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AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 24 No. 5
May 2024
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

Afr. J. Food Agric. Nutr. Dev. 2024; 24(5): 26333-26350 https://doi.org/10.18697/ajfand.130.24405

Date	Submitted	Accepted	Published
	15th December 2023	19th May 2024	31st May 2024

FISH BIODIVERSITY IN MODIFIED ECOSYSTEMS: A CASE STUDY OF NIGERIA'S CHALLAWA AND TIGA DAMS IN THE CHALLAWA AND KANO RIVERS

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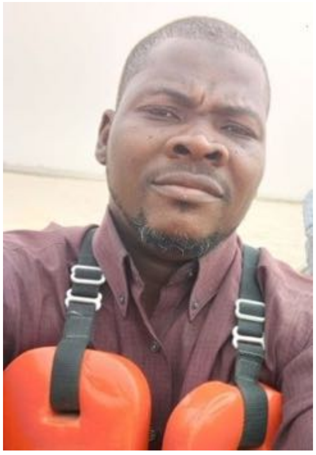

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ABSTRACT

River impoundment is usually accompanied with consequences of alteration in the hydrological system and change in the biodiversity composition of the ecosystem. This study investigated the impact of the dams built on Challawa (that is, Challawa George-Dam) and Kano (that is, Tiga Dam) on the fish biodiversity of the reservoir and below-dam sections of the two rivers. Fish sampling was done using long lines, Malian traps, cast and gill nets from stations on the reservoir and below-dam sections of the rivers. Ten fish species were identified from the reservoir and the below-dam sections of Challawa River belonging to nine families and four orders. Fish communities of the reservoir and below-dam sections of Kano River consisted of 28 species belonging to 12 families and 7 orders. Results of the Shannon diversity index (H') indicated that the two reservoirs have relatively higher fish species diversity measures (that is, Challawa=1.948 & Kano=2.294) than the below-dam parts (that is, Challawa=1.833 & Kano=2.247) of their respective rivers. Non-metric Multidimensional Scaling (NMDS) analysis produced two-dimensional maps with stress values of 0.0554 and 0.0537, an indication that the model provided good representation of the original data in reduced-dimensional space. The ordination map indicated wide dissimilarities between fish communities of the impounded and below-dam sections. Furthermore, a one-way analysis of similarity indicated significant difference (P=0.0001) and high dissimilarities (R=0.643) between fish communities in the two sections of Challawa River and also in Kano River (P=0.001, R=0.929). Analysis of Similarity Percentage indicated 74.45% of the dissmilarities between fish communities in the two sections were cummulatively contributed by four species in Challawa River and 72.18% by five species in Kano River. The distinct differences in fish abundance and richness between the two sections is ascribed to increased ecosytem productivity often associated with the inundated portion of dammed river. It is recommended that more water flow across the dams should be encouraged as a mitigating measure to boost basin sizes of the rivers at the below-dam sections.

Key words: Diversity, dam, impound, reservoir, community, freshwater and fish species

INTRODUCTION

Anthropogenic activities are major factors behind the fast deteriorating state of world's freshwater bodies[1]. The strive by many sub-Saharan Africa countries to attain food security and rural development places enormous pressure on the freshwaters of the region. Human interferen ces with most freshwater rivers threatened the sustainability, abundance and diversity of the aquatic organisms therein [2].

Impounding rivers for socio-economic activities like irrigation farming, municipal water supply, flood control and hydro-power generation have critical effects on aquatic ecosystem. The dams, reservoirs and weirs constructed for these purposes pose as barriers to free movement of aquatic animals across the different sections of the rivers. Thus, disconnecting various parts of the ecosystem from each other [3].

Dams constructed on rivers affect the downstream and upstream in diverse ways such as modifying the upstream environment and changing it from its lotic conditions to a relatively lentic water which occasionally leads to extirpation of native species adapted to the initial condition while such change allows some flexible, non-endemic ones to flourish [4]. As dams pose as barrier on rivers, fish movement for migration, spawning and nursery activities become restricted thereby leading to fragmentation of population into isolated smaller subpopulations. Some opportunistic sedentary native species of a general feeding habits might also find such situation favourable for their well-being [4, 5].

