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SCHOLARLY, PEER REVIEWED
Volume 25 No. 1
January 2025
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

*Afr. J. Food Agric. Nutr. Dev*. 2024; 25(1): 25501-25519 https://doi.org/10.18697/ajfand.138.25430

| Date | Submitted | Accepted | Published |
|---|---|---|---|
| | 11th March 2024 | 14th October 2024 | 29th January 2025 |


# EFFECTS OF CHALLAWA AND TIGA DAMS ON THE PHYSICOCHEMICAL WATER QUALITIES OF THE BELOW-DAM SECTIONS OF CHALLAWA AND KANO RIVERS, NIGERIA

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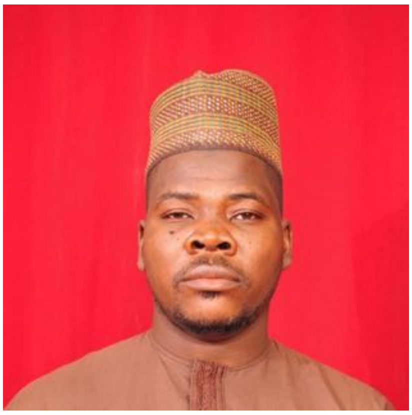

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SCHOLARLY, PEER REVIEWED
Volume 25 No. 1
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ISSN 1684 5374

## ABSTRACT

River impoundment resulting from dam construction leads to substantial alterations in the seasonal flow pattern as well as the physical and chemical qualities of the downstream water. This study assessed the effects of Challawa Gorge-dam and Tiga Dam on physicochemical parameters of surface water in the below-dam sections of Challawa and Kano Rivers, with emphasis on seasonal variations. Eight physicochemical water parameters were assessed at six stations over six months, distinguishing between reservoir and below-dam sections. *In situ* measurements included temperature, dissolved oxygen (DO), pH, electrical conductivity (EC), salinity, and total dissolved solids (TDS) while alkalinity and hardness were determined *ex situ* using titrimetric methods. Significant differences ($p$< 0.05), were observed between reservoir and below-dam sections of the two rivers in some parameters, the others exhibited no significant differences ($p$>0.05). Surface water temperature ranged from 26.90 to 30.10$^{o}$C and 26.60 to 28.00$^{o}$C for Challawa and Kano Rivers, respectively with significant differences ($p$< 0.05) during the dry and wet seasons in Challawa River. Decreasing water temperature at the below-dam sections was observed during the dry season and attributed to hypolimnetic water discharge from the reservoirs. Elevated atmospheric temperature in the dry hot season increases water loss through evaporation and consequently leads to increased concentration of EC, TD, and salinity in the reservoirs. A plausible reason for the higher concentrations of these parameters could be the non-point discharge from surrounding irrigation farms. Higher DO during the dry season was partly attributed to higher rates of photosynthetic production of oxygen as a result of elevated solar radiation, atmospheric temperature, and nutrient related parameters during the period. The variability exhibited by all the parameters in all the sections of the two rivers indicated that the parameters are within favourable ranges suitable for the survival and development of aquatic biota and fit as drinking water for man. Thus, the findings of this study considered water in all sections of the rivers fit for the development and sustainability of freshwater biota. The study concluded by recommending the need for further investigation on the effect of these dams on the distribution and abundance of different aquatic biota in the below-dam sections to guide in the adequate fisheries management measures.

**Key words**: Impoundment, reservoir, hypolimnetic, downstream, dam, discharge, physicochemical, season

## INTRODUCTION

Water, being a critical factor for all living organisms, is indispensable, and any deviation from its natural state poses a significant risk to the livelihood of organisms dependent on it [1]. The well-being of all life forms is intricately tied to the quality of water they inhabit or depend upon. Assessing the physical and chemical parameters of water enables evaluation of its quality, with optimal parameters ensuring the health of living organisms [2]. However, the relentless pursuit to meet the socio-economic demands of the rapid increasing human population has exerted immense pressure on freshwater bodies across most part of the world [3]. Anthropogenic activities, driven by the need for resources to power industrialization, urbanization, and other socio-economic pursuits, have placed enormous stress on these bodies of water. Consequently, most of these human interferences often lead to alterations in the aquatic environment, leaving a lasting effect on the quality of water in these vital ecosystems [4].

Dams are complex engineering edifices usually leading to major transformations in the river's character [5]. Some of the major resulting transformations include changes in water flow patterns, transport of sediments, temperature regimes, and initiation of new items into the aquatic environment. Alterations of this nature have far-reaching consequences on the river's ecological balance, the quality of the river water, and the livelihood of human communities connected with the river [6]. Kano and Challawa Rivers are major upstream tributaries of the Hadejia River that have long been vital lifelines for both the environment and the communities that depend on them [7]. These rivers, while providing support for sustainable agriculture, domestic use, and industrial activities, have also experienced significant transformations in recent decades. Central to these transformations are the dams constructed along the rivers' courses, which have changed the dynamics of these once free-flowing water bodies [8, 9].

