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RESEARCH PAPER

Seasonal Variations in Some Physico-Chemical Parameters of Selected Inland Water Bodies in Niger State Nigeria

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ABSTRACT

Niger state is blessed with a lot of inland water bodies including Numu Pond, Bosso Dam, Shiroro Dam, Tagwai Dam, Kainji Lake, Chanchaga River, and a host of others. These water bodies are important ecosystems since they are being used for irrigation purposes, domestic purposes such as washing, cooking, and bathing, fishing as a source of livelihood, flood control and transportation. Physico-chemical properties of some of these inland water bodies in Niger state were investigated seasonally from the wet season of 2019 to the dry season of 2021 to determine seasonal variation, as well as providing a baseline data for monitoring water quality changes prompted by human induced factors. Surface water samples were collected and analyzed using standard methods. A two – way analysis of variance (ANOVA) was used to evaluate relationships between environmental variables and the inland water bodies with R-satistica. Findings revealed that mean temperature ranged from 28.2 to 30.3°C, neutral to weak alkaline pH range of 7.1 to 8.8, dissolved oxygen concentration (2.53-3.83 mg/l) was marginally low, while the BOD_5 (0.75-1.13 mg/l) was relatively high. The essential primary productivity nutrients, Nitrogen (0.25-2.0 mg/l), Phosphate (0.11-1.64 mg/l) and Sulphate (9.60-29.36 mg/l) were relatively high in all the sampled inland water bodies. Chlorophyll-a (1.9 µg/L-5.8 µg/L) was relatively low in all the inland waterbodies. These inland water bodies are mostly mesotrophic in nature and thus require effective management strategies to ameliorate their status. Some of the physicochemical properties varied significantly ($p<0.05$) among the water bodies and with wide fluctuations across the seasons, however nearly all values obtained were within the recommended limit for fish production.

Keywords: Inland water bodies, Seasonal variations, Environmental variables, Human activities.

INTRODUCTION

Niger state is blessed with a lot of inland water bodies including Numu Pond, Bosso Dam, Shiroro Dam, Tagwai Dam, Kainji Lake, Chanchaga River, and a host of others. These water bodies are important ecosystems since they are being used for irrigation purposes, domestic purposes such as washing, cooking, bathing, and fishing as a source of livelihood, flood control and transportation. Other uses include damming them for the supply of drinking water and for recreational purposes. (Mbuligwe and Kaseva, 2005; Yillia, 2008; Imaobong *et al*., 2015).

These water bodies are exposed to anthropogenic pollutants generated from human influences for instance a portion of Tungan kawo dam Wushishi is filled with harvested rice selves, and it may become a norm thereby giving rise to serious pollution problems. Others are being affected by oil spills from engine boats, run-off of fertilizers from farmlands near the water bodies, and detergents being introduced into the water bodies because of laundry as well as other activities. All these activities bring about pollution of these water bodies which will affect not only the biotic ecosystems of these water bodies but also the people's health living around the environment that depend on these water bodies and their functions (Mohammed, *et al*., 2018).

Environmental variables such as temperature (air and water), Conductivity, pH (Hydrogen concentration), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Depth, Alkalinity, Total Dissolve Solid, Phosphate, Nitrate, Chlorophyll- *a* and others are used to assess the quality of water (Goldman and Horne,

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1983; Boyd and Tucker, 1998; Idowu, *et al*., 2013). The use of diverse methods for water quality monitoring is of importance to the management of fisheries, pollution, water supply, sewage treatment reservoirs and freshwater impoundments. These inland water bodies were constructed for domestic consumption and for other uses such as irrigation, and transportation. There is a dearth of information on some selected physico-chemical parameters of these inland water bodies. The present investigation is aimed at filling the information gap and contributing to the knowledge of the limnology of inland water bodies. This study is necessary and timely especially as it will provide the opportunity for monitoring changes in the physical and chemical status of the inland water bodies which will help to initiate policy for the overall management of the ecosystem health and productivity.

METHODOLOGY

Study Area

Niger State was created in the year 1976, it lies within the Longitude 3 º 30' E to 7º 40' E and Latitude 8°00'N to 11º 30' N covering a land area of 76,469.903km^2 with an estimated population of about 3,954.772 (Three Million. Nine Hundred and Fifty -Four Thousand, Seven Hundred and Seventy-Two) people as at 2006 estimate (National Population and Housing Census, 2006).

Climate

Niger State experiences distinct dry and wet seasons with annual rain fall varying from 1,100mm in the northern parts to 1,600mm in the southern parts. The maximum temperature (usually not more than 41 º C) is recorded between March and June, while the minimum is usually between December and January. The rainy seasons last for about 120 days in the northern parts to about 150 days in the southern parts of the State. Generally, the fertile soil and hydrology of the State permits the cultivation of most of Nigeria's staple crops and still allows sufficient opportunities for grazing, freshwater fishing and forestry development. (Niger State Bureau of Statistics, 2012).

Vegetation

Niger State vegetation is a Guinea Savannah characterized by wood lands and tall grasses interspersed with tall dense species. However, within the Niger trough and flood plains occur taller trees and a few oils palm trees. In some areas traces of rain forest species can be seen (Yusuf *et al*., 2017).

Sampling Techniques

Ten lentic water bodies spread across the three geographical zones of the State was studied. They include, Bakajeba dam, Bosso dam, Danzaria lake, Tungan Kawo reservoir Kontagora, Shiroro dam, Tagwai dam, Jamila Ville farm lake, Earthen dam Gawu Gaube , Tungan Kawo dam Wushishi and Zungeru dam. The GPS coordinates of the ten inland water bodies and their primary usage are shown in table1. The map of Nigeria, Niger State and the sampled water bodies and points are shown in Figure 1. Sampling of the ten inland water bodies was carried out twice a year, once in the wet season and once in the dry season beginning from June 2019 to October 2019 for the wet season and November 2019 to March 2020 for the dry season. This process was repeated for the wet season from April 2020 to October 2020 and November 2020 to March 2021 for the dry season towards the end of every month between 9am and 11.30am every sampling day.

Table 1: The GPS Coordinates of the ten inland water bodies and their primary usage

Reservoirs	Latitude	Longitude	Primary usage
Bakajeba Dam	9.240554	6.621295	Water supply
Bosso Dam	9.678719	6.531333	Water Supply
DanZaria Lake	9.510421	6.451508	Irrigation
Tungan Kawo Reservoir Kontagora	10.41066	5.341788	Water supply
Earthen Dam Gawu	9.268016	6.974819	Irrigation
Shiroro Dam	9.915276	6.831636	Hydro-electrical power, water supply
Tagwai Dam	9.573668	6.661405	Water supply
Jamila Ville farm Lake	9.549314	6.512537	Irrigation
Tungan Kawo Dam (Wushishi)	9.653963	6.112435	Irrigation
Zungeru Dam	9.902767	6.293253	Hydro-electrical power

