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Analysis of Physicochemical Characteristics of River Benue, Nigeria

***Egesi, O.C.[1] Alum-Udensi, O.[1], Ugor, N.N.[2] and Ogbonna, P.C.[2]**

[*1]Department of Fisheries and Aquatic Resources Management,
Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria.
[2]Department of Environmental Management and Toxicology,
Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria.
Corresponding author's email: chiomaegesi@yahoo.com

Abstract
World Health Organization (WHO) published the guidelines for drinking water to protect aquatic life and public health. The study, therefore, assessed the water quality of River Benue in Makurdi, Nigeria to ascertain its suitability for human consumption vis-à-vis the health of aquatic organisms. Water samples were collected in four distinct stations to evaluate the contents of pH, temperature, total hardness $CaCO_3$ (TH), electrical conductivity (EC), turbidity, total dissolved solids (TDS), total suspended solids (TSS), dissolved oxygen (DO), five-day biochemical oxygen demand (BOD5), chemical oxygen demand (COD), nitrate (NO^-_3), fluoride ion (F^-), nitrite (NO^-_2), ammonia (NH^+_3), sodium (Na^+) and magnesium (Mg^{2+}) using standard methods. Statistical analysis of the laboratory results shows that the highest values of TDS (470.03±9.24 mg/L), TSS (673.03±7.96 mg/L), turbidity (496.60±4.90 NTU), TH (52.02±0.03 mg/L), NO^-_3 (5.80±2.90 mg/L), Mg^{2+} (40.96±7.33 mg/L), Na^+ (79.18±10.8 mg/L), NH^-_3 (3.49±0.95 mg/L) and NO^-_2 (52.36±5.5 mg/L) were recorded in water samples collected at the major storm drain station while the highest values of pH ((9.18±0.09), EC (24.76±8.00 µs/cm), BOD5 (43.13±1.29 mg/L) and COD (1174.08±28.79 mg/L) were recorded at the Wurukun abattoir station. The highest value of DO (14.31±1.60 mg/L) was recorded in the control area. The values of physicochemical parameters tested in this study were within the permissible limits recommended by WHO and FMEnv except for TSS, pH, turbidity, temperature, fluoride, BOD5 and COD. Consequently, periodic monitoring of the water quality of River Benue is vital to ascertain its suitability for human consumption, irrigation agriculture and the safety of aquatic life.

Keywords: River Benue, Makurdi, water quality, and physico-chemical properties

Introduction

River is a naturally flowing watercourse usually freshwater that can be used for households, municipal water supplies, navigation and transport, sacred, irrigation of farmlands, building construction, processing in industries or for the production of energy. They (rivers) are also complex systems of flowing waters draining specific land surfaces which are defined as river basins or watersheds. The characteristics of the river, or rivers, within the total basin system, are related to several features like the size, form and geological characteristics of the basin and the climatic conditions which determine the quantities of water to be drained by the river network (Meybeck, 1996). Poor governance by political officeholders coupled with a poor sense of responsibility and accountability vis-à-vis inadequate investment in basic water supply and treatment infrastructure is increasing water quality deterioration in Nigeria. Significant deterioration of water quality often occurs when the rivers (and their tributaries) flow through densely populated areas due to the receiving of large quantities of wastewater from industrial and municipal sources (World Bank, 2006) or agricultural lands where agrochemicals and livestock manure (Hu and Cheng, 2013) are used to boost crop yield. Water pollution and eutrophication occur when the amounts of pollutants discharged into the water body can no longer be accommodated by the natural ecosystem and threaten the aquatic ecosystem and human health (Strokal *et al*., 2016; Tang *et al*., 2006; Tong *et al*., 2016; Li *et al*., 2021). The direct impacts of poor water quality are losses in agriculture and fishery while the indirect effects include disease infection, economic loss, dissipation of energy trekking distances to fetch potable water and loss of human health. Water scarcity and pollution problems are more prominent in developing countries than in developed countries, because of the rapid economic growth and population explosion (Zheng *et al*., 2008). Thus, the ever-increasing demand for potable water due to anthropogenic pressure in