Two years after the construction of the Tiga dam on the Kano River in 1974, more than 50 million cubic meters of river water was lost from the reservoir's surface through evaporation. In addition, the downstream experienced a reduction of approximately 100 million $m^3$ per year in river level through water diversion for irrigation agriculture [8]. At the same time, the combined impact of the two major dams constructed in the 1970s (that is, Tiga and Bagauda Dams), water diversion for irrigation farming, and regional climate change have led to a 35% decrease in the Komadugu-Yobe basin, a parent river to the Hadejia-Jama'are river. This fall in the river volume, limited socio-economic benefits, especially at the downstream [10].

Despite all the estimations on water shortage and potential impacts of Challawa Gorge-dam and Tiga Dam on the hydrology and the socio-economic activities of

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Volume 25 No. 1
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ISSN 1684 5374

downstream riparian communities, the influence of the dams on the physicochemical parameters in the sections below the dams remain unknown. This study not only addresses this critical gap but also establishes a crucial baseline for future investigations, as to the best of our knowledge, no prior work has delved into this specific aspect. By examining alterations in physicochemical parameters of the rivers in both the reservoir and below-dam sections during wet and dry seasons, this study aims to unravel the previously unknown impacts. This study also provides valuable insights into the extent to which the water in the different sections of the rivers meets the recommended standards for various human uses, including domestic and municipal water use, agriculture, and the maintenance of healthy aquatic ecosystems and aquaculture.

## MATERIALS AND METHODS

### Study Area

Kano and Challawa Rivers are Hadejia River main upstream tributaries located within Kano State, in the Northwestern Nigeria. Tiga Dam was constructed in 1974 on Kano River with storage water capacity of $1492 \times 10^6$ $m^3$. On the other hand, Challawa Gorge-dam was built on Challawa River in 1992 with water storage capacity of $972 \times 10^6$ $m^3$, irrigation and municipal water supply, and hydro-power generation are main reasons behind the establishment of these two dams [11]. Kano State exhibits a mean annual rainfall of approximately 1,000mm in the far south and little less than 800mm in the extreme north. The state experiences three to five months rainy season. Dry season extends from October to May within which the state encounters months characterized by cool temperature as low as 16$^o$C and as high as 41$^o$C [12].

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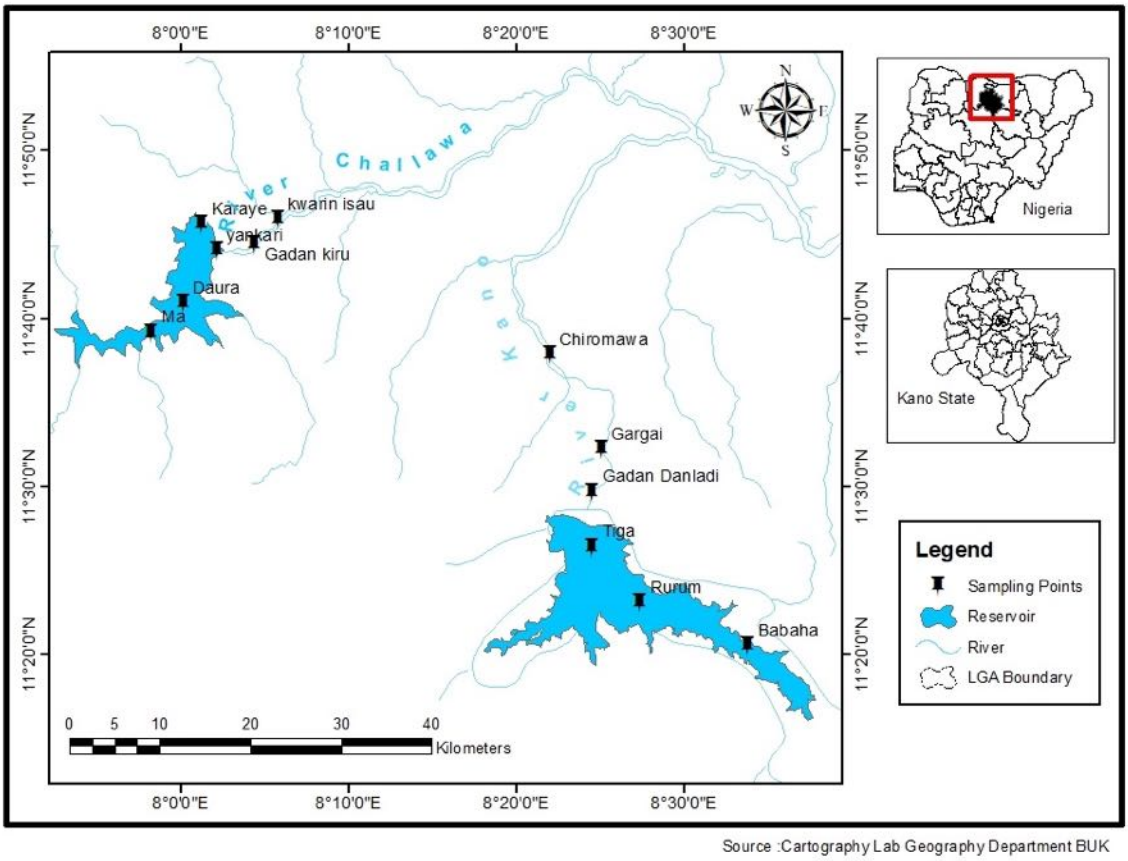