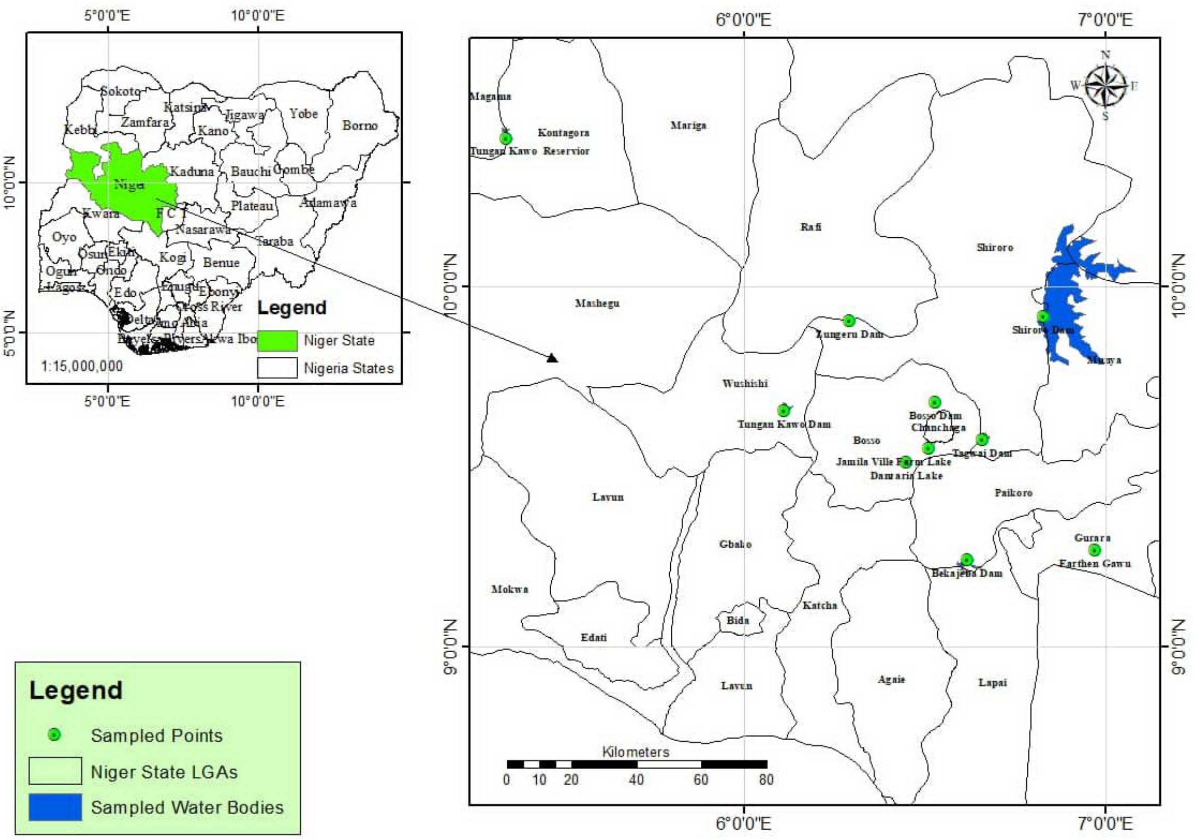

Figure 1: Maps showing Nigeria, Niger State, and the selected sampling points on the inland water bodies.

Physico-chemical parameters

Air shade and water temperature, Dissolved Oxygen (DO) were taken in-situ and Biochemical Oxygen Demand (BOD) after five days using a multi-probe potable meter model JBP 607. Hydrogen Ion Concentration (pH), Electrical Conductivity and Total Dissolved Solid (TDS) were determined in situ using the HANNA CROCHEK meter model HI9813. (APHA, 2017). The turbidity of water was measured with turbidity probe (Nathanson, 2003). The nitrate and phosphate concentrations in the water samples were determined by spectrophotometric method (APHA, 2017) and sulphate was determined by turbidimetric method as reported by Golterman and Clymo (1969) and Chlorophyll a was determined using the method described by Holm-Hanson (1978). Chlorophyll-*a* was recorded in µg/l and the indication of the result that was obtained as shown on Table 2.

Data Analysis

Range means and standard error for each parameter and water body was calculated. Physical and chemical features of water bodies was compared using two-way ANOVA on log(x+1) transformed data but the pH was not transformed by any method but left as it was . Fix effect ANOVAs was performed using data as replicate. Significant ANOVAs ($p<0.05$) was followed by post hoc {Tukey Honest significant differences (HSD)} tests to identify differences between water bodies means and the waterbody that differ since it will clearly identify the waterbodies with significant differences in their physico-chemical parameters.

Table 2: Lake Trophic State Indicator

Lake Trophic State	Chlorophyll-*a*
Oligo-Mesotrophic	≤ 2.50
Mesotrophic	2.51-7.20
Slightly Eutrophic	7.21-11.99
Fully Eutrophic	12.00-19.99
Very Eutrophic	20.00-29.99
Lower Hypereutrophic	30.00-53.99
Upper Hypereutrophic	≥ 56.00

Source: Kansas Department of Health and Environment (KDHE) (2011).

RESULTS

Environmental Variables

The summary of some physico-chemical parameters of the studied inland water bodies in Niger State is shown in Table 3. The mean Water temperature for the inland water bodies ranges from 26.13°C (Shiroro dam) to 30.30°C (Bakajeba dam). There were fluctuations in the electrical conductivity values recorded for the inland water bodies. The mean range was from 46µS cm^{-1} (Shiroro Dam) to 190.5µS cm^{-1} (Danzaria Lake), while the highest mean value mg/L of the total dissolved solid was recorded at Danzaria Lake and the lowest value of 72.33 at Shiroro Dam. The dissolved Oxygen mean ranged from 2.53 mg/L (Tungan Kawo Reservoir) to 3.83 mg/L (Bosso Dam).

Biochemical Oxygen Demand mean value after 5days incubation in the dark was rather low for all the inland water bodies with Tagwai and Tungan Kawo Reservoir having lower values of 0.75 mg/L and 0.78 mg/L respectively.

The overall pH characteristics was between alkalinity to neutrality in all the inland water bodies. However, the range of the mean value was from 7.1 at Jamila Ville farm Lake to 8.8 at Tungan Kawo Reservoir and Shiroro Dam respectively. The essential primary productivity nutrients, Nitrate (0.25 mg/L at Earthen dam Gawu to 2 mg/L at Jamila Ville farm Lake), Phosphate (0.11 mg/L at Shiroro Dam to 0.88 at Zungeru Dam) and Sulphate (7.5mg/L at Danzaria Lake to 29.36 mg/L at Earthen Dam Gawu) were relatively high in all the inland water bodies. The mean Chlorophyll-*a* concentration (1.9 µg/L at Zungeru Dam to 5.53 µg/L at Tungan Kawo Lake) was relatively low. Bosso dam and Tagwai dam had mean high concentration of Chlorophyll-a (5.8 µg/L), followed by the Earthen dam Gawu and Jamila Ville Lake having relatively high concentration of Chlorophyll-a too (5.5 &5.6 µg/L). On the other hand, Wushishi dam had the lowest mean concentration of chlorophyll-a (1.9 µg/L).

The mean concentration for Chlorophyll-*a* obtained from different studied selected inland waterbodies varied from 1.9 µg/l to 5.8 µg/l. The results indicated that the Chlorophyll-*a* concentration of all the selected inland waterbodies was low to moderate.

In general, there were significant differences ($p>0.05$) for the following parameters across the inland water bodies and in between the seasons as shown on table 4. These parameters includes Electrical conductivity, Total Dissolved Solids, pH, Turbidity, Total Hardness, Total Alkalinity and the nutrients, Nitrate, Phosphate and Sulphate and Chlorophyll-*a*.

Temporal Variation of Some Physico-chemical parameters of the Inland water bodies in Niger State

There were no significant differences in the temporal variation of the physico-chemical parameters across the seasons in the inland waterbodies in Niger State except for electrical conductivity, total dissolved solids, turbidity, total alkalinity and phosphate during the dry season in the period of this study as shown in Figure 2a-e.

DISCUSSION

The marked variation and significant differences in physico-chemical parameters of the inland water bodies indicate different environmental conditions. These variations may be related to patterns of water use, temperature, and rainfall (Ayoade *et al*., 2006; Abolude, 2007; Atobatele and Ugwumba, 2008; Oso and Fagbenro, 2008; Usman, 2015).

The mean water temperature obtained in this study was typical of tropical inland fresh water and rivers (Arimoro *et al*., 2017). Temperatures were relatively higher throughout the period of the study from the wet season of 2019 to the dry season of 2021 across the study inland water bodies. The lowest mean water temperature was recorded at Shiroro dam (26.13ºC) while the highest mean water temperature was recorded at Bakajeba dam (30.3°C). Bosso dam, Danzaria lake, Tungan kawo reservoir, Tagwai dam, Jamila ville lake, Tungan Kawo dam Wushishi, Zungeru dam, and Earthen dam Gawu had high temperature mean values of 28.33ºC, 28.45°C, 28.68°C, 28.15°C, 28.25°C, 28.83°C, 28.68°C and 29.80ºC. This result agreed with previous reports that the temperatures in tropics vary between 21ºC and 32ºC (Kramer and Botterweg,1991; Atobatele and Ugwumba, 2008; Usman, 2015; Akachukwu *et al*., 2019).