Effect of dams at the downstream often leads to changes in the seasonal flow pattern of rivers with direct effect on breeding grounds of fish which often puts survival of their juveniles at risk. The changes in the seasonal flow have strong effects on the water temperature and chemistry which are vital environmental factors controlling fish breeding and larvae developments [4].

Changes in the structure and composition of fish communities are strongly related to the changes in their environmental conditions. Studying how the environmental conditions makes changes to fish communities through quantifying the effects is important in fisheries conservation and management [6].

Tiga and Challawa Dams were constructed on the two major upstream tributaries of Hadejia River; Kano and Challawa Rivers, to provide important social services of irrigation, municipal water supply and hydro-electrical power generation. The impacts of these dams have consequentially led to drastic reduction in river flow at the downstream sections of Hadejia River basin. About 100 million cubic meters per year reduction of river flow experienced in 1976 at Gashua (downstream of

Hadejia River) was ascribed to water retained in Tiga Reservoir. Also, more than 50 million cubic meters of water is lost through evaporation from the surface of the reservoir [7]. To date, there is dearth of information on the effect of Tiga and Challawa gorge dams on the fish biodiversity of the two rivers. This biodiversity study therefore, sought to investigate the effect of the riverine impoundments on the composition and abundance of fish communities across the sections of the two rivers.

MATERIALS AND METHODS

Study area

Kano and Challawa Rivers are the major upstream tributaries of the Hadejia River. Tiga Dam (storage capacity: 1492 x 10^6 m^3) and Challawa gorge Dam (storage capacity: 972 x $10^6 m^3$) were respectively constructed in 1974 and 1992 primarily for irrigation, municipal water supply and hydro-electricity power generation. The two dams are located within Kano State in Northwestern Nigeria. Kano State is a prominent commercial center in northern Nigeria and located between latitude 10^o25‘and 13^o53‘North of the equator and longitude 7^o40‘and 10^o53‘East of the Greenwich meridian [8, 10]. The state experiences varying rainfall patterns, ranging from less than 600 mm in the northernmost areas to 800 mm in the southern tips. The northern part of the state experiences a rainy season lasting approximately 4 months, while the middle to southern tips have a longer duration of 5 to 6 months for most of the year. The remaining months of the year predominantly constitute the dry season [11].