**Figure 1: Map showing sampling locations on Kano and Challawa Rivers**

## Sampling Location

The reservoir and below-dam sections of each of the two rivers were identified and three different sampling locations were made in each section (Fig. 1). Global positioning system (GPS) was used in measuring the geographical coordinates and elevations of the sampling locations (Table 1).

## Water Sampling Procedure

Water samples were collected in triplicate from each sampling station at a depth of approximately 5 cm in the morning (0800–1100 hour) monthly for 6 months. The sampling period was made of 3 months of dry season (April, May and October 2022) and 3 months wet season (July, August and September 2022).

## Analysis of Water Samples

The water parameters measured include water temperature, dissolved oxygen (DO), total dissolved solids (TDS), potential hydrogen ion concentration (pH), alkalinity, hardness, salinity, and electrical conductivity (EC). Water parameters measured *in situ* included water temperature, pH, TDS, salinity, EC, and DO using Exstik® II digital meter and Digital DO meter (Milwaukee DO portable meter-MW600). Calibration of the digital meters was usually done following the manufacture's manuals at each sampling station before use. Samples for total alkalinity and total hardness were collected in 1L plastic sampling bottles and transported in ice for further analyses.

**Alkalinity**

Methyl orange indicator method was used for the alkalinity determination [13]. 50ml sample water was pipetted into a conical flask, 2 drops of methyl orange indicator added and shake for thorough mixture. It was then titrated against $H_2SO_4$ (0.02N) until the solution changes from orange yellow to red. The titre values were used in the following formula to calculate the alkalinity level:

$$Alkalinity(\text{ mg CaCO}_3/\text{L}) = \frac{H_2SO_4\ Volume\ used(titre\ value)X\ 50X1000}{Volume\ of\ sample}$$

**Hardness**

50ml water sample was pipetted into conical flask, 2.5 ml of ammonia buffer was added and 2 drops of Erichrome black T indicator was added after shake. The mixture was titrated against (0.01N) EDTA until it changes from wine red to blue colour [14]. The titre value was used in the following expression to calculate the Total Hardness value of the water samples:

$$Total\ Hardness(\text{mg CaCO}_3/\text{L}) = \frac{Volume\ of\ EDTA\ used(titre\ value)X\ 50X1000}{Volume\ of\ sample}$$

**Data Analysis**

Water quality and geographical coordinate readings were recorded in Microsoft 2016 Excel sheets for easy access for data processing, storage and analysis. The physicochemical data were documented in Microsoft Excel 2016 office. Since most of the water parameters' data exhibited non-normal distribution based on Shapiro-Wilk test, Mann–Whitney U tests were employed as a non-parametric technique to assess significant differences ($p$< 0.05) among each water parameter between reservoir and below-dam sections during both dry and wet seasons. Statistical analyses were done in R statistical software.

## RESULTS AND DISCUSSION

**Surface Water Temperature**

The results of the surface water temperature revealed significant differences ($p$<0.05) between the reservoir and the respective below-dam sections of each of the two rivers. The study unveiled a noticeable trend of decreasing temperature as water moves from the reservoirs into the below-dam stations as depicted in Figures

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SCHOLARLY, PEER REVIEWED
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PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
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2 and 3. Notably, the reservoir sections attained peak of surface water temperatures during the dry season at mean values 30.10 and 28.00°C for Challawa and Kano Rivers, respectively (Tables 2 and 3). These findings concur with the established fact that surface water temperatures are influenced by the exchange of heat between water and the atmosphere [15]. Given that the atmospheric temperature around the study area could be as high as 38.2°C during the hot period of dry season [16], it is evident that local weather conditions play a crucial role in influencing surface water temperatures.

However, contrary to the expectation of proportional rise in the surface water temperature of the below-dam sections of the two rivers due to the influence of the elevated atmospheric temperature during hot dry season period, water temperature remains relatively lower. This was in contrast with the outcome of an investigation on the water quality status of an undammed upstream section of Galma River located within the same Northwestern region as the present study [17]. A plausible reason for the lower water temperature in the below-dam sections could be attributed to the discharge of hypolimnetic (bottom layer) water from the reservoirs. This observation aligns with the understanding that dams disrupt natural temperature patterns downstream, consequently altering natural habitats and inducing changes in the structure of aquatic community at the downstream [18].