The hydrogen ion concentration (pH) of water is important because many biological activities can occur only within a narrow range of pH. Thus, any variation beyond acceptable range could be fatal to aquatic organisms. The pH mean values were slightly natural to alkaline during the sampling period and fluctuated between 7.1 and 8.8 with the lowest pH mean value 7.1 at Jamila Ville Lake and the highest mean 8.8 at Tunga kawo reservoir and Shiroro dam respective. There were significant seasonal variations of pH amongst the inland water bodies and though this study did not have a predictable seasonal pattern, there were a number of high pH values (>8) recorded in some of the inland water bodies during the rainy season of 2019 due to landscape runoff into the waters and during the dry season of 2019 due to evaporations and concentration of the ions owing to the surrounding rocks such as limestone which increases the pH, and due to decrease in the water levels and concentration of nutrient in the inland water bodies (Narayana *et al*., 2008; Qureshimatv *et al*., 2015; Abdullahi *et al*., 2015). The pH range observed during the study period was slightly acidic to slightly alkaline (5.1-10.1) throughout the seasons of study, and it was slightly above the range for inland waters (pH 6.5 - 8.5), as reported by Teame and Zebib (2016). Thus, the pH range obtained in this study was not within the acceptable level of 6.5 to 8.5 for the recommended levels for drinking water (WHO, 2011). Nigerian Standard for Drinking Water Quality (NSWQ 2015)) recommended pH 6.5- 8.0 for drinking water. However, it will support aquatic life (Ayanwale *et al*., 2018; Kinta *et al*., 2021) The pH range obtained in this study compares well with those of Tungan Kawo reservoir whose pH was high throughout the study of the reservoir (Kinta et al., 2021) but is in contrast with Usman (2016) who reported that pH level of Ajiwa reservoir was within the acceptable recommendation for drinking water.

The level of conductivity in water gives a good indication of the amount of substances dissolved in it, such as phosphate, nitrate and nitrites. Different ions vary in their ability to conduct electricity (Zeb *et al*., 2011). Generally, conductivity of the natural water is directly proportional to the concentration of ions (Usman, 2015). Conductivity levels below 50 µS/cm are regarded as low; those between 50-600 µS/cm are medium while those above 600 µS/cm are high (Anago *et al*., 2013). Therefore, the mean Conductivity value for the period of this study in all the study inland water bodies of 46µS/cm -190 µS/cm shows that the conductivity of the inland water bodies was low to medium. The seasonal variation of Conductivity values of all the inland water bodies fluctuated between 10µS/cm-406 µS/cm. The trend in some of the inland water bodies studied was that conductivity tend to decrease in the wet season and increased during the dry season. This was observed at Bakajeba dam, Bosso dam, Danzaria lake, Tungan Kawo dam Wushishi, and Earthen dam Gawu. Increased conductivity during the dry season was enhanced by increased water evaporation and upwelling from wind, wave, and tide (Olele and Ekelemu, 2008; Usman, 2015). This result is in conformity with the report of Oben, (2000) who reported an increase in conductivity values during the dry season and attributed this to evaporation. Furthermore, Elleta (2005) opined that ion were lower in the wet season then in the dry season since conductivity declines in the wet period as the concentration of salts becomes dilute. This also support the findings on this study. On the other hand, another trend was observed for the other inland water bodies studied. The conductivity tends to increase in the wet season and decrease in the dry season as observed at Tungan kawo reservoir, Shiroro dam, Jamila ville lake, and Zungeru dam. The high level of Electrical conductivity during the wet season can, therefore, be attributed to the anthropogenic activities at the immediate surroundings of these inland water bodies shore which include (but not limited to) runoff from farmlands and domestic waste, of which similar observations were made by Bhat *et al*. (2014) and it is also in conformity with Mustapha, (2009) and Teame and Zebib (2016) who reported lower value of Conductivity obtained in the dry season.

The mean dissolved oxygen values obtained during the period of study for the inland water bodies Bakajeba, Bosso dam, Danzaria lake, Shiroro dam, Jamila ville lake, Tungan Kawo dam Wushishi, Zungeru dam and Earthen dam Gawu were low (3.05mg/L, 3.83mg/L, 3.65mg/L, 3.10mg/L, 3.48mg/L, 3.10mg/L, 3.35mg/L, and 3.23 mg/l), while that of Tungan kawo reservoir and Tagwai dam were very low (2.53mg/L and 2.63mg/L). This result is not in conformity with the works of Adedeji *et al*., 2019 who recorded high mean dissolved oxygen at Lake Ribadu, Adamawa state and attributed it to low temperature. However, low primary productivity caused by low transparency and low nutrient load was implicated for low oxygen content of the inland water bodies (Kadiri and Omozusi, 2002). Seasonal variation of Dissolved Oxygen for all the inland water bodies studied shows fluctuations from high to low and low to high. The high oxygen value for the dry season coincides with periods of lowest turbidity and temperature. The amount of dissolved oxygen in water has been reported not to be constant but fluctuates, depending on temperature, depth, wind and amount of biological activities such as degradation (Usman, 2015). The cool harmattan wind which increases wave action and decrease surface water temperature might have contributed to the increased oxygen concentration during the dry season, while the torrential rains, created increased turbidity and decreased oxygen concentration during the wet season. Abolude (2007) and Usman (2015) made similar observation on A.B.U Zaria reservoir and Wawan Rafi lake in Kazuare respectively. In general, the inland water bodies were within the permissible limits of water (NIS, 2015). The work agrees with Ayoade *et al*. (2007) and Abubakar *et al*. (2015) and Kinta *et al*., (2021) who worked on Dadin-kowa reservoir and Tungan Kawo reservoir recorded a Dissolved Oxygen level of (2.73 to 4.92 mg/L and 2.4 to 5.2 mg/L respectively) which indicates a thriving basis for aquatic organisms.

Biochemical oxygen demand (BOD) indirectly depicts the amount of putrescible organic matter degradable by microbial metabolism on the assumption that the water medium has no bacteriostatic effects. Adakole *et al*. (1999); Abolude (2007); Idowu & Gadzama (2011) and Abolude *et al*., (2012) reported that BOD is a fair measure of cleanliness of any water on the bases that values of less than 2 mg/l are clean, 3 -5 mg/l, fairly clean and 10 mg/l definitely bad and polluted. The mean BOD values in Tagwai dam, Tungan Kawo Reservoir, Kontagora, Tungan Kawo dam Wushishi, Jamila Ville lake, Bakajeba dam were relatively low (0.75 mg/L, 0.78mg/L, 0.9mg/L, 0.9mg/L, and 0.98mg/L) when compared with Bosso dam, Danzaria lake, Shiroro dam, Zungeru dam, and Earthen dam Gawu (1.75mg/L, 1.03mg/L, 1.13mg/L, 1.1mg/L, and 1.07mg/L). The seasonal variation of BOD values in Bakajaba Dam, Shiroro dam and Tagwai dam were high in the wet season but low in the dry season though the values are less than 2mg/L which indicates that they are clean but the increase in the value of the BOD during the wet season could be as the result of inflow of organic matter into these inland water bodies. This is in conformity with the findings of Usman (2015) who recorded high BOD values in the wet season at Wawan Rafi lake Kazaure and attributed it to the higher organic matter washed into the lake due to runoffs from surrounding lands in the rainy season. In Bosso dam and Earthen dam Gawu, the BOD was high in the dry season but low in the wet season 3.9mg/L and 1.2mg/L, which indicates fairly clean and clean water. This could probably be because of the dead and decay of the aquatic organisms at these inland water bodies. This is in conformity with the findings of Usmam (2016) who recorded high BOD values (2.28 and 0.85mg/L) in Ajiwa Reservoir, Katsina State and attributed it to the period of oxygen consumption by decomposers on the biodegradable materials and evaporations in the dry season. Furthermore, the BOD values of Danzaria lake, Jamila Ville Farm lake, and Zungeru dam fluctuated all through the seasons. This fluctuation could be because of high organic matter washed into the water bodies, probably be because of the dead and decay of aquatic organisms. While Tungan Kawo dam Wushishi experienced increase in the BOD values across the seasons. This may be due to the anthropogenic activities going on the bank of the shore although the season.