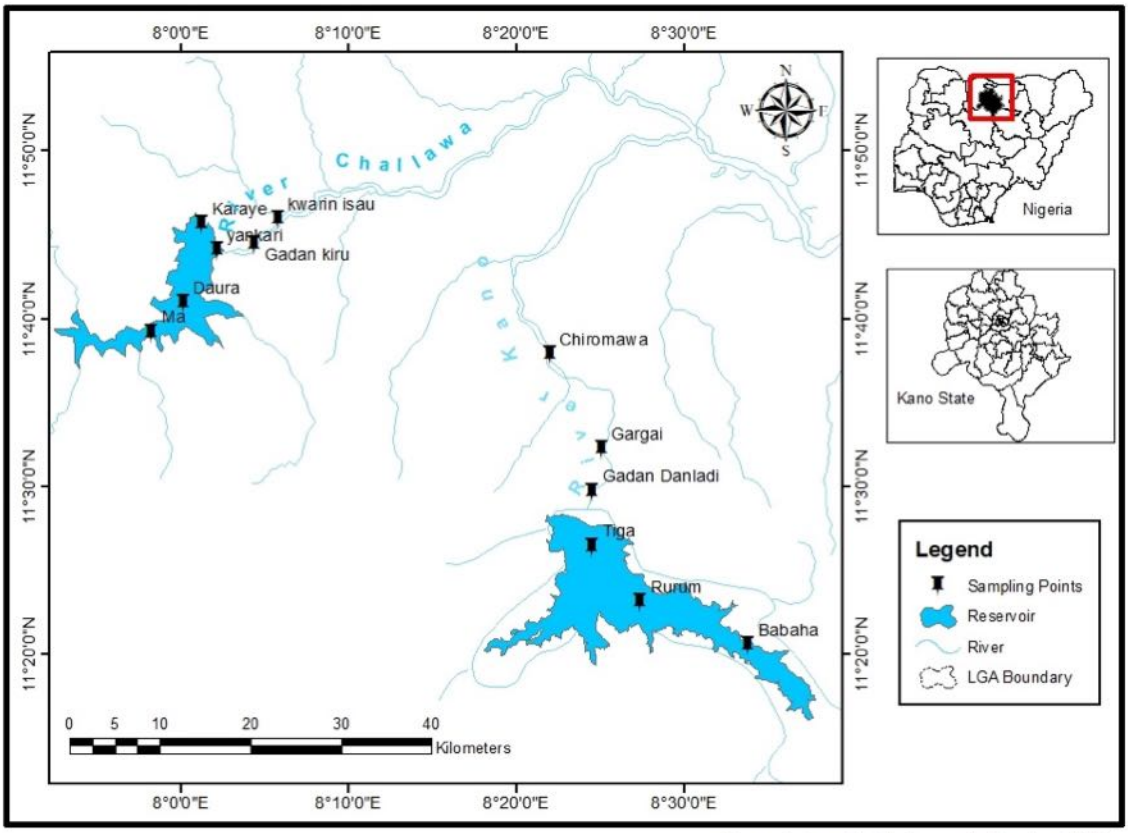

Figure 1: Map showing sampling locations on Kano and Challawa Rivers

Sampling Location and sampling technique

Three different sampling locations were selected within each of Challawa and Tiga Reservoirs and also three on each of the below-dam sections of Challawa and Kano Rivers (Figure 1). Geographical coordinates and elevations of the sampling locations were equally recorded using Global Positioning System (GPS), (Table 1).

The services of local artisanal fishermen were utilized for fish sampling. Two long lines, Malian traps and cast nets, and three gill nets (0.5-, 1.2-, and 2.5-inches mesh sizes) were used for fish sampling at each sampling site. Sampling was undertaken for approximately 2 hours in the morning (0900–1100 hours) with cast nets in active mode, whereas the three other methods were setup in the evening and checked in the morning for catch. Sampling was performed in triplicate (that is, for 3 days) at each sampling site per season (Dry and wet season).

Fish identification

Identification of fish up to species level was done with the aid of guides, keys and pictures by Olaosebikan and Raji [12], while image scanning of the fish samples were also done on the field. Representative samples of each species were transported in chilled condition to the Aquaculture and Fisheries Departmental

Laboratory of Bayero University, Kano, Nigeria and temporarily preserved in 70% formaldehyde.

Data collection

Data recorded for the species diversity analysis included the number of species and individual counts of fish specimens per species. Species data was collected in triplicate (3 days of data) during the dry season (May, 2022) and rainy season (September, 2022).

Data analysis

The Shannon–Weiner diversity index (H') of fish communities in the various sections of the rivers was calculated using PAST, using the following equation:

$$\boldsymbol{H'} = -\sum \boldsymbol{Pi} * \log \boldsymbol{Pi}$$

where $\mathbf{Pi} = \mathbf{ni}/\mathbf{N}$, ni is the number of individuals of each species in the sample, and N is the total number of individuals of all species in the sample.

Non-metric multidimensional scaling was conducted to demonstrate the underlying similarities between fish communities in the reservoirs and those in the below-dam section of the rivers. A one-way analysis of similarity was performed to check whether the influence of species distribution and abundance in the two communities significantly accounted for the variability between the fish communities of the two river sections [13]. The percentage contribution of the most influencing fish species to the variability between the two communities was estimated using similarity percentage analysis (SIMPER) [14]. The analyses were performed using the R statistical software [15].

RESULTS AND DISCUSSION

Ten species were recorded from the Challawa River in varying proportions, belonging to nine families and four orders (Tables 2 and 3). In contrast, fish communities across the Kano River comprised 28 species belonging to 12 families and 7 orders. The reservoir sections of the two rivers had high fish abundances, accounting for 80.56% (Challawa River) and 78.59% (Kano River) of the total fish composition. However, five species, *Tilapia zillii*, *Hyperopius bebe*, *Merusenius senegalensis*, *Auchenoglanis occidentalis*, and *Chrysichthys auratus* were absent from the below-dam section of the Kano River. The observed fish biodiversity in these two reservoirs shares similarities with Dadin Kowa Lake, an artificial lake in northern Nigeria with dominant species belonging to the families of *Schilbedae*, *Alestidae* and *Cichlidae* [16].