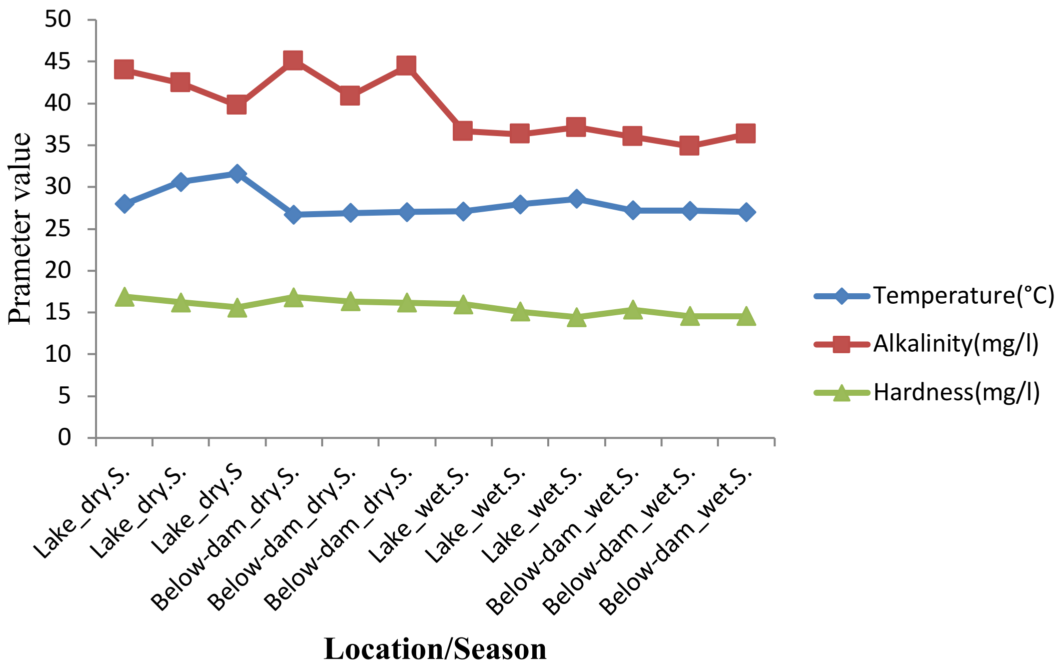


**Figure 2: Temperature, Alkalinity and Hardness of Challawa River Surface water**

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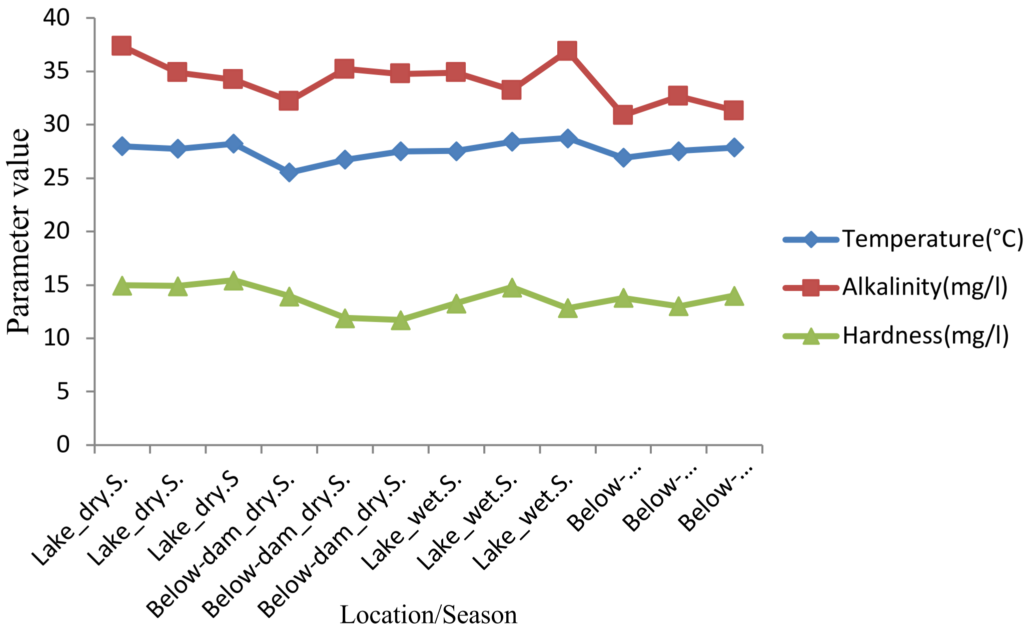