The mean Total Hardness value for Shiroro dam, Bakajeba dam, Zungeru dam, Bosso dam, Earthen dam Gawu, Tungan Kawo dam Wushishi, Tagwai dam, Tungan Kawo reservoir, Jamila ville lake were low (16.33mg/l-42.25mg/l), while the mean total hardness value for Danzaria lake was high (81.75mg/L). The seasonal variations fluctuated between 29mg/l-50mg/l at Bosso dam,36mg/L-50mg/L at Tungan Kawo reservoir, 14mg/L-19mg/L at Shiroro dam, 32mg/L-54mg/L at Tagwai dam, 14mg/L-62mg/L at Wushishi and in Zungeru dam the values fluctuated between 18mg/L - 40mg/L. While in Bakajeba dam, Danzaria lake, Jamila ville lake and earthen dam Gawu, the total hardness values were high in dry season and low in the wet season. This may be due to the presence of high calcium and magnesium ions in the sewage waste as well as sulphate and nitrate, because of low water levels and the concentration of ions. This result is in contrast Ojok *et al*., (2017) who recorded high values for total hardness during the wet season in River Rwizi, Uganda but in conformity with the finding of Teame and Zebib (2016) and Kinta *et al*., (2021) who recorded high values for total hardness during the dry season in Tekeze reservoir, Ethiopia, and the same region of study. The lowest value for Total hardness was recorded in the wet season of 2020 at Shiroro dam and Tungan Kawo dam Wushishi (14mg/L) while the highest value of 200mg/L was recorded at Danzaria lake in the dry season of 2021. The hardness scale of Hanna (2003) categorized water into very soft (0 - 70mg/l), soft (70 - 150mg/l), slightly hard (150 - 250mg/l), moderately hard (250 - 320mg/l), hard (320 - 420mg/l) and very hard (420mg/l and above). Therefore, the inland water bodies were very soft and soft water. This result agrees with the reports of Mustapha, (2009) of Oyun reservoir, who reported values of (32 -60 mg/L). These values were found to be lower than the recommended value of WHO (2011) which is 500 mg/L. These findings implied that the inland water bodies' environment was not hard. Although hard water has no known effects on health, but it is unsuitable for domestic use (Sangpal *et al*., 2011 & Teame and Zebib 2016).

The Total dissolved solids which usually consist of organic and inorganic substances dissolved and washed into the lake by runoffs (Bala and Bolorunduro, 2011) are essential in the life of aquatic bio-community. Mean Total Dissolved Solids values obtained during the study period were high in all the inland water bodies. The seasonal variation of the Total Dissolved solid fluctuated between 30mg/L-197mg/L in Bosso dam and Tungan kawo reservoir. But Bakajeba dam, Danzaria lake, Shiroro dam, Tagwai dam, Jamila ville lake, Tungan Kawo dam Wushishi, Zungeru dam and Earthen dam Gawu experienced high values of total dissolved solids during the dry season. In all, the values were not above recommended values. Total Dissolved solids determination are important in water quality studies, though no serious health effect has been associated with dissolved solids ingestion in water but some regulatory agencies (WHO,2011 and Nigerian Industrial Standard,2015) recommended a maximum Total dissolved solids value of 500mg/l in drinking water supplies. The result agrees with Mustapha, (2009) and Usman, (2015) whose recorded values for Total Dissolved Solid were not beyond the recommended maximum value of 500mg/l.

Alkalinity also results from the dissolution of calcium carbonate ($CaCO_3$) from limestone bedrock which is eroded during the natural processes of weathering. The carbon dioxide (CO_2) released from the calcium carbonate into the stream, lakes and reservoirs water undergoes several equilibrium reactions (Kadhim, 2014). The mean values of Alkalinity in the study inland water bodies were high. The season variation of the Alkalinity fluctuated in Bosso dam, Tungan kawo reservoir, Tagwai dam and Zungeru dam throughout the period of the wet season of 2019 to the dry season of 2021 between 26 $CaCO_3$ mg/L to 54 $CaCO_3$ mg/L. While the total alkalinity values were high in the dry season and low values in the wet season in Bakajeba dam, Danzaria lake, Shiroro dam, Jamila Ville Farm Lake, Tungan Kawo dam Wushishi, and Earthen dam Gawu. This could be due to low water levels with its attendant concentration of salts and the lower value in the rainy season could be due to dilution (Teame and zebib 2016), and when compared, it favours well with the range given for lakes and reservoirs by WHO, (2011); thus, this implies an indicator of a good quality of the inland water bodies. This agrees with the work of Suguna (1995) and Mohammed *et al*., (2015) who reported that total alkalinity above 40 mg/L suggest high productivity of a lake. This result is in contrast with the findings of Odo *et al*., (2014) in a tropical freshwater lake which recorded low values for alkalinity.

Turbidity measures the "cloudiness" of water; more precisely, it measures the extent to which light is scattered and absorbed by suspended sediment, dissolved organic matter, and, to a lesser extent, plankton, and other microscopic organisms (Clesceri, *et al*. 1994). Turbidity is also referred to as the inverse of the "clarity" of water. Light that is not scattered or absorbed by turbidity-causing particles passes through the water. In other words, increased turbidity reduces the distance that light can penetrate the water column. Water turbidity is mainly due to suspended in organic substances like clay, silt, phyto- zooplankton and sand grains and reservoirs and lakes with clay bottoms are likely to have high turbidity (Mohammed et al., 2015). In this present study, there was a significant difference in the mean values of turbidity among the inland water bodies studied. The mean turbidity values were high in Shiroro dam, Tungan kawo reservoir, Zungeru dam, Bakajeba dam, Earthen dam Gawu and Tagwai dam (25,27.5,27.5,32.75,32.33, and 39 NTU) while Tungan Kawo dam Wushishi, Jamila ville lake, Bosso dam, and Danzaria lake recorded very high turbidity values (43.75, 70.75,77.5 and 132.5 NTU). The seasonal variations turbidity of the inland water bodies had different trends. Tungan kawo reservoir, Tagwai dam, and Tungan Kawo dam Wushishi turbidity values fluctuated through the seasons, while that of Danzaria lake, Jamila ville lake, Zungeru dam, and Earthen dam Gawu was high in the wet season and low in the dry season. This may be because of the soil erosion of the prepared agricultural fields with loose top layer of the soil. Also, debris falling off due to the wind and rainfall could have contributed particles to these inland water bodies. The increased agricultural land use and built-up intensity in the inland water bodies catchment at the onset of the wet season also contributed to variation in this parameter. In addition, the increased water volume in these inland water bodies may have resuspended the bottom sediments due to rapid flow rate of runoff into them. This result is in conformity with Ojok *et al*., (2017) who recorded high turbidity values during the wet season at River Rwizi Mbarara Municipality, Uganda and Popoola *et al*., (2019) who also recorded high values of turbidity during the wet season at Erelu reservoir, Oyo town, Oyo state, Nigeria. This result is in contrasts with Mohammed *et al*., (2015) who recorded low values of turbidity at Wyra reservoir, Khammam district, Telangana, India. Furthermore, the values of turbidity were high in the dry season at Bakajeba dam, Bosso dam and Shiroro dam. In general, the turbidity values where above the standard value of 5NTU (WHO, 2011; NIS, 2015) for all the inland water bodies.