The Shannon-Weiner diversity indices (Figure 2) of fish communities in the Challawa (1.948) and Kano (2.294) reservoirs were relatively higher than those in their respective below-dam parts of the Challawa (1.833) and Kano (2.247) Rivers.

However, it is apparent that the reservoir on the Kano River (Tiga Reservoir) had higher species richness than the Challawa Reservoir, which explains the higher Shannon–Weiner diversity index of the former. Higher Shannon–Weiner diversity index of the two reservoirs indicated higher number of species and/ individual member of the species. Regarding the differences in the index between the two sections of the Challawa River, where same number of species were identified, higher Shannon index in the reservoir section imply a higher numerical abundance of fish in that habitat [17].

The observed differences in the ichthyofaunal composition between the reservoir and below-dam sections of Challawa and Kano Rivers are majorly attributed to the impoundments through the creation of Challawa and Tiga Dams. The impoundments changes river hydrology by converting the free-water flowing at the above-dam sections into lentic water through which river basins here becomes larger to accommodate more aquatic communities. Through this, there will be also increased biomass accumulation, often associated with lake formation due to the inundation of terrestrial areas [18]. These would largely be responsible for the higher fish composition of the reservoirs over the below-dam section as most of the fish species with low or no representations in the below-dam parts of these two rivers have been reported to thrive and flourish in other undammed rivers of Northern Nigeria [19, 21].

Additionally, leaching of nutrients and the influx of organic biomass from submerged terrestrial areas further contribute to this phenomenon. Notably, the presence of many irrigation farms around the lakes would enable leaching of nutrients and amplify biomass accumulation, subsequently improving lake productivity. The abundance of food resources would play a pivotal role in driving higher fish biodiversity among various trophic groups, including detritivores, planktivores, and herbivores [18].

One plausible reason for the lower fish species diversity in the lotic parts of the rivers is the reduced water volume during the dry season. Given that the study areas experience an extended dry season period of approximately eight months, it is evident that the non-impounded river sections may not make favourable conditions that will support higher fish biodiversity. Additionally, the reduced water volume may disconnect adjoining breeding, nursery, and feeding grounds of fish, which could further exacerbate the challenges faced by fish species with specific functional traits requiring these habitats [5, 22].

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ISSN 1684 5374

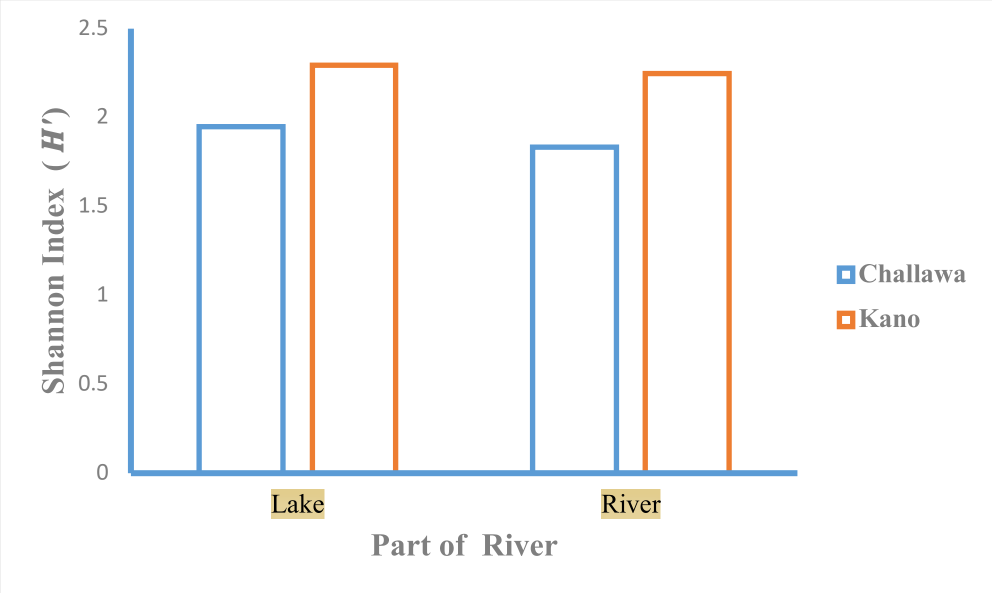

Figure 2: Shannon diversity index of fish communities of Challawa and Kano Rivers