Nigeria seems to be exerting significant stress on the country's freshwater resources. Contaminants that are generated in the terrestrial environment due to human activity find their way into surface waters, where they accumulate in sediments (Tarnawski 2012). Bottom sediments constitute an integral part of the aquatic environment since it is the location of accumulation and chemical transformations of numerous contaminants that penetrate to waters (Szydłowski *et al*., 2017). Part of the harmful substances contained in aquatic sediments are transferred to water as a result of chemical and biochemical processes and become available to living organisms (Baran and Tarnawski 2012; Bojakowska 2001; Szydłowski and Podlasińska 2016). Fish is an essential constituent of the human diet because of its low cholesterol, high nutrient content, and palatability as well as the most affordable source of animal protein for poor households in urban and semi-urban areas and for rural communities as it provides minerals and nutrients like fat, vitamins D and B complex (Bene and Heck, 2005; Ogbonna *et al*., 2020a). The gills are important organs in fish for respiration, osmotic regulation, acid-base balance and nitrogenous waste excretion (Heath, 1987; Kroupova *et al*., 2005) but may be contaminated with toxic substances in the course of performing these functions. For instance, elevated ambient nitrite concentration is a potential problem for freshwater fish since nitrite is actively taken up across the gills epithelium in competition with chloride and accumulates to very high concentrations in the body fluids (Aggergaard and Jensen, 2001; Kroupova *et al*., 2005). The maintenance of healthy freshwater bodies is dependent on physicochemical properties and the important physical and chemical parameters that affect natural water quality are temperature, pH, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD) (Ogbonna *et al*., 2018, 2020b), chemical oxygen demand (COD), alkalinity, Nitrates and Phosphates (Lawson, 2011; Nduka *et al*., 2008). Similarly, minerals such as magnesium and sodium are very essential in fish since they play crucial roles as integrators of organic compounds in their body and in controlling important biological functions (Ozden *et al*., 2010). These parameters are principal factors for the survival of aquatic organisms (Lawson, 2011). River Benue is an important source of water for domestic use, transportation, habitats for aquatic animals, source of livelihood for inhabitants of Makurdi, Benue State but passes through many urban towns in Makurdi where abattoirs, urban markets, breweries, ecological storm drains, agricultural areas where agrochemicals and animal manure are used for large scale production of food crops such as yam, beans, cassava, maize among others. As the water passes through these areas, it collects domestic, agricultural and industrial wastes that may contain contaminants as well as nutrients which are released into River Benue through runoffs and may accumulate in aquatic organisms and at the bottom sediment. There are very few studies on the physicochemical properties of River Benue in Makurdi. However, there is no comprehensive study on levels of physicochemical parameters such as nitrate, fluoride, nitrite, ammonia, sodium and magnesium in water, fish and sediments of River Benue. Consequently, this study aimed to fill this gap by investigating the levels of the key physicochemical parameters and available nutrients within River Benue in Makurdi, Benue State of Nigeria. The results of this study provide information that will ensure sustainable management of the aquatic ecosystem via enactment of laws and policy vis-à-vis thorough implementation by the relevant agencies in Benue State and Nigeria.

Materials and Methods

Description of the study area

Physicochemical properties were tested to determine the water quality of River Benue in Makurdi, Benue State of Nigeria. The capital of Benue State is Makurdi located on latitude 7° 41' N and longitude 8° 28' E and the size of the River Benue within Makurdi and the major settlements it runs through is approximately 671 meters (Akaahan *et al*., 2015). The rainy season starts in April and ends in October while the dry season commences in November and ends in March The soil consists of basement complex rocks, cretaceous sandstones and Albian limestone sediments. (Umeji, 2013). The main economic activity in Benue State is agriculture which is facilitated by the rich alluvial soil of the Benue valley. However, large-scale fishing activity is carried out on the River. Four (4) sampling stations were selected for this study viz: behind Wurukun abattoir, behind Wadata market, major storm drain and upstream at Angbaaye on the outskirts of Makurdi town (i.e. the control).

Sample collection

Water sampling

Water sampling was done twice (6 am and 4 pm) from five different points at each sampling station (Wurukun abattoir, Wadata market, major storm drain and upstream at Angbaaye (i.e. control)). Each sampling bottles of one (1) litre by volume were pre-conditioned with 5% nitric acid and later rinsed thoroughly with distilled de-ionized water. At each sampling station, the sampling bottles were rinsed with sampled water three times before sampling was done. The pre-cleaned sampling bottles were filled to the brim at a depth of 20 cm below the surface of the river and covered tightly. The five representative water samples from each sampling station and control were acidified with 10% HNO_3 analytical grade, covered air-tight, labelled well, placed in an ice-chest container and transferred to the laboratory for pre-treatment and analysis. Samples from each station were mixed separately to form one homogenous representative sample for the station (e.g. all water samples from five different points behind the Wadata market were mixed thoroughly). While in the laboratory; the homogenous water samples were stored in the refrigerator at about 4°C before the analysis (APHA, 1998). Adequate precautions were exercised to avoid contamination of water during sampling, transport, and handling. Twenty (20) water samples each were collected morning and evening every ten (10) days in June 2019 from the three (3) sampling stations and control sites. A total of 480 water samples were collected in all. Analyses of pH, temperature, electrical conductivity, and turbidity were carried out at the site of sample collection following the standard protocols and methods of the American Public Health Organization (APHA, 1995) and the American Society for Testing and Materials (ASTM) using different calibrated standard instruments (Dezuane, 1997) as described in Rahmanian *et al*. (2015).

Laboratory analysis

The measurements of TSS and TDS in water samples were carried out according to the standard methods of APHA (1995) and Sawyer *et al*. (1994) by the filtration process as described by Rahmanian *et al*. (2015). The analysis of DO, BOD and COD was carried out as per the method described in APHA (1992) and Ma *et al*. (2020). The procedure of Oremo *et al*. (2020) was adopted in the extraction of nitrate in water samples. Sodium and magnesium were measured by the flame photometric method, nitrite was measured by the Diazotisation spectrophotometric method fluoride was measured by the SPADNS spectrophotometric method (Fadaei and Sadeghi, 2014), and ammonia was determined by Berthelot (phenate) method, and total hardness by EDTA titration method.

Quality Control/Quality Assurance

Due care was taken during sampling to avoid any possibility of contamination. Temperature, electrical conductivity, turbidity and pH were measured in situ. Known buffer solutions of pH 4, pH 7, and pH 10 were prepared and used to standardize the equipment, and the pH readings of the water samples were immediately taken. All field meters and equipment were checked and calibrated according to the manufacturer's specifications and instructions (HACH, 1997). Parallel experiments, blank tests and recovery tests were carried out. Distilled and de-ionized waters were used and all glass wares were thoroughly cleaned by socking in nitric acid for 24 hours, rinsed twice with distilled water and triced with de-ionized water.