Nitrates are contributed to freshwater through the discharge of sewage and industrial wastes and run-off from agricultural fields (Solanki, 2012). The highest amount of nitrate concentration was known to support the formation of algae bloom (Qureshimatva *et al*., 2015). The mean Nitrate values were relatively high in Earthen dam Gawu, Tungan Kawo dam Wushishi, Tagwai dam, Bakajeba dam, Danzaria lake and Shiroro dam (0.25 mg/L, 0.37mg/L, 0.40mg/L, 0.50mg/L, 0.50mg/L & 0.57mg/l), while Bosso dam, Zungeru dam, Tungan Kawo reservoir and Jamila Ville Farm lake (0.75mg/L, 0.80mg/L, 0.93mg/L & 2.0 mg/L) were high when compared to the other inland water bodies. The seasonal variations in Nitrate levels were relatively high in all the sampling inland water bodies. Certain trends were observed in the cause of the study. In Bakajeba dam, there was fluctuations in the seasonal value of nitrate. This may be due to human activities along the shore of the dam and evaporation which brings about concentration in the nutrient level of the water during the dry season, and run-off of agricultural fields into the dam during the wet season. While Bosso dam, Danzaria lake, and Shiroro dam nitrate values increased across the seasons from wet of 2019 to the dry season of 2021. This may be due to heighten human activities around the inland water bodies. Another trend was observed at Jamila Ville Farm Lake, Tungan Kawo reservoir Kontagora, and Tungan Kawo dam Wushishi experienced high nitrate values during the wet season. These inland water bodies are surrounded by farmlands and farmers use nitrate base fertilizers to enhance crop yield hence during the wet season the run-off from these farmlands are washed in them and hence the increase in nitrate during the wet season. This result is in conformity with Ibrahim *et al*., (2009) and Rabiu *et al*., (2018) who stated that high nitrate concentration in inland water bodies could be related to inputs from agricultural land. On the other hand, Zungeru dam, Earthen dam Gawu, and Tagwai dam experienced low nitrate values during the wet season and high nitrate values during the dry season. This result is in conformity with the findings of Imoobe and Akoma, (2008) in Bahir Dar Gulf of Lake Tana, Ethiopia, Arimoro and Oganah, (2010) in a perturbed tropical stream in the Niger Delta, Nigeria and Kinta et al., (2021) in Tungan kawo Reservoir, Kontagora, Niger State, Nigeria, who reported a high value for nitrate concentration (0.92-4.18mg/L, 0.22-2.87mg/L and3.6-7.5mg/L respectively). The result, however, is in contrast with the findings of Imoobe, (2011), Sarma *et al*., (2011) and Yakubu *et al*., (2014) who recorded low value for nitrate.

Phosphate is an essential nutrient for living organisms and exists in water bodies as both dissolved and particulate species. It is generally the limiting nutrient for algal growth and, therefore, controls the primary productivity of a water body. Artificial increases in concentrations due to human activities are the principal cause of eutrophication. Natural sources of phosphate are mainly the weathering of phosphorus-bearing rock sand the decomposition of organic matter. Domestic wastewaters (particularly those containing detergents), industrial effluents and fertiliser run-off contribute to elevated levels in surface waters. Phosphate associated with organic and mineral constituents of sediments in water bodies can also be mobilised by bacteria and released to the water column. (Chapman and Kimstach, 1996; Wetzel, 2001; Ude *et al*., 2011; Mohammed and Saminu, 2012 and Usman, 2015). The mean Phosphate level was relatively high (0.11mg/L in Shiroro dam - 1.64mg/L in Jamila ville lake) in all the sampling inland water bodies. This result is in conformity with Adakole and Anunne (2003) who recorded a titre value of 0.05-5.89gm/l and Usman (2015) who also recorded very high phosphate value of 7.0-16.73mg/l in Wawan –Rafin Lake. This result is in contrast with the report of Olele and Ekelemu (2008) who recorded titre values of 0.80-1mg/L; Imoobe and Akoma, 2008; Arimoro and Oganah, 2010; Imoobe, 2011; Sarma *et al*., 2011; Joseph and Yamakanamardi, 2011 who recorded lower values for phosphate in their studies. The seasonal variations of the phosphate levels in the inland water bodies shows certain patterns such as Bakajeba dam, Bosso dam, Tagwai dam, and Jamila ville lake, fluctuated all through the season in the levels of phosphate from high to low in the wet and low to high in the dry season. This could be because of varying anthropogenic and microbial activities going on in and around these inland water bodies during those seasons. On the other hand, levels of phosphate increased significantly at Danzaria lake, Shiroro dam, Earthen dam Gawu, Zungeru and Tungan Kawo dam Wushishi throughout the study period. This could be due to leaching and run-off of fertilizers from nearby farmlands, washing with detergents and soaps into these inland water bodies. Furthermore, Tungan Kawo reservoir Kontagora maintained a pattern of high phosphate value in the wet season and low phosphate values in dry season. The high value of phosphate in the reservoir in the wet season may be because the period is usually the peak of agricultural activities around the reservoir. Washing of cow dungs and bathing and washing with phosphate-based detergents and soaps into the reservoir could have also caused the high concentration of the ions. (Mustapha, 2008; Kinta *et al*., 2021). While the low phosphate concentration experienced in the reservoir during the dry season may be due to nutrients uptake by phytoplankton and aquatic macrophytes as well as microbial activities might have contributed to the low nutrients' concentration. (Arimoro *et al*., 2015 and Ghali *et al*., 2020).

Sulphates naturally occur in surface water which arises from the leaching of sulphur compounds either as sulphate minerals such as gypsum or sulphite as pyrite or from sedimentary rocks (Usman,2015). The mean Sulphur concentration obtained in Danzaria lake, Tungan Kawo dam Wushishi, Bakajeba dam, and Shiroro dam were moderate (7.51mg/L, 9.60mg/L, 10.93mg/L &11.94mg/L).While, the mean sulphur concentrations in Jamila ville lake, Bosso dam, Tungan Kawo reservoir, Tagwai dam, Zungeru dam and Earthen dam Gawu were relatively high (13.35mg/L, 13.82mg/L, 15.09mg/L, 15.76mg/L,18.50mg/L & 29.36mg/L respectively). Seasonal concentration of Sulphur fluctuated in Tungan Kawo dam Wushishi, Tungan kawo reservoir, and Jamila ville lake between 8.35mg/L-17.37mg/L in the seasons during sampling. This result agrees with Mustapha, (2009) & Usman, (2015) who had values of 9.4mg/l±0.2 in Oyun reservoir and 5.94mg/l-14.98mg/l in Wawan-Rafi Lake respectively. Bakajeba dam, Bosso dam, Tagwai dam, Zungeru dam, showed high concentration of sulphate during the dry season and low sulphate concentration during the wet season while Danzaria lake exhibited high concentration of sulphate during the wet season and low concentration of sulphate during the dry season. Shiroro dam, decreased significantly across the seasons and Earthen dam Gawu increased significantly across the seasons. These variations in the concentration of sulphate at different inland water bodies could be because the sulphate discharged into the inland water bodies, which was used up as a source of oxygen by bacteria and was converted entirely to H_2S under anaerobic conditions (Kolo *et al*., 2010) A., the high sulphate concentration probably be due to decay of phytoplankton and aquatic macrophytes or due to the oxidation of sulphide or sulphite to sulphate in the presence of photosynthetic sulphur bacteria and evaporation which could lead to concentration of Sulphate in the inland water bodies.(Toufeek and Korium 2009 & Ojok *et al*., 2017).

In this present study the concentration of Chlorophyll-*a* was relatively low in all the inland waterbodies. All the inland waterbodies in this study from Zungeru dam to Tagwai dam had chlorophyll-a concentration ranging from 3.3 to 5.8µg/L and are mesotrophic based on the Lake Trophic State Indicator by Kansas Department of Health and Environment (KDHE), (2011) as shown in Table 2. However, Wushishi dam had the lowest concentration of 1.9µg/L and is oligotrophic based on the Lake Trophic State Indicator by Kansas Department of Health and Environment (KDHE), (2011). This finding is however in contrast with Celik, (2012) in Caygören reservoir Turkey, Usman *et al*., (2015) in Cole mere and Kadiri et al., (2019) in a Gulf of Guinea, Nigeria, who independently recorded high values for Chlorophyll-*a* indicating that the water bodies were eutrophic. The findings were however in conformity with the findings of Kondowe et al., (2022) who recorded a low conceration of Chlorophyll-a in a shallow tropical Lake in western Kenya and attributed it to open waters.