Non-metric multidimensional scaling (NMDS) ordination derived from Bray–Curtis dissimilarity matrices revealed distinctions between the fish communities of the Reservoir and below-dam sections of the two rivers (Figures 3 and 4). In the Challawa River, the ordination plot showed a favourable stress value of 0.0554. Despite clearly demonstrating dissimilarities between fish communities in the two sections, the plot revealed some overlaps, indicating similarities in species richness and, to some extent, the proportion of the species. Similarly, the NMDS plot for fish communities in the reservoir and below-dam sections of the Kano River (Figure 4) displayed a notable stress value of 0.0537, and distinct dissimilarity between the two communities. This implies that the species richness and proportion of fish communities in this river are quite different. Further quantitative analysis using one-way ANOSIM indicated highly significant dissimilarities between fish communities in the reservoir and non-impounded segments of the Challawa ($P<0.05$, $R=0.643$) and Kano ($P<0.05$, $R=0.929$) Rivers.

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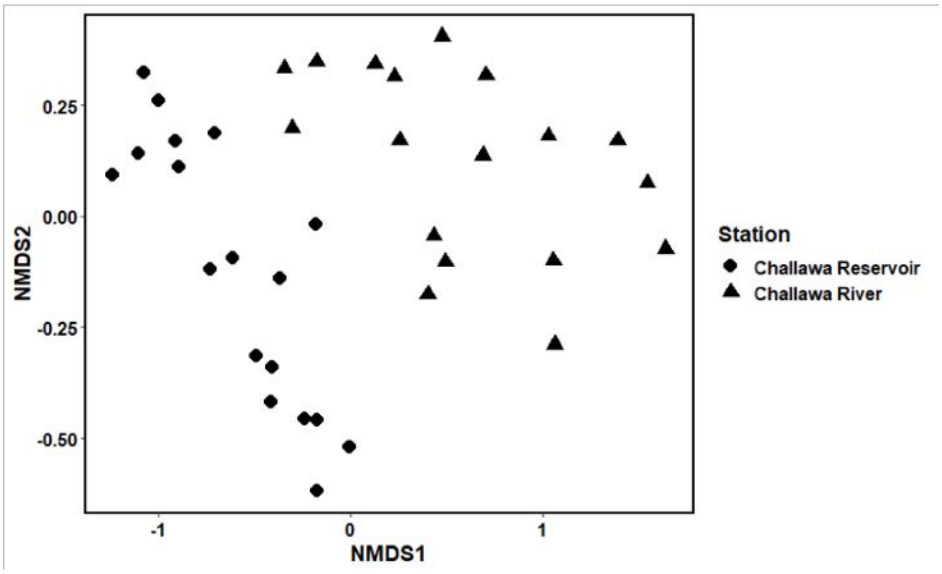

Figure 3: Non-metric multidimensional scaling (NMDS) map of fish communities of Challawa River

