British Journal of Environmental Sciences 14(1),11-27, 2026
Print ISSN : 2055-0219 (Print)
Online ISSN: 2055-0227(online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development UK

Assessment of River Benue Water Quality and its Suitability for Human Consumption in Makurdi Town

Patricia Ali, Glory Obene Ogiji, Joseph Enefu, Odeh Andrew Adimanyi, Monday Akpegi Onah

Department of Geography, Rev. Fr. Moses Orshio Adasu University, Makurdi
*Corresponding Author: email patriciaali07@yahoo.com

doi: https://doi.org/10.37745/bjes.2013/vol14n11127 Published February 11, 2026

Citation: Ali P., Ogiji G.O., Enefu J., Adimanyi O.A., Onah M.A. (2026) Assessment of River Benue Water Quality and its Suitability for Human Consumption in Makurdi Town, *British Journal of Environmental Sciences*, 14(1),11-27

Abstract: *This study assessed the Effects of Economic Activities on River Benue Water Quality: Case studies of Rice Mill Wadata and Pure Biotech Company Makurdi, Benue State, Nigeria. The objectives of the study include; to examine and analyse the physical, chemical, biological/microbiological water quality and to examine the suitability of water for human consumption and its implications for public health in the study area. Water samples were collected from 3 sample location (River Benue at Abinsi, the waste water discharge points of the Pure Biotech Company and Rice Mill Wadata). The study used purposive sampling technique to select the points (upstream, midstream, and downstream) were water samples were collected and