Conclusion

This study revealed that these inland water bodies are mostly mesotrophic in nature and thus require effective management strategies to ameliorate their status. Some of the physicochemical properties varied significantly ($p<0.05$) among the water bodies and with wide fluctuations across the seasons, however nearly all values obtained were within the recommended limit for fish production.

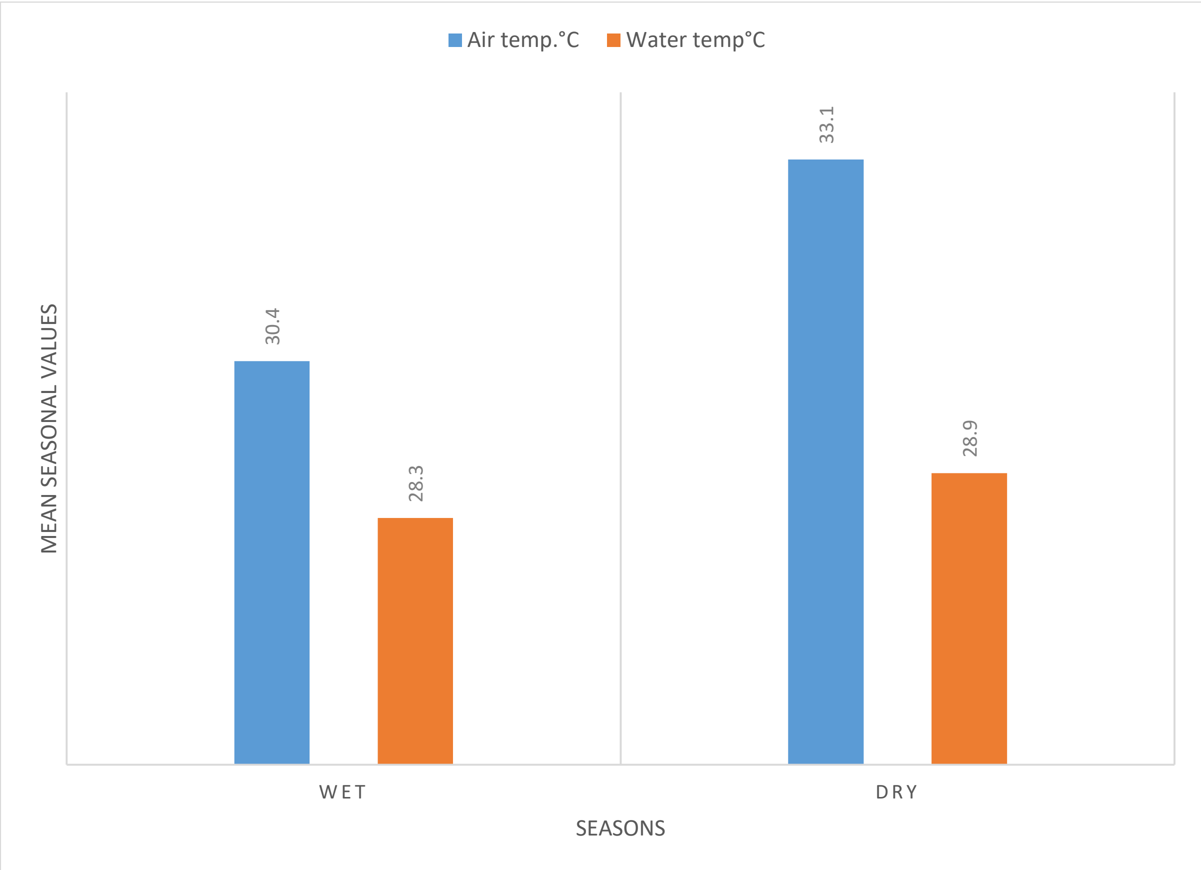

Fig 2a: Temporal variation of air and water temperature across the seasons in the inland waterbodies in Niger State

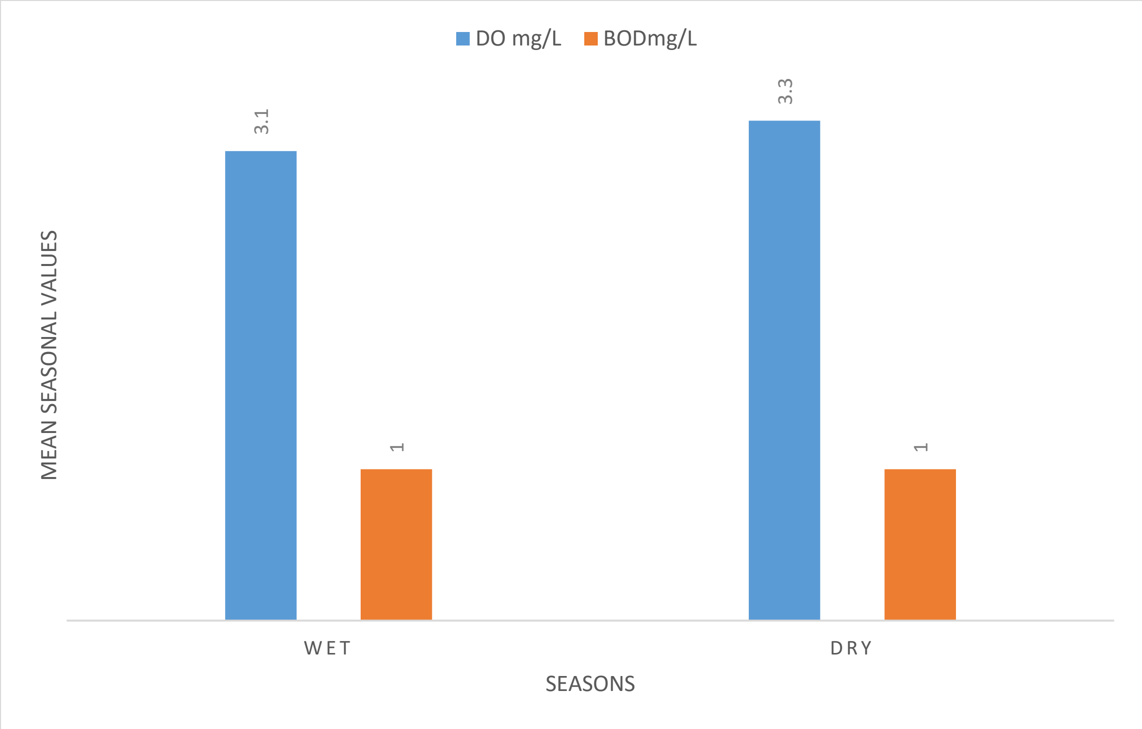

Fig 2b: Temporal variation of DO and BOD across the seasons in the inland waterbodies in Niger State.