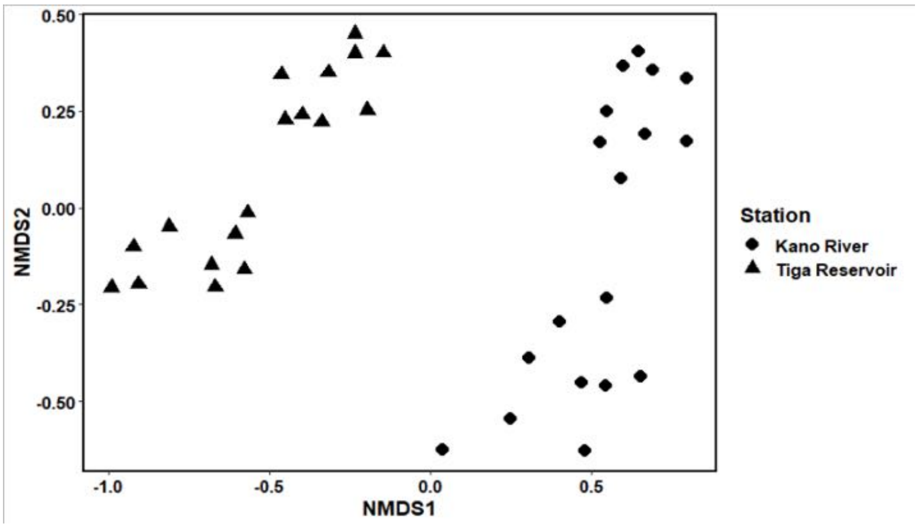

Figure 4: Non-metric multidimensional scaling (NMDS) map of fish communities of Kano River

SIMPER analysis revealed the cumulative contribution of the species responsible for the observed dissimilarities between fish communities within the reservoir and below-dam segments (Table 4). *Brycinus nurse*, *Schilbe uraoscopus*, *Oreochromis niloticus*, and *Polymirus. isidori* cumulatively contributed to 74.45% of the total dissimilarity between the two distinct segments of Challawa River. In contrast, 72.18% was cumulatively contributed by *P. pellucida*, *S. uraoscopus*, *B. leonensis*, *O. niloticus*, and *S. galillaus* to the total dissimilarity between the two communities located in Kano River.

A notable finding was the significant contribution of fish species of the Schilbeidae family to the dissimilarities observed between reservoir and below-dam sections in Challawa and Kano Rivers. Specifically, in the Challawa and Tiga reservoirs, *S. uraoscopus* and *P. pellucida* made up 14.79% and 26.29%, respectively (Tables 2 and 3), implying their substantial presence. This prevalence in the reservoirs may be attributed to the preferred habitat of a related species, *Schilbe mystus*, which prefers standing or slow flowing open water in lakes, ponds, rivers, and shallow swamps with marginal vegetation [23].

Oreochromis. niloticus and *Sarotherodon. galillaus*, memebers of the Cichlidae family characterized with high adaptability to harsh environmental conditions [24], played a significant role in the dissimilarity between reservoir and below-dam sections. Their ability to thrive in diverse aquatic environments, coupled with prolific breeding and effective parental care, gives them a competitive advantage in colonizing their habitat [24]. The influx of nutrients from run-offs and inundated terrestrial areas, along with the expanded river basin above the dams, might be crucial factors facilitating the dominance of these species [18].

Species of the family of Alestidae, such as *B. nurse*, exhibited its dominace most especially on Challawa reservoir. Despite the ability of the species to thrive in both lacustrine and riverine conditions [25], the preferential conditions created by the dam impoundment likely contributed to their higher population in the reservoirs. Moreover, mormyrids, primarily described as invertivores or insectivorous with diverse trophic levels due to variations in their snout forms have higher species representation in the reservoir sections of both rivers and that could be attributed to the rich food web of these areas. However, mormyrids being predominantly bottom feeders are poorly adapted to living in deoxygenated lake bottom [26]. This feature might be the reason for the proportionally low abundance of many species of the mormyrids in the two lakes.

Different conservation measures are often recommended to mitigate the impacts of dams and to ensure sustainability of fisheries resources. Construction of fish passage, dam removal/ its opening, and fish stocking are some of the management measures to improve the hydrological condition of the affected downstream, permit the movement of fish, and to improve species richness and abundance of the downstream [4, 27]. In the present study area, the hindrance posed by the dams to fish movement is not perceived as a major cause of the downstream low fish composition. Rather, the reduced river water volume experienced at the non-impounded parts of the rivers reduces fish access to breeding, nursery, and feeding grounds during seasons of low precipitations. This assertion is based on observations of the hydrological and geological dynamics of the rivers during varying precipitation seasons. Notably, water conservation in the reservoirs during the dry season reduces water availability downstream, influencing the non-impounded section of the rivers.