Results and Discussion

Physical Properties of River Benue

The results of the physical parameters of water samples collected at different stations of River Benue are summarized in Table 1. The result reveals that the highest contents of TDS (470.03±9.24 mg/L), TSS (673.03±7.96 mg/L), and turbidity (496.60±4.90 NTU) were recorded in water samples collected at the major storm drain station, and the values were significantly ($P<0.05$) higher than their (TDS, TSS and turbidity) contents at Wurukun abattoir station (393.06±1.50 mg/L, 366.58±8.51 mg/L, 313.03±12.7 NTU), Wadata market station (350.01±9.01 mg/L, 188.01±6.01 mg/L, 275.02±6.02NTU) and the control area (230.01±5.77 mg/L, 68.51±6.63 mg/L, 234.56±4.10 NTU), respectively for TDS, TSS, and turbidity. The high content of TDS, TSS, and turbidity at major storm drain stations may be attributed to surface runoff that carried eroded soil particles, and decayed organic materials from agricultural farms into River Benue, Nigeria. Surface runoff due to heavy rainfall, decaying organic material, and effluent discharge influences turbidity, total dissolved solids, and total suspended solids of water (Murhekar, 2011). The contents of TDS (230.01±5.77 to 470.03±9.24 mg/L) and TSS (68.51±6.63 to 673.03±7.96 mg/L) which shows constituents conveyed in suspended pattern (Amadi *et al*., 2006; Akubugwo *et al*., 2012; Ogbonna *et al*., 2020b) were within maximum allowable limit of 200 to 500 mg/L (TDS) but higher than 80 to 150 mg/L (TSS) established by WHO (2003, 2011) respectively (Table 2). The content of TDS is lower than 1000 mg/L (TDS) but TSS is higher than 25 mg/L (TSS) established by NDWQS (2007) (Table 2). The high TSS values may be attributed to effluent discharged from the abattoir vis-à-vis surface runoff from heavy rainfall that eroded clay soil particles into the major storm drain station of River Benue. For instance, heavy rainfall carries eroded particles into water bodies thereby enhancing TSS and TDS of water (Anhwange *et al*., 2012). Suspended solids may destroy flora and fauna inhabiting water bodies by triggering harsh wounds obstructing the gills and breathing channels, covering the river bottom, causing serious damage to the breeding beds, and blocking light needed for photosynthetic processes of aquatic flora (Ma *et al*., 2020). The contents of TSS in River Benue were higher than the maximum allowable value established by WHO and this may affect aquatic life. Turbidity is the murkiness of water triggered by a multiplicity of particles that may arise from earth runoff (Ogbonna *et al*., 2018). The highest value of turbidity (496.60±40.9 NTU) is observed in water sampled at the major storm drain station of the River Benue and the value is significantly ($P<0.05$) higher than values obtained at the Wurukun abattoir station (313.03±12.7 NTU), Wadata market station (275.02±16.02 NTU) as well as the control area (234.56±41.0 NTU) of River Benue. The high turbidity recorded at the major storm drain station of River Benue may be associated with colour-based organic matter due to the clay profile of the study area that is carried to the River Benue by surface runoff during the wet season. Colour-based organic matter from clay profiles is carried by surface runoff during heavy rain and deposited in water bodies (Ogbonna *et al*., 2018). Additionally, the high rate of river flow and turbulence in the wet season may have increased the turbidity level of River Benue. For instance, suspended particles from surface runoff vis-à-vis the high rate of water flow, turbulence and circulation enhance the turbidity of water (Anhwange *et al*., 2012). The value of turbidity in this study ranged from 234.56±41.0 to 496.60±40.9 NTU, which is well above the maximum turbidity limit of 5 NTU set by the World Health Organization for drinking water (WHO, 2011) (Table 2). The high turbidity may have reduced light ray penetration into River Benue, thus, affecting photosynthetic processes. The adverse effect of turbidity on freshwater includes decreased penetration of light rays (Deeker *et al*., 2010). The highest value of pH (9.18±0.09) is recorded in water samples collected at the Wurukun abattoir station and the value is significantly ($P<0.05$) higher than its (pH) values obtained at the Wadata market station (8.92±0.02), control area (6.80±0.58), and major storm drain station (6.48±1.19). The value of pH in this study ranged from 6.48±1.19 to 9.18±0.09, which is slightly acidic to alkaline. The high pH value recorded at the Wurukun abattoir station may be associated with the organic composition of the abattoir wastes. The decomposition of organic material has a buffering effect in water bodies (Ogbonna *et al*., 2020b). The values of pH (6.48±1.19 to 9.18±0.09) in this study exceeded the 6.5 to 8.5 recommended by the World Health Organization (WHO, 2003) and 6.0 to 9.0 established by the Federal Ministry of Environment (FMEnv, 2011) (Table 2). Consequently, the high pH value recorded in River Benue may have affected the activities of aquatic organisms since the metabolic activities of aquatic organisms are pH-dependent (Ogbonna *et al*., 2018). Electrical conductivity is the quantity of liquefied ionic constituent of a river vis-à-vis its electrical features (Ogbonna *et al*., 2018). It specifies the quantity of total dissolved replacement in the aquatic body (Yilmaz and Koc, 2014). The highest value of electrical conductivity, EC (24.76±8.00 µs/cm) is recorded at the Wurukun abattoir station but the value is statistically ($P>0.05$) equal to the value of EC recorded at the major storm drain station (24.25±7.44 µs/cm) but significantly ($P<0.05$) higher than values of EC observed at Wadata market station (16.68±8.86 µs/cm) and control area (0.61±0.01 µs/cm) of River Benue. Water runoff resulting from heavy rainfall in the study area may be connected to the uneven content of EC in the river since the study was conducted in the wet season. Similarly, the high EC at the abattoir station may be a result of the high concentration of salts, and organic and inorganic materials from effluent discharge from the abattoir (Anhwange *et al*., 2012). The values of EC in this study increased from 0.61±0.01 to 24.76±8.00 µs/cm, which is well below the 1,000 µs/cm maximum allowable level of conductivity set by National Drinking Water Quality Standard (NDWQS, 2007)(Table 2).