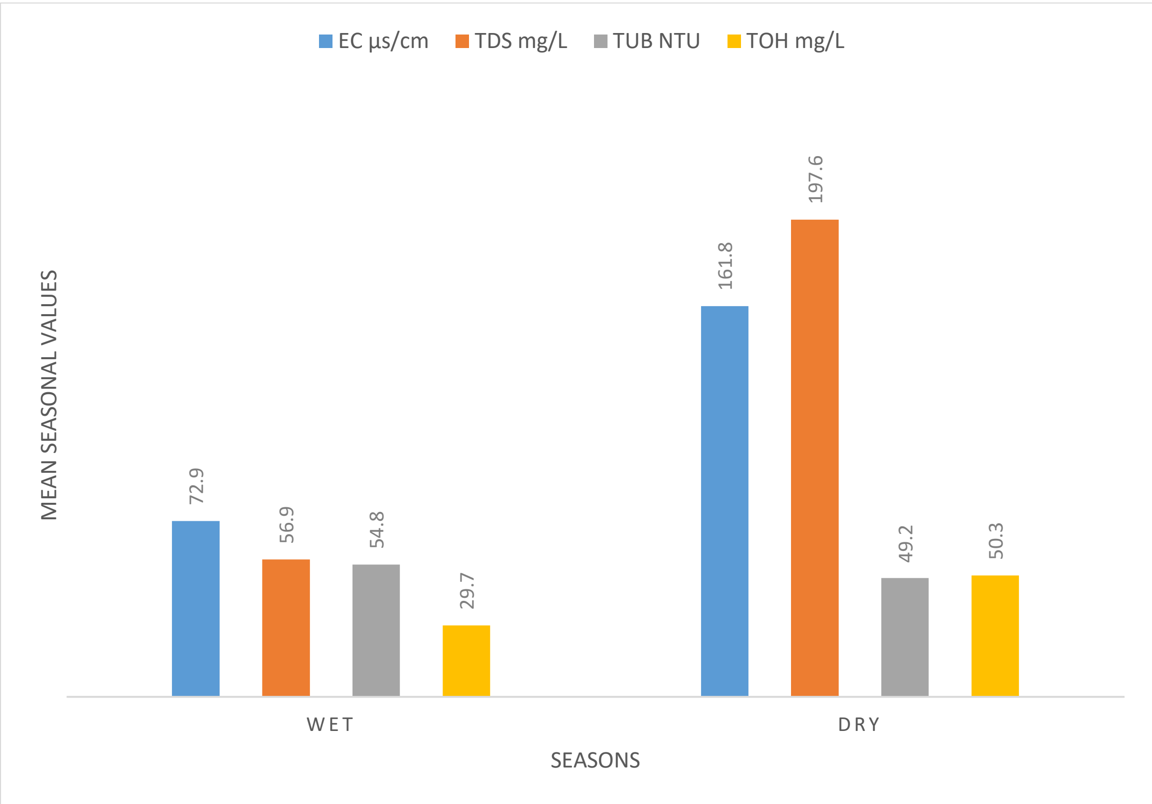

Fig 2c: Temporal variation of EC, TDS, TOH and TUB across the seasons in the inland waterbodies in Niger State

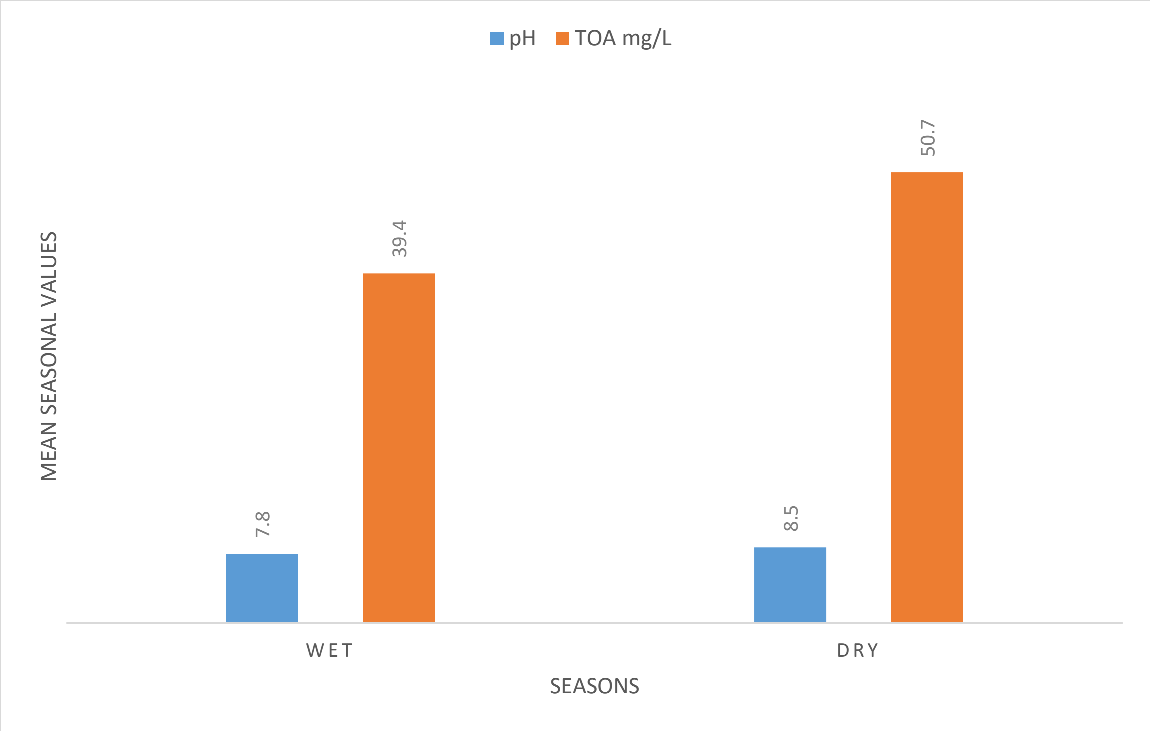

Fig 2d: Temporal variation of pH and TOA across the seasons in the inland waterbodies in Niger State

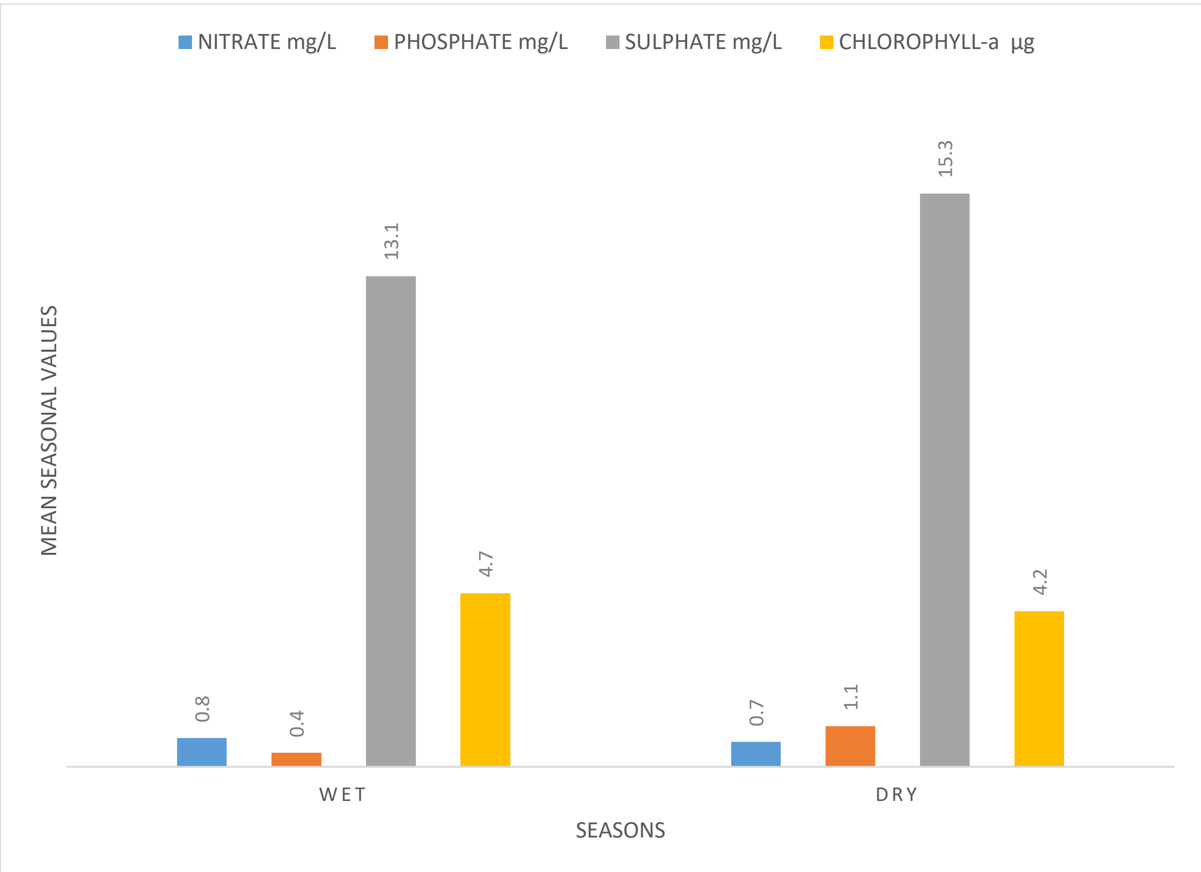

Fig 2e: Temporal variation of Nitrate, Phosphate, Sulphate and Chlorophyll-a across the seasons in the inland waterbodies in Niger State