**Figure 3: Temperature, Alkalinity and Hardness of Kano River Surface water**

## Dissolved Oxygen (DO)

Significant difference ($p$<0.05) in DO levels between the reservoir and below-dam sections of the Challawa River during the dry season was observed, with highest mean DO values of 6.16 and 6.76 mg/l recorded in the reservoir and below-dam sections, respectively during this period (Table 2 and Figure 4). The respective sections of Kano River also exhibited higher DO in the dry season than during the wet season but with no significant difference ($p$<0.05) between the sections (Table 3 and Figure 5). Dissolved oxygen (DO) in aquatic environments primarily comes from photosynthesis by aquatic plants and diffusion from atmospheric oxygen [19]. Influence of season on water DO as observed in this study could be attributed to increased rates of oxygen production from photosynthetic aquatic plants, facilitated by favourable conditions related to higher salinity levels and other related factors that are more available during the dry season. The elevation of oxygen production occurs during most parts of the dry season when solar energy, salinity, and low water turbidity prevail [17]. In addition, the cool harmattan wind which increases wave action during the dry season could further facilitate the diffusion of atmospheric oxygen, thereby increasing DO concentrations in the surface water [20]. Oxygen consumption through decomposition of organic materials could also be lower during the dry season as influx of organic materials into the river systems through erosion and run-offs are minimal [17]. This could also be a plausible reason for the observed higher DO concentration during the dry season. However, it is noteworthy that the mean DO record for both the reservoir and below-dam sections of the Challawa (4.27 & 4.23 mg/l) and Kano (4.39 & 4.49 mg/l) rivers are above the 4mg/l recommended

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level for maintaining healthy condition of fish [21]. Importantly, these values are above the 2mg/l threshold that could pose a risk to the life of fish [22, 23].