The values of temperature in River Benue did not differ significantly ($P>0.05$) at the major storm drain station (30.70±0.64°C), Wurukun abattoir station (30.38±0.31°C), Wadata market station (30.12±0.03°C), and the control area (28.00±1.12°C), respectively. The turbidity level may not have allowed light to reach the lower depth of the river. This, in turn, resulted in statistically the same temperature values at the four stations sampled in this study. The temperature of River Benue increased from 28.00±1.12 to 30.70±0.64°C, which is relatively above 25 to 30°C (temp) recommended by the World Health Organization (WHO, 2003)(Table 2). Increased temperature can expedite the multiplication of bacteria, fungi, and algae in aquatic ecosystems, thereby resulting in colour increase (UNICEF, 2008; Ogbonna *et al*., 2018). The temperature range in River Benue may not facilitate microbial explosion and reduction in dissolved gases (Oyem *et al*., 2014; Yilmaz and Koc, 2014) as well as the food consumption rate of aquatic organisms (Kishi *et al*., 2005; Dallas, 2009). Generally, the order of abundance of the physical parameters is as follows: TSS>turbidity>TDS>temperature>EC>pH.

Chemical Properties of River Benue

The results of some selected chemical properties of water samples collected at various sampling stations of River Benue are summarized in Table 3. The result reveals that the highest content of total hardness, $CaCO_3$ (52.02±0.03 mg/L), nitrate, NO^-_3 (5.80±2.90 mg/L), magnesium, Mg^{2+} (40.96±7.33 mg/L), sodium, Na^+ (79.18±10.8 mg/L), and ammonia, NH^-_3 (3.49±0.95 mg/L) were observed in water samples collected at the major storm drain station, and the values were significantly ($P<0.05$) higher than their corresponding values at Wurukun abattoir station (33.06±1.21 mg/L, 2.19±1.33 mg/L, 32.20±0.14 mg/L, 58.58±3.66 mg/L, and 2.13±0.18 mg/L), Wadata market station (17.52±6.35, 1.75±0.24, 25.21±1.22, 30.11±0.01, and 1.57±0.01 mg/L), and the control area (15.53±0.61, 0.15±0.01, 19.11±0.81, 19.78±3.89, and 0.88±0.02 mg/L), respectively for total hardness, nitrate, magnesium, sodium, and ammonia. The high content of total hardness, nitrate, magnesium, sodium, and ammonia at major storm drain stations may be associated with surface runoff from fertilized cropland, animal manure areas, industrial discharge as well as flow over or through deposits of limestone. Benue State is the food basket of Nigeria where farmers apply organic (animal manure) and inorganic (chemical) fertilizers to boost crop yield and it (Benue State) has large deposits of limestone (Egirani *et al*., 2002; Ofulume *et al*., 2017) that may be washed or eroded by surface runoff during heavy rainfall into River Benue via the major storm drain station. For instance, Rajmohan *et al*. (2019) opined that agricultural activities and organic nitrogen fertilizers from animal manure, human waste, and inorganic nitrogen fertilizers contain nitrate and/or NH^+_4. The values of total hardness ($CaCO_3$) in River Benue increased from 15.53±0.61 at the control station to 52.02±0.03 mg/L at the major storm drain station, which is well below 500 mg $CaCO_3$/L set by the World Health Organization (WHO, 2017) (Table 4). Meanwhile, Alsuhaimi *et al*. (2019) stated the degree of hardness as soft (0-75 mg $CaCO_3$/L), moderate (75-150 mg $CaCO_3$/l), hard (150-300 mg $CaCO_3$/L), and very hard (> 300 mg $CaCO_3$/L). According to this classification, the total hardness of the various stations of River Benue sampled in this study is classified as soft. The result indicated the suitability of the water in industrial and irrigation pipes because water should have a total hardness of less than 85 mg $CaCO_3$/L and magnesium hardness of less than 40 mg $CaCO_3$ to minimize scaling at elevated temperatures (Al-Shidi, 2014; Ahmad *et al*., 2020). The values of nitrate in water samples collected in River Benue increased from 0.15±0.01 at the control area to 5.80±2.90 mg/L at the major storm drain station, which is well below 50 mg/L (NO^-_3) set by World Health Organization (WHO, 2017) (Table 4). Nitrates enter water bodies via farming activities where excessive inorganic nitrogenous composites and fertilizers are used, wastewater discharge as well as nitrogenous waste products (WHO, 2006; Savci, 2012; Yaron *et al*., 2012; Oremo *et al*., 2020) situated within the vicinity of the ecosystem. Drinking water with a high nitrate level causes infants to have methemoglobinemia, causes cyanosis, oral, colon, gastrointestinal, and lymphoma cancers (Al-Kalbani and Price, 2015; Adimalla and Venkatavogi, 2018). However, nitrates stimulate the growth of plankton and water weeds that provide food for fish, hence enhancing the fish population but if algae grow too rapidly, oxygen levels will decline, thus, resulting in the death of fish in the River Benue. The values of magnesium in water samples collected in River Benue increased from 19.11±0.81 at the control area to 38.96±7.33 at the major storm drain station, which is relatively lower than the permitted limit of 50 mg/L (Mg^{2+}) recommended by World Health Organization (WHO, 2011) and 40 mg/L (Mg^{2+}) recommended by Federal Ministry