CONCLUSION, AND RECOMMENDATIONS FOR DEVELOPMENT

Dams constructed on the Challawa and Kano Rivers have significant impacts on the river ecosystems, particularly on the fish communities of the rivers. As the two rivers were dammed upstream, the resulting impoundments modified these portions by widening the basin therein, thereby providing more habitats to accommodate higher fish species composition than those in the downstream sections. The impounded sections could be rich with nutrients leached from surrounding irrigation farms and from organic materials on the inundated terrestrial areas during lake formation which are expected to influence primary productivity of the reservoirs and, thus, fish composition.

In contrast, the below-dam portions of the rivers had relatively low fish species richness and abundance, as the river basin at these segments experienced a drastic reduction in water inflow from reservoirs during most periods of the year. Adjoining streams, pools, and swamps serving as breeding, nursery, and feeding grounds, were perceived to be disconnected from the river basins at the below-dam sections during water shortfalls.

It is recommended that increased water volume at the non-impounded sections through improved water discharge from dams during periods of shortfall be encouraged. This will ensure accessibility of fish to additional feeding and breeding areas. Comprehensive ecological studies should be conducted in the future to unveil inadequacies in the ecological niches of fish to guide for appropriate management measures.

ACKNOWLEDGEMENTS

We would like to acknowledge the Executive Director and staff of Hadejia Jama'are River Basin Development Authority (HJRBDA), Nigeria, Heads of the Tiga and Karaye fisherfolks Associations, and staff of Fisheries and Aquaculture Department of Bayero University, Kano, Nigeria. Bayero University, Kano, Nigeria is hereby acknowledged for funding this research.

Conflict of interests

The authors declared no conflict of interest.

Authors' Contributions

Abdul-Azeez H.: Conceptualization (lead); Data curation (lead); Formal analysis (lead); Methodology (lead); Writing-review & editing (equal).

Kassam D: Conceptualization (equal); Methodology (equal); Supervision (lead); Writing-review & editing (equal).
Jere WWL: Conceptualization (equal); Formal analysis (supporting); Methodology (equal); Supervision (supporting); Writing-review & editing (equal).
Abdussamad AM: Supervision (equal); Formal analysis (supporting); Writing review & editing (equal).

Data Availability Statement
The data underlying this research can be found in the Dryad repository database:

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Volume 24 No. 5
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PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

Table 1: Location and coordinates of the sampling stations

River	Sampling station	Section of river	Coordinates		
			Latitude	Longitude	Altitude
Challawa	Ma	Reservoir	11.661638	7.969820	519.6m
Challawa	Daura	Reservoir	11.708888	7.986813	518.7m
Challawa	Karaye	Reservoir	11.748163	8.030780	516.2m
Challawa	Yankari	Non-impounded	11.733933	8.034957	491.4m
Challawa	Gan Kiru	Non-impounded	11.740303	8.072517	479.4m
Challawa	Kwarin-isau	Non-impounded	11.762055	8.095992	471.0m
Kano	Babaha	Reservoir	11.341043	8.562487	512.9m
Kano	Rurum	Reservoir	11.410552	8.448852	510.4m
Kano	Tiga	Reservoir	11.469073	8.366125	505.5m
Kano	Gadan Danladi	Non-impounded	11.474992	8.402500	481.0m
Kano	Gargai	Non-impounded	11.536472	8.416765	480.4m
Kano	Chiromawa	Non-impounded	11.630522	8.365405	448.5m

Table 2: Classification and proportion of fish sampled from Challawa River

Order	Family	Species	Total	%	Reservoir	River
Perciformes	Cichlidae	*Oreochromis niloticus*	1,411	20.90	1077	334
Perciformes	Latidae	*Lates niloticus*	341	5.05	318	23
Characiformes	Alestidae	*Brycinus nurse*	2026	30.01	1684	342
Siluriformes	Clariidae	*Clarias gariepinus*	635	9.41	317	318
Siluriformes	Bagridae	*Bagrus bayad*	380	5.63	342	38
Siluriformes	Claroteidae	*Auchenoglanis occidentalis*	121	1.79	101	20
Siluriformes	Mockokidae	*Synodontis schall*	214	3.17	173	41
Osteoglossiformes	Mormyridae	*Polymyrus isidori*	440	6.52	366	74
Osteoglossiformes	Mormyridae	*Marcusenius senegalensis*	184	2.73	137	47
Siluriformes	Schilbeidae	*Schilbe uraoscopus*	998	14.79	923	75
Total-4	**9**	**10**	**6,750**	**100.00**	**5,438**	**1,312**