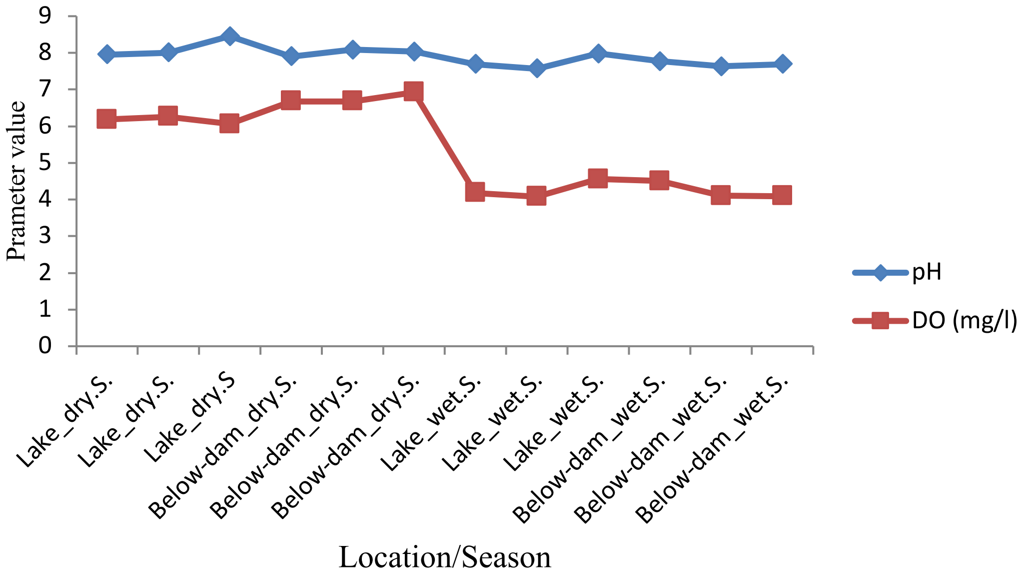


**Figure 4: Hydrogen Ion and Dissolved oxygen concentrations in Challawa River surface water**

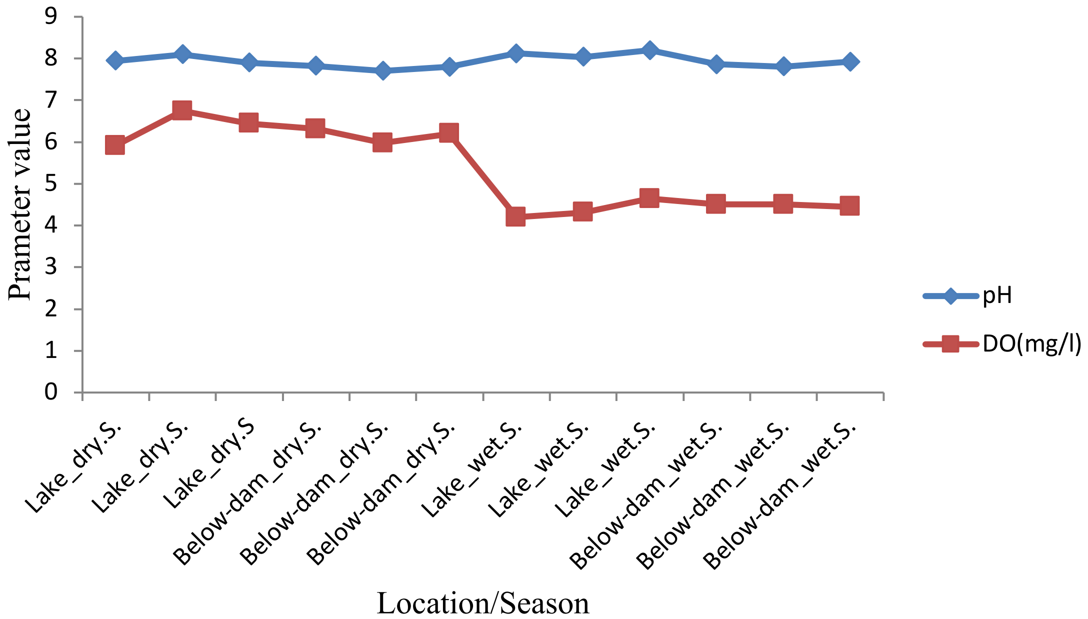


**Figure 5: Hydrogen Ion and Dissolved oxygen concentrations in Kano River surface water**

## Water pH

The variation in surface water pH revealed a significant difference ($p<0.05$) between the reservoir and below-dam sections of the Kano River during both dry and wet seasons (Table 3). The Challawa River exhibited no significant differences ($p$>0.05) between the two sections of the river neither in the dry season nor during the wet season (Table 2). Despite these distinctions, the numerical differences between the pH values of the two river sections were not considerably different (Figure 4 and 5). Specifically, the ranges of water pH in the Challawa River sections were 7.40-8.14, and 7.77-8.12 for Kano River. It's noteworthy that all these values falls within the WHO permissible limits of 6.5 to 8.4 for irrigation farming and 6.5 to 9 for aquaculture [22, 23].

**Electrical Conductivity (EC), Total Dissolved Solids (TDS) and Salinity**

The seasonal variation in the values of EC, TDS, and salinity revealed significant differences ($p$<0.05) among each of the parameters in the reservoir and below-dam sections of the Challawa River during period of dry season (Table 2 and Figure 6). Conversely, there were no significant differences ($p$>0.05) among each of the parameters in the Tiga reservoir and its below-dam sections of Kano River (Table 3 and Figure 7). Ranges of the three water parameters recorded from Challawa River were as follows: EC (104.00-249.00 μS/cm), TDS (73.80-179.00 mg/l), and Salinity (50.00-104.00 mg/l). In comparison, each of the parameters in Kano River ranges from 89.50-227.00 μS/cm (EC), 73.80-149.00 mg/l (TDS) and 43.30-107.00 mg/l (salinity). The EC values recorded complied with the recommended limits of <600mS/m [24]. It is undesirable for EC values of surface water to exceed 1000 μS/cm [18]. Total dissolved solids(TDS) values obtainable were below the 500-1000mg/l range prescribed for drinking water [23, 24]. The salinity levels recorded from the different sections of the two rivers were below 1000mg/l limit that could lead to adverse effect on aquatic biota if exceeded and expose people drinking such to risk of hypertensiveness [25].

Given the inter-connectedness of temperature with many other parameters, higher water temperatures facilitate water loss through evaporation. As evaporation exceeds precipitation, particularly during the dry season, it contributed to increased concentrations of water salinity, EC, and TDS during the period. Additionally, the reservoirs sections exhibited higher concentrations of these water parameters due to the movement of nutrients from surfaced runoffs from surrounding irrigation farms and from particulate matters in the inundated terrestrial margins [26, 27].

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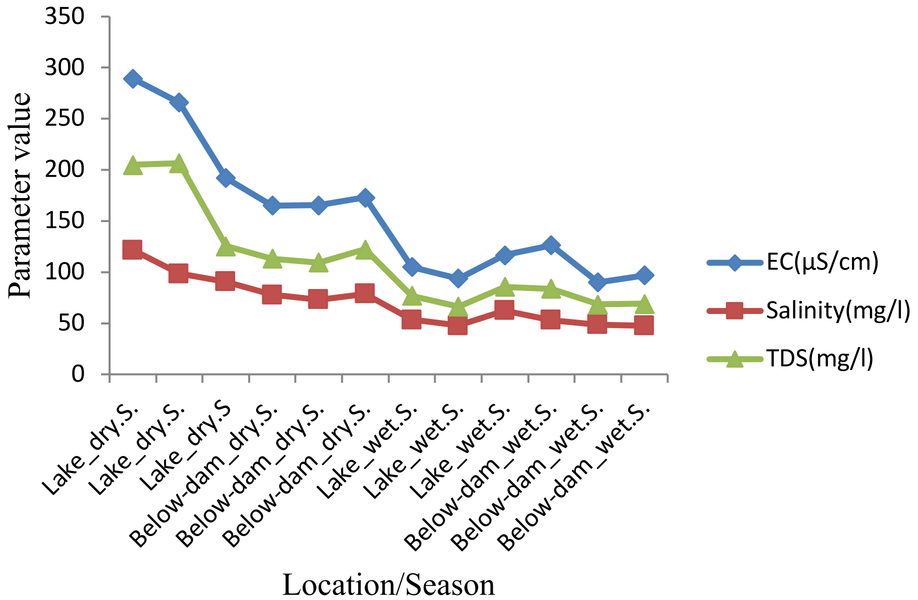