of Environment (FMEnv, 2011) (Table 4). Magnesium is a macronutrient for the healthy living of fauna and flora resident in aquatic bodies. Magnesium (Mg^{2+}) activates numerous enzymes and also modifies specific enzyme substrates (Heaton, 1990; Black and Cowan, 1995) but its deficiency in fish is accompanied by disturbances in the balance of other minerals such as potassium and sodium (Bijvelds *et al*., 1998). The values of sodium in the water samples collected in River Benue increased from 19.78±3.89 at the control area to 79.18±10.89 mg/L at the major storm drain station, which is lower than 200 mg/L (Na^+) established by World Health Organization (WHO, 2017) (Table 4). Sodium in the form of sodium chloride aids in controlling water balance, the nervous system, sustaining steady blood pressure, contaminants elimination from the body, or effective working of the digestive system but can have deleterious effects on aquatic bodies when the concentration exceeds its threshold (Frak and Bednarczyk, 2021). Acute silver toxicity is due to a reduction in sodium uptake by the blockade of gill Na^+, K^+ ATPase (Bianchini *et al*., 2002). The values of ammonia in water collected in River Benue increased from 0.88±0.02 at the control area to 5.49±0.95 mg/L (NH^-_3) at the major storm drain station. Ammonia enters surface water from the decomposition of nitrogenous organic matter (e.g. domestic waste) and effluents from industries, and high ammonia levels in water could result in consumer complaints due to odour and taste problems (Markesbery *et al*., 1984; Mosley *et al*., 2005; Hasan *et al*., 2011), toxicity to aquatic lives, oxygen depletion and occurrence of eutrophication (Vayenas *et al*., 1997). The contaminant also created hazardous by-products of carcinogenic chloramines when reacted with chlorine during the chlorination process at the final stage of a DWTP process (Okoniewska *et al*., 2007). Long-term ingestion of water containing more than 1 mg/L (ppm) ammonia may be damaging to the internal organ systems of humans (Oregon Department of Human Services, 2000).The National Academy of Science recommends, and many European nations have adopted, a drinking water standard of 0.5 mg/L (ppm) (Oregon Department of Human Services, 2000). The values of fluoride in water samples collected in River Benue were highest at the major storm drain station (3.55±0.12 mg/L) but the value is not significantly (P>0.05) different from its (F^-) values at Wurukun abattoir station (2.31±0.61 mg/L), Wadata market station (2.11±0.64 mg/L) but significantly (P<0.05) different from its value at the control area (1.79±0.01 mg/L). The values of fluoride in this study increased from 1.79±0.01 to 3.55±0.12 mg/L, which is higher than the drinking permissible limit of 1.5 mg/L (F^-) recommended by the World Health Organization (WHO, 2017) (Table 4). The sources of fluoride in River Benue may be attributed to erosion of granite along the river banks. The eroding force of surface or runoff water rubs off fluoride from deposits of granite gneisses and is deposited into aquatic ecosystems (Adimalla and Venkatayogi, 2018; Alsuhaimi *et al*., 2019). The drinking of such fluoride-contaminated water can result in its assimilation into the bloodstream (Fawell *et al*., 2006) and can be toxic at high concentrations (Liteplo *et al*., 2002). It is one of the elements that can cause serious deleterious effects on man (WHO, 2006). Recent studies have shown adverse associations between fluoride and intellectual capability. The intelligence quotient of Mexican children was discovered to be poorer as long as their mammas ingested fluoride-contaminated food or water during pregnancy (Bashash *et al*., 2017). A rise of 1 milligram of fluoride was concomitant to the decline of virtually 4 intelligent quotient points especially in boys (Frak and Bednarczyk, 2021). Additionally, high doses of fluoride in drinking water cause fluorosis in the teeth and bones (Rajmohan *et al*., 2019). The highest value of nitrite, NO^-_2 (52.36±5.5 mg/L) was recorded at the major storm drain station and the value is significantly (P<0.05) higher than its values at Wurukun abattoir station (37.88±3.82 mg/L), Wadata market station (14.13±1.37 mg/L) as well as the control area (2.75±0.07 mg/L). The presence of nitrite in River Benue may be attributed to nitrogenous fertilizers from runoff water and mineral deposits. Nitrite accumulation is attributed to large inputs of agriculturally derived nitrogen (N) substrates into aquatic environments (Kelso *et al*., 1997). Consequently, the ingestion of water from River Benue may be a route of entry of nitrite in the human alimentary system. Nitrite interacts with nitrosatable compounds in the human alimentary system to form N-nitroso compounds that are carcinogenic (FAO/WHO, 2003a, b; WHO, 2011). It also interrupts the potential of haemoglobin to release oxygen in the bloodstream vis-à-vis infants and can develop life life-threatening blood ailments in children called methemoglobinemia (Mosley *et al*., 2005). Generally, the order of abundance of the chemical properties is as follows: Sodium>nitrite>hardness>magnesium>nitrate>fluoride>ammonia.