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Table 3: Classification and proportion of fish sampled from Kano River

Order	Family	Species	Total	%	Reservoir	River
Perciformes	Cichlidae	*Oreochromis niloticus*	775	8.49	549	226
Perciformes	Cichlidae	*Sarotherodon galillaus*	313	3.43	310	3
Perciformes	Cichlidae	*Tilapia zillii*	28	0.31	28	0
Perciformes	Latidae	*Lates niloticus*	66	0.72	32	34
Perciformes	Alestidae	*Hydrocynus Vittatus*	174	1.91	153	21
Characiformes	Alestidae	*Alestes nurse*	372	4.07	159	213
Osteoglossiformes	Mormyridae	*Mormyrops anguilloides*	24	0.26	22	2
Osteoglossiformes	Mormyridae	*Mormyrus rume*	86	0.94	57	29
Osteoglossiformes	Mormyridae	*Mormyrus tapirus*	78	0.85	55	23
Osteoglossiformes	Mormyridae	*Hyperopisus bebe*	133	1.46	133	0
Osteoglossiformes	Mormyridae	*Marcusenius senegalensis*	19	0.21	19	0
Siluriformes	Claridae	*Clarias gariepinus*	347	3.80	221	126
Siluriformes	Bagridae	*Bagrus bayad*	336	3.68	203	133
Siluriformes	Claroteidae	*Auchenoglanis Occidentalis*	176	1.93	176	0
Siluriformes	Claroteidae	*Chrysichthys auratus*	83	0.91	83	0
Siluriformes	Mockokidae	*Synodontis filamentatus*	124	1.36	55	69
Siluriformes	Mockokidae	*Synodontis membranacea*	221	2.42	130	91
Siluriformes	Malateruridae	*Malapterurus minjiriya*	172	1.88	60	112
Characiformes	Distichodontidae	*Distichodus rostratus*	78	0.23	16	0
Lepidosireniformes	Protopteridae	*Protopterus annectens*	133	0.04	4	0
Polypteriformes	Polypteridae	*Polypterus senegalus*	19	0.05	5	0

https://doi.org/10.18697/ajfand.130.24405

Osteoglossiformes	Arapaimidae	*Heterotis niloticus*	347	0.20	18	0
Siluriformes	Schilbeidae	*Schilbe uraoscopus*	336	14.71	1005	338
Siluriformes	Schilbeidae	*Parailla pellucida*	176	26.29	2400	0
Cypriniformes	Cyprinidae	*Barbus Leonensis*	83	18.00	1143	500
Cypriniformes	Cyprinidae	*Raiamas nigeriensis*	124	0.95	87	0
Cypriniformes	Cyprinidae	*Labeo Coubie*	46	0.50	14	32
Cypriniformes	Cyprinidae	*Garra waterloti*	39	0.43	39	0
Total=7	**12**	**28**	**9,128**	**100.00**	**7,176**	**1,952**

Table 4: Species discriminating the Reservoir and non-impounded segments of the two rivers using SIMPER Analysis

CHALLAWA RIVER Reservoir Vs Below-dam sections			**KANO RIVER Reservoir Vs Below-dam sections**		
Species (74.45%)	**Av. dissimilarity**	**% contribution**	**Species (72.18%)**	**Av. Dissimilarity**	**% contribution**
B.nurse	0.188	27.93	*P. pellucida*	0.247	37.90
S.uraoscopus	0.166	24.64	*S.uraoscopus*	0.077	11.76
O.niloticus	0.104	15.43	*B.leonensis*	0.072	11.02
P.isidori	0.043	6.45	*O.niloticus*	0.040	6.16
			S.galillaus	0.035	5.40

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