption because the microbial load of the different fish species obtained from both sampled locations (Cement

Dam and Buruku River) remains within acceptable limits for consumption, indicating a low level of spoilage from both sources. The study further revealed that *Escherichia coli*, *Salmonella arizonae*, and *Streptobacillus moniliformis* were the microorganisms identified in association with the smoked fish from these locations. The results showed that fish collected from the river exhibited a higher microbial load compared to those from the dam. Nevertheless, the total microbial counts recorded in the study remained within the recommended limits of 1.5×10^5 cfu/g for bacteria and fungi, and 1×10^2 cfu/g for coliform bacteria, as specified by the International Commission on Microbiological Specifications for Foods [55] and the United States Food and Agriculture Department (USFAD), as described by Allende et al. [56].

The presence of all these bacteria and fungi may make their consumption hazardous to health, as some of these microorganisms have been analyzed to be hazardous for human consumption. Ayeloja et al. [57] found that fish spoilage is primarily caused by the activity of psychrotrophic Gram-negative bacteria, particularly *Shewanella putrefaciens* and *Pseudomonas species*. Anihouvi et al. [58] also noted that the spoilage of fish and fish products is influenced by specific spoilage organisms (SSOs), which vary depending on the processing method, preservation technique, and storage temperature. Common SSOs associated with different fish and fish products include *Pseudomonas*, *Shewanella putrefaciens*, *Photobacterium phosphoreum*, *Aeromonas hydrophila*, *Alteromonas putrefaciens*, members of the *Vibrionaceae*, *Aeromonas*, *Moraxella*, *Acinetobacter*, Enterobacteriaceae, as well as yeasts and molds. According to Ayeloja et al. [57], in artisanal fishery, freshly caught fish are covered with damp sacks, and at times they are mixed with wet grass or water weeds to reduce the temperature. Fish treated this way are prone to contamination with microorganisms such as Salmonella and Aspergillus. This indicates that the spoilage of fish starts right from the aquatic ecosystem. Processed fish are also prone to microbial attack, especially in artisanal fisheries due to unhygienic methods of processing and preservation.

The microorganisms isolated in this study include *Escherichia coli (E. coli)*, *Micrococcus*, *Salmonella spp.*, *Staphylococcus aureus*, and *Pseudomonas*. The fungal isolates found are *Aspergillus niger*, *Penicillium spp.*, *Aspergillus flavus*, and *Mucor*. These findings are similar to the study by Emmanuel et al. [59], which identified Penicillium species as the most frequently detected fungi in fish, occurring at high rates, while Aspergillus fumigatus and Mucor species were also present. This suggests that both bacteria and fungi are commonly found on fish, regardless of whether they are exposed or not. Microorganisms like *Escherichia coli (E. coli)* and *Salmonella species* are fecal-borne pathogens that may be introduced through contamination by handlers or from polluted environments. Fish harvested from contaminated waters, especially those affected by poor water quality, agricultural runoff, or fecal contamination from wildlife, can harbor Salmonella. In humans, infection with these bacteria can lead to diarrhea, kidney complications, and in severe cases, death [60]. The detection of *A. flavus* and *A. fumigatus* in this study is particularly concerning due to their ability to produce mycotoxins. Their presence in fish may result from inadequate handling during smoking, cross-contamination during storage, or improper practices during the sale of smoked fish. During the smoke-drying process, the use of artisanal smoking kilns and overcrowding of fish on trays can lead to inadequate processing, promoting fungal growth. Furthermore, during storage, poor practices by fish sellers, such as poorly ventilated storage areas, allow pests to access the smoked dried fish, increasing contamination risk [61]. The conditions in which fish are displayed in markets are often unhygienic, creating additional opportunities for microbial contamination. Frequently, retailers place smoked fish on open trays near gutters or refuse piles, which promotes fungal and bacterial growth and the potential production of toxins [57].

5. Conclusion

The disparities observed between water and fish from the dam and the river, both physicochemical and hematological variations, were seen to affect fish physiology, suggesting a direct impact on fish populations. The higher biochemical oxygen demand (BOD) in the river indicates increased organic pollution, which could affect fish health and disturb the aquatic ecosystem. Changes in the blood parameters of dam fish may indicate active physiological responses to environmental stressors. The evaluated proximate composition and microbial quality of smoked *Oreochromis niloticus* from the dam and the river, using standardized analytical methods, also identified microorganisms such as *Escherichia coli*, *Salmonella arizonae*, and *Streptobacillus moniliformis*, but their levels remained within safe limits, indicating that the fish are still suitable for human consumption. Proximate analysis further revealed differences in nutritional composition between fish from the two sources. Overall, the findings highlight the need for regular monitoring of water quality and fish health to support sustainable production and protect public health. Continuous assessment of pollution levels and water quality is essential for the sustainable management and conservation of aquatic resources.

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