Biological Properties of River Benue

The result of the biological properties of water samples collected in River Benue is summarized in Table 5. The result indicates that the highest contents of biochemical oxygen demand, BOD (43.13±1.29 mg/L) and chemical oxygen demand, COD (1174.08±28.79 mg/L) were observed in water sampled from Wurukun abattoir station, and the contents are significantly ($P<0.05$) higher than their (BOD and COD) contents in water sampled from major storm drain station (38.03±10.19 and 604.10±10.14 mg/L), Wadata market station (30.55±8.07 and 604.10±10.14 mg/L), as well as the control area (14.88±4.65 and 374.08±6.46 mg/L), respectively for BOD and COD. The values of BOD increased from 14.88±4.65 to 43.13±1.29 mg/L, which is higher than the maximum permissible limit (MPL) of 3 mg/L (BOD) established by the Federal Ministry of Environment of Nigeria (FMEnv, 2011) and World Health Organization (WHO, 2011) (Table 6). The level of BOD in water shows that oxygen-demanding species desire more oxygen to thrive on. The decomposition processes in the river utilized some oxygen needed for optimum growth and development of aquatic organisms (Ogbonna *et al*., 2018). The values of COD increased from 374.08±6.46 to 1174.08±28.79 mg/L, which is higher than the maximum permissible limit (MPL) of 7.5 mg/L (COD) established by the World Health Organization (WHO, 2011) (Table 6). The high values of COD in the water samples are an indication that River Benue is polluted, which may be attributed to the high nutrient level in the river. Chemical oxygen demand is triggered by the entry of agronomical, abattoir and manufacturing waste that has a high content of organic pollutants (Garg *et al*., 2010). The higher content of COD than BOD in this study may be attributed to more organic compounds being chemically oxidized than biologically oxidized in the river. For instance, COD is the amount of oxygen consumed to chemically oxidize organic matter contaminants to inorganic end products (Ogbonna *et al*., 2020b). The highest value of dissolved oxygen, DO (14.31±1.60 mg/L) is observed in water sampled from the control area and the concentration is significantly ($P<0.05$) higher than its values at the Wadata market station (9.38±1.42 mg/L), major storm drain station (8.03±1.02 mg/L) and Wurukun abattoir station (7.65±0.07 mg/L**)**. The high value of DO at the control area may be attributed to low nutrient levels and organic matter content unlike the Wurukun abattoir station and major storm drain station that received high organic content from effluent discharged from the large abattoir and runoff from agricultural farms, respectively. The inflow of agrochemicals (like pesticides, and inorganic fertilizers), livestock wastes and sewage runoff contribute nutrients in water bodies (Sheets, 1980; Hamid *et al*., 2020). Additionally, high organic content from slaughterhouses in water bodies results in oxygen depletion (Oremo *et al*., 2020). The values of DO increased from 7.65±0.07 to 14.31±1.60 mg/L, which is higher than the 5 mg/L (DO) established by (WHO, 2011) and 7.5 mg/L (DO) recommended by the Federal Ministry of Environment (FMEnv, 2011) (Table 6). Dissolved oxygen is the oxygen present in a dissolved form in a water body (DWAF, 1993) and it is one of the important predictors of the ability of the aquatic body to hold aquatic life forms (APHA, 2005). The level of DO in River Benue will enhance the survival and reproductive capacity of aquatic organisms living therein. Generally, the level of abundance of the biological properties of River Benue followed a decreasing order: COD>BOD>DO.

Conclusion

The results of the study show that anthropogenic pressure is a key player influencing water quality at the four sampling stations of River Benue. The levels of the physicochemical parameters in water samples were within the permitted level recommended by the World Health Organization and the Federal Ministry of Environment of Nigeria except for TSS, pH, turbidity, temperature, fluoride, BOD and COD. The level of these parameters (TSS, pH, turbidity, temperature, fluoride, BOD, and COD could affect the health performance and reproductive ability of aquatic organisms (e.g. fishes) in River Benue. It is, therefore, recommended that cottage industries stop releasing wastes into the river and farmers should desist from the use of agrochemicals in farmlands near River Benue. Furthermore, similar studies should be carried out at regular intervals to sustain aquatic life.