Table 3: Summary of the environmental variables of the selected inland water bodies in Niger State

	PARAMETERS	BJD	BSD	DZL	TKR	SHD	TWD	WSD	JVL	ZGD	EDG
1	AIR TEMP ^{0}C	34.1±2.23 (28.2-38.9)	31.66±0.61(30-32.7)	31.58±1.28 (28.1-34.2)	30.53±1.30 (28.3-34)	27.67±1.43 (25-29.9)	30.75±3.02 (26-39.6)	32.88±1.30 (30-36.2)	30.5±1.55 (26.3-32.9)	34.7±1.42 (31.1-37.7)	31.93±1.59 (29.7-35)
2	WATER TEMP ^{O}C	30.3±1.89 (25-33.9)	28.33±1.73 (23.2-30.7	28.45±1.98 (22.8-32)	28.68±1.34 (26-32.4)	26.13±1.08 (24-27.5)	28.15±1.57 (25-32.1)	28.83±0.57 (27.6-30.3)	28.25±1.50 (24.1-30.7)	28.68±1.60 (24.5-32.3)	29.8±0.80 (28.9-31.4)
3	DO mg/L	3.05±0.05 (3-3.2)	3.83±0.72 (2.6-5.9)	3.65±0.37 (3.1-4.7)	2.53±0.23 (2-3.1)	3.1±0.32 (2.5-3.6)	2.63±0.17 (2.3-3.1)	3.1±0.53 (2-4.5)	3.48±0.19 (3.1-4)	3.55±0.37 (2.5-4.3)	3.23±0.03 (3.2-3.3)
4	BOD mg/L	0.98±0.26 (0.5-1.7)	1.75±0.72 (0.9-3.9)	1.03±0.54 (0.2-0.2.6)	0.78±0.36 (0.1-1.4)	1.13±0.61 (0.1-2.2)	0.75±0.27 (0.1-1.2)	0.9±0.28 (0.5-1.7)	0.9±0.15 (0.5-1.2)	1.1±0.3 (0.6-1.8	1.07±0.09 (0.9-1.2)
5	EC µS/CM	84.5±25.8* (40-159)	111.25±33.94* (74-213)	190.5±74.07* (86-406)	118.2±30.02* (80-207)	46±3.22** (40-51)	108±36.77* (60-217)	112.5±36.11* (60-216)	162.86±69.25 (84-370)	90.25±49.84 (10-234)	136.33±32.30 (95-200)
6	TDS mg/L	98.5±26.5* (20-137)	100.75±25.02* (30-148)	254.8±100 (30-472)	142.3±23.31* (102-197)	72.33±26.01 (26-116)	91.5±41.82 (10-176)	111±52.36 (12-214)	110.3±49.12 (16-208)	121.8±57.03 (10-280)	165.7±72.90 (20-244)
7	pH	8.4±0.17** (7-9.8)	8.4±0.61*** (7.3-9.5)	8.2±0.68** (6.9-9.4)	8.8±0.71** (6.8-10)	8.8±0.68** (7.4-9.5)	7.7±0.6** (6.6-9.4)	7.9±0.63** (6.3-9.1)	7.1±0.82** (5.1-9.1)	8.7±0.66*** (7.5-10.1)	7.8±0.80* (6.9-9.4)
8	TURBIDITY (NTU)	32.75±6.7* (21-52)	77.5±6.34** (60-90)	132.5±11.07* (110-160)	27.5±2.63** (23-35)	25±6.24* (18-30)	39±6.07** (26-55)	43.75±5.30** (30-55)	70.75±5.59** (58-82)	27.5±4.80* (19-40)	32.33±6.36* (25-45)
9	TOTAL HARDNESS (TH) mg/L	27.75±6.7* (20-48)	34.25±5.27** (28-50)	81.75±39.97 (28-200)	42.25±2.90** (36-50)	16.33±1.45** (14-19)	37.75±5.42** (32-54)	41.25±9.98* (14-62)	42.25±6.26** (30-60)	27.5±4.86* (18-40)	37.33±6.36* (26-48)
10	TOTAL ALKALINITY (TA)mg/L	33.75±1.4** (30-36)	39.5±1.26**** (36-42)	77.25±20.62* (42-130)	50.5±1.26*** (48-54)	23.67±1.87** (20-26)	40.25±3.17** (32-50)	49.75±5.33** (36-60)	53.5±7.37** (38-68)	32.25±4.33* (26-45)	44.53±4.79* (35.6-52)
11	NITRATE mg/L	0.5±0.062** (0.35-0.62)	0.75±0.11** (0.47-0.96)	0.5±0.047** (0.39-0.61)	0.93±0.18* (0.56-1.27)	0.57±0.027* (0.53-.62)	0.4±0.104* (0.18-062)	0.37±0.055** (0.25-0.51)	2±0.62* (1.25-3.84)	0.8±0.17* (0.46-1.23)	0.25±0.064 (0.14-0.36)
12	PHOSPHATE mg/L	0.23±0.051* (0.16-0.38)	1.42±0.971 (0.38-4.33)	1.32±1.113 (0.18-4.66)	0.32±0.0497* (0.22-0.44)	0.11±0.0088* (0.1-0.13)	0.27±0.048* (0.16-0.35)	0.23±0.105 (0.11-0.54)	1.64±0.596 (0.68-3.28)	0.88±0.575 (0.08-2.55)	0.82±0.539 (0.08-1.87)
13	SULPHATE mg/L	10.93±0.5* (9.62-12.17)	13.81±0.92*** (12.22-16.38)	7.51±1.11** (5.16-10.2)	15.09±0.85** (13.48-17.36)	11.94±2.24* (8.74-16.26)	15.76±1.01** (13.35-18.24)	9.60±0.67*** (8.35-11.42)	13.05±1.13** (11.12-16)	18.50±1.66* (15.25-22.34)	29.36±2.68** (26.55-34.72)
14	CHLOROPHYLL- A µg/L	2.9±1.01 (0.3-5.2)	4.85±1.69 (0.4-7.8)	4.78±1.37* (2.1-8.6)	5.53±1.34* (1.7-8)	3.77±1.79 (0.6-6.8)	2.55±0.75* (0.4-3.9)	2.48±0.78 (0.9-46)	3.98±1.24* (0.8-6.6)	1.9±0.54* (1.3-3.5)	3.27±1.68 (1.3-6.6)

Key:

BJD=Bakajeba Dam; BSD=Bosso Dam; DZL=Danzaria Lake; TKR=Tungan Kawu Reservior Kotangora; SHD=Shiroro Dam; TGD=Tagwai Dam; WSD=Tungan Kawo dam Wushishi; JVL=Jamila Ville Farm Lake; ZGD=Zungeru Dam; EDG=Earthen Dam Gawu Gaube.
EC= Electronic conductivity. DO= Dissolved Oxygen. BOD=Biochemical Oxygen Demand. TDS= Total Dissolved Solids.

Table 4: F- ANOVA and P-VALUES of the Environmental variables.

Seasons		Stations	
F-ANOVA	P-VALUE	F-ANOVA	P-VALUE
1.944	0.1483	1.301	0.2855
0.5018	0.6845	0.3582	0.9443
0.4511	0.7188	1.194	0.3416
0.5226	0.6707	0.4873	0.8692
39.52	<0.0001****	2.844	0.0187*
17.14	<0.0001****	2.361	0.0435*
12.10	<0.0001****	1.245	0.3138
1.751	0.1823	31.30	<0.0001****
5.086	0.0069	1.832	0.1118
1.802	0.1729	3.570	0.0056**
0.4260	0.7361	4.441	0.0015**
8.722	0.0004***	1.608	0.1689
4.646	0.0103*	26.18	<0.0001****
8.964	0.0003	1.912	0.0970

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