**Figure 6: Electrical conductivity, salinity and total dissolved solids concentrations in Challawa River surface water**

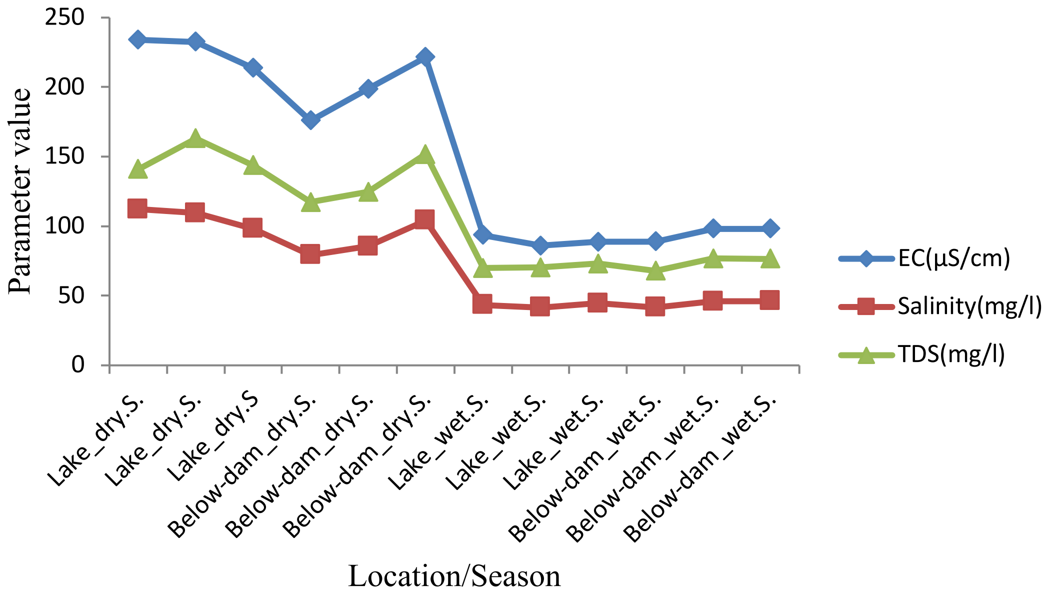


**Figure 7: Electrical conductivity, salinity and total dissolved solids concentrations in Kano River surface water**

## Alkalinity and Hardness

Alkalinity and hardness are vital water quality parameters with implications on the use of water for municipal water supply, aquatic organism productivity, and aquaculture [14]. Alkalinity stands for water's buffering capacity against changes in acidity and ensuring pH stability. Hardness represents the concentration of divalent cations in water, determining the usability of water for municipal purposes and affecting the efficiency of engineering and metallic materials [13]. Alkalinity shows significant difference ($p$<0.05) between the reservoir and below-dam sections only in the Kano River during the wet season (Table 3 and Figure 3). Notably, in the Challawa River, the water Alkalinity ranges from 35.70 to 43.50 mg/l while water hardness ranged between 14.80 to 16.40 mg/l (Table 2 and Figure 2). Conversely, in the Kano River, the Alkalinity values ranges from 31.60 to 35.50 mg/l while hardness was from 13.20 to 15.10 mg/l. The alkalinity levels of the sections of the two river falls within the recommended 5- 500 mg/l for fresh waters. On the other hand, hardness of the rivers' sections was within the range of soft water (0 to 75 ppm $CaCO_3$). However, the reservoir sections of the two rivers seem to meet up with the 15mg/l minimum water hardness required for optimum health of warm water fishes [28].

## CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

The presence of dams in Challawa and Kano Rivers has significant and varied effects on the physicochemical parameters of their respective below-dam river waters. The study highlights alterations in key water parameters across the river sections mainly caused by the alteration of river flows caused by the dams. Some consequential factors leading to changes in the parameters between the lakes and below-dam sections are linked to the alteration in water temperature of the below-dam sections. The change was due to discharge of cold layer water in to the below-dam sections. The non-point discharge of nutrients from irrigation farms and terrestrial inundated areas by the lake also contributed to the observed differences in concentrations of the parameters.