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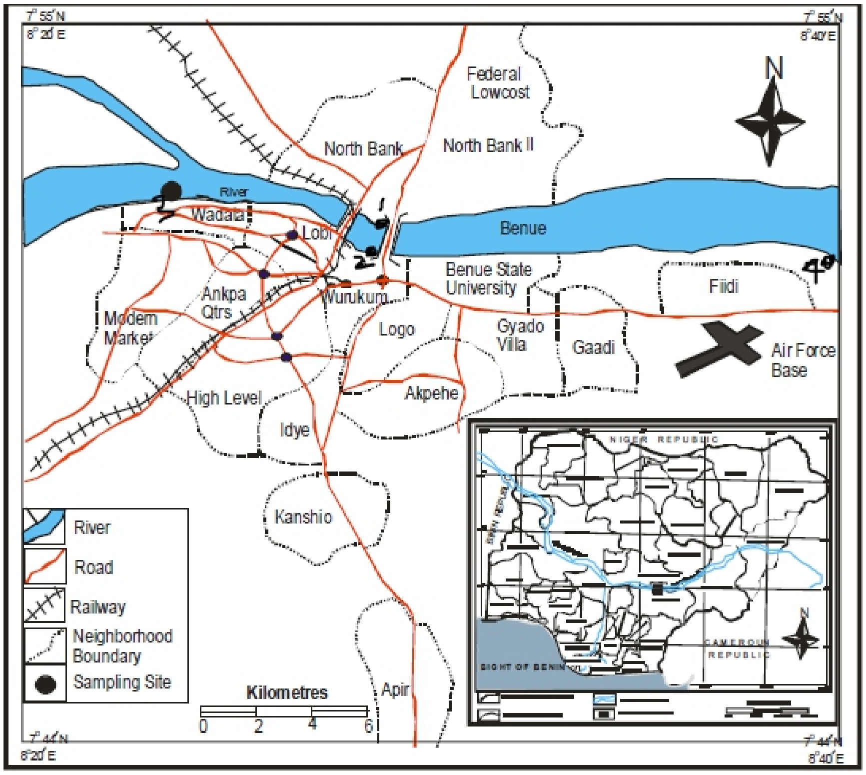

Fig. 1: Map showing the study area

Table 1: Physical properties of water samples collected in River Benue

	Sampling stations			
Water parameters tested	**Wurukun abattoir**	**Wadata market**	**Major storm Drain**	**Control**
Temperature (°C)	30.38^{a}±0.31	30.12^{a}±0.03	30.70^{a}±0.64	28.0^{a}±1.12
pH	9.18^{a}±0.09	8.92^{b}±0.02	6.48^{c}±1.19	6.80^{c}±0.58
Total dissolved solids, TDS (mg/L)	393.06^{b}±15.0	350.01^{c}±9.01	470.03^{a}±9.24	230.01^{d}±5.77
Total suspended solids, TSS (mg/L)	366.58^{b}±8.50	188.01^{c}±6.01	673.03^{a}±7.96	68.51^{d}±6.39
Turbidity (NTU)	313.03^{b}±12.7	275.02^{c}±16.0	496.60^{a}±40.9	234.56^{d}±14.0
Electrical conductivity (µs/cm)	24.76^{a}±2.80	16.68^{b}±8.86	24.25^{a}±2.44	0.61^{c}±0.01

Values are mean ± standard deviation of 3 replicates

^{a,b,c,d} Means in the same row with different superscripts are significantly different (P<0.05)

Table 2: Comparison with international standards and similar studies on physical properties of rivers in Nigeria and other countries

Source	Temp (°C)	pH	TDS (mg/L)	TSS (mg/L)	Turbidity (NTU)	EC (µs/cm)	Location
This study	28–30.7	6.8–9.18	230–470	68.51–673.03	234.56–496.60	0.61–24.76	River Benue, Makurdi, Nigeria.
Uddin *et al*. (2020)	25–32	5.80–7.01	56.20–2950	–	–	–	Karnaphuli estuarine water, Chittagong, Bangladesh.
Ogbonna *et al*. (2020b)	28.43–30.67	6.23–7.29	223–335	46.63–115.68	–	–	Pond water at Ishiagu, Ebonyi State, Nigeria.
Garba (2019)	21–26	6.90–7.30	–	–	22.3–200	340–970	Jos, Nigeria.
Ogbonna *et al*. (2018)	27.05	5.92–6.22	–	77.5–101.5	40.05–60.35	40.05–200.05	Ubeyi River, Ebonyi State, Nigeria.
Ling *et al*. (2017)	25.7–29.3	6.3–7.1	–	5-0–1363.3	3.1–1091.5	36.9–48.0	Tropical river in Sarawak, Malaysia.
Amoo *et al*. (2017)	–	6.65–6.96	1494–1953	30–90	–	2450–3260	Jakara River, north-western Nigeria.
Enuneku *et al*. (2017)	25.38–26.18	6.12–6.31	7.42– 19.43	4.93– 9.73	8.67–16.33	14– 36.67	Obueyinomo River, Edo State, Nigeria.
Uncumusaoğlu *et al*. (2017)	7.02–24.41	6.96–8.57	0.11–0.28	0.264–2	1.920–74.540	175–428	Yağlidere Stream, Turkey.
Mutlu *et al*. (2014)	3.8–26.4	7.26-7.82	–	0.1-4.9	–	–	Beydilli River,
Mutlu *et al*. (2013)	6-16	8.11–8.47	–	0.03–4.12	–	–	Horohon Creek,
Anhwange *et al*. (2012)	26–27.40	6.76–6.81	17.19–38.78	–	18.18–24.19	59.40–91.0	River Benue, Nigeria.
WHO (2003; 2011) permissible limit	25–30	6.5–8.5	200–500	80–150	5		
FMEnv (2011) standard	<40	6–9	NA	50			
NDWQS (2007) standard	NA	6.5–8.5	1000	25		1000	

Table 3: Chemical properties of water samples collected from River Benue

	Sampling stations			
Water parameters tested	**Wurukun abattoir**	**Wadata market**	**Major storm Drain**	**Control**
Total hardness, $CaCO_3$(mg/L)	$33.06^b±1.21$	$17.52^c±6.35$	$52.02^a±0.03$	$15.53^c±0.61$
Nitrate, NO^-_3 (mg/L)	$2.19^b±1.33$	$1.75^c±0.24$	$5.80^a±2.90$	$0.15^d±0.01$
Nitrite, NO^-_2 (mg/L)	$37.88^b±3.82$	$14.13^c±1.37$	$52.36^a±5.50$	$2.75^d±0.07$
Fluoride, F^- (mg/L)	$2.31^{ab}±0.61$	$2.11^b±0.64$	$3.55^a±0.12$	$1.79^c±0.01$
Magnesium, Mg^{2+} (mg/L)	$32.20^b±0.14$	$25.21^c±1.22$	$38.96^a±7.33$	$19.11^d±0.81$
Sodium, Na^+ (mg/L)	$58.58^b±3.66$	$30.11^c±0.01$	$79.18^a±10.8$	$19.78^d±3.89$
Ammonia, NH^+_3 (mg/L)	$2.13^b±0.18$	$1.57^c±0.01$	$5.49^a±0.95$	$0.88^d±0.02$

Values are mean ± standard deviation of 3 replicates

^{a,b,c,d} Means in the same row with different superscripts are significantly different (P<0.05

Table 4: Comparison with international standards and similar studies on chemical properties of rivers in Nigeria and other countries

	Total hardness (mg/L)	Nitrate, NO^{-}_3 (mg/L)	Fluoride, F^{-} (mg/L)	Nitrite, NO^{-}_2 (mg/L)	NH_3 (mg/L)	Magnesium, Mg^{2+} (mg/L)	Sodium, Na^{+} (mg/L)	Location
This study	15.53–52.02	0.15–5.80	1.79–3.55	2.75–52.36	0.88–5.49	19.11–38.96	19.78–79.18	River Benue, Makurdi, Nigeria.
Uncumusaoğlu *et al*. (2017)	9–23.70	0.311–2.100		0.001–0.038	0.001–0.081	–	1.30–9.70	Yağlidere Stream, Turkey.
Amoo *et al*.(2017)	–	0.07–1.61	–	–	0.07–1.75	–	–	Jakara River, north-western Nigeria.
Enuneku *et al*. (2017)	9.33±3.13–11.33±4.88	0.96±0.64–1.44±1.47	–	–	–	1.17±0.60–1.52±0.84	–	Obueyinomo River, Edo State, Nigeria.
Mutlu *et al*. (2014)	99.42-155.26	Nd-0.95	–	Nd-0.013	–	–	12.48-46.12	Beydilli River,
Mutlu *et al*. (2013)	–	Nd-4.20	–	Nd-0.009	–	–	7-77	Horohon Creek,
Anhwange *et al*. (2012)	40–88.40	21.42–37.40	–	–	–	–	–	River Benue, Nigeria.
Uddin *et al*. (2020)	50.10–2308.4	–	–	–	–	–	–	Karnaphuli estuarine water, Chittagong, Bangladesh.
Ogbonna *et al*. (2020b)	–	–	–	–	–	0.98–3.99	0.28–0.99	Pond water at Ishiagu, Ebonyi State, Nigeria.
Garba (2019)	40.5–101.20	2.1-20	–	–	–	–	–	Jos, Nigeria
WHO (2003; 2011; 2017) permissible limit	500	50	1.5	–	–	50	200	
FMEnv (2011) standard	NA	NA	NA	NA	NA	40	120	

Table 5: Biological (organic) properties of water samples collected in River Benue

	Sampling stations			
Water parameters tested	**Wurukun abattoir**	**Wadata market**	**Major storm Drain**	**Control**
Dissolved oxygen, DO (mg/L)	7.65^{c}±0.07	9.38^{b}±1.42	8.03^{b}±1.02	14.31^{a}±1.60
Biochemical oxygen Demand, BOD (mg/L)	43.13^{a}±1.29	30.55^{c}±8.00	38.03^{b}±10.19	14.88^{d}±4.65
Chemical oxygen demand, COD (mg/L)	1174.08^{a}±28.79	572.02^{c}±63.5	604.10^{b}±10.14	374.08^{d}±6.46

Values are mean ± standard deviation of 3 replicates

^{a,b,c} ***Means in the same row with different superscripts are significantly different (P<0.05***

Table 6: Comparison with international standards and similar studies on biological properties of rivers in Nigeria and other countries

	DO	COD	BOD
This study	7.65–14.31	374.08–1174.08	14.88–43.13
Ling *et al*. (2017	6.2–7.3	14–90	1.6–5.2
Enuneku *et al*. (2017)	2.04–4.27	–	1.23– 1.93
Amoo *et al*. (2017)	36.0–54.8	–	20.0–49.2
Ogbonna *et al*. (2020b)	5.75–18.06	20.37–61.28	25.13–53.15
Anhwange *et al*. (2012)	4.20–5.22	91.60–128.93	66.40–81.44
Ogbonna *et al*. (2018)	5.85–6.35	–	0.067–0.405
Uncumusaoğlu *et al*. (2017)	7.04–15.52	–	0.51–11.72
WHO 2003, 2011	5	7.5	3
FMEnv 2011	7.5	NA	3
NDWQS 2007	NA	NA	NA