The study places emphasis on the alterations in surface water temperature across the various sections of the two rivers attributing these changes to impoundments. It interrelates influence of thermal changes on other parameters. The significance of the observed physicochemical parameters of surface water of the rivers was assessed in relation to standard recommendations for diverse water uses. To comprehensively grasp the effects of the constructed dams on the Challawa and Kano Rivers, it is important to delve into their impacts on diverse biota communities inhabiting various habitats of the rivers. Information on such investigations will facilitate accurate assessments of the repercussions on indigenous organisms, providing crucial baseline information for ecosystem restoration and effective fisheries 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 Interest**

The authors declared no conflict of interest.

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**Table 1: Locations and coordinates of the sampling stations**

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

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**Table 2: Mean (±SEM) and results of Mann–Whitney U test among water parameters of the two sections in the Challawa River during dry and wet seasons**

| | Dry Season | | | | Wet Season | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Lake** | **River** | **W-Value** | **P-Value** | **Lake** | **River** | **W-Value** | **P-Value** |
| DO (mg/l) (Mean±SEM) | 6.16±0.09 | 6.76±0.11 | 142.50 | 0.000 | 4.27±0.07 | 4.23±0.06 | 379.50 | 0.801 |
| pH (Mean±SEM) | 8.14±0.05 | 8.01±0.02 | 425.50 | 0.294 | 7.40±0.07 | 7.70±0.03 | 302.00 | 0.283 |
| Temp. (°C) (Mean±SEM) | 30.10±0.52 | 26.90±0.14 | 631.50 | 0.000 | 27.90±0.17 | 27.10±0.14 | 531.00 | 0.004 |
| TDS (mg/l) (Mean±SEM) | 179.00±18.10 | 115.00±7.36 | 534.00 | 0.003 | 76.20±7.15 | 73.80±7.27 | 371.00 | 0.917 |
| EC (µS/cm) (Mean±SEM) | 249.00±23.60 | 168.00±10.20 | 522.00 | 0.007 | 105.00±8.50 | 104.00±8.87 | 343.50 | 0.723 |
| Salinity (mg/l) (Mean±SEM) | 104.00±8.89 | 76.40±4.84 | 534.50 | 0.003 | 54.50±3.21 | 50.00±2.92 | 421.50 | 0.328 |
| Alk.(mg/l $caco_3$) (Mean±SEM) | 42.10±1.54 | 43.50±1.50 | 317.00 | 0.409 | 36.70±1.84 | 35.70±1.95 | 410.00 | 0.432 |
| Hard. (mg/l$caco_3$) (Mean±SEM) | 16.20 ±0.23 | 16.40±0.31 | 343.50 | 0.719 | 15.20±0.35 | 14.80±0.44 | 412.00 | 0.411 |

TDS=Total dissolved solids; EC=Electrical conductivity, Alk. = Alkalinity; Hard. =Hardness, W=Mann-Whitney statistic, *p*<0.05

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**Table 3: Mean (±SEM) and results of Mann–Whitney U test among water parameters of the two sections in the Kano River during dry and wet seasons**

| | Dry Season | | | | Wet Season | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Lake** | **River** | **W-Value** | **P-Value** | **Lake** | **River** | **W-Value** | **P-Value** |
| DO (mg/l) (Mean±SEM) | 6.34±0.10 | 6.16±0.08 | 434 | 0.230 | 4.39±0.16 | 4.49±0.19 | 356.50 | 0.896 |
| pH (Mean±SEM) | 7.98±0.05 | 7.77±0.04 | 518.50 | 0.008 | 8.12±0.03 | 7.86±0.03 | 662.50 | 0.000 |
| Temp. (°C) (Mean±SEM) | 28.00±0.77 | 26.60±0.42 | 472.00 | 0.064 | 27.90±0.18 | 27.40±0.18 | 491.00 | 0.029 |
| TDS (mg/l) (Mean±SEM) | 149.00±15.20 | 131.00±14.30 | 419.00 | 0.350 | 71.20±8.46 | 73.80±8.53 | 280.50 | 0.149 |
| EC (µS/cm) (Mean±SEM) | 227.00±23.60 | 198.00±22.30 | 450.00 | 0.141 | 89.50±8.51 | 95.10±9.56 | 309.50 | 0.346 |
| Salinity(mg/l) (Mean±SEM) | 107.00±11.40 | 89.60±9.56 | 420.50 | 0.337 | 43.30±4.44 | 44.50±4.13 | 275.00 | 0.123 |
| Alk. (mg/lcaco$_3$) (Mean±SEM) | 35.50±1.36 | 34.10±0.85 | 423.00 | 0.313 | 35.00±0.93 | 31.60±0.72 | 521.00 | 0.006 |
| Hard. (mg/lcaco$_3$) (Mean±SEM) | 15.10±0.54 | 13.20±0.32 | 516.00 | 0.009 | 13.60±0.40 | 13.60±0.29 | 343.00 | 0.711 |

TDS=Total dissolved solids; EC=Electrical conductivity, Alk. = Alkalinity; Hard. =Hardness, W=Mann-Whitney statistic, $p<0.05$

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Since 2001 ajfand AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 25 No. 1
January 2025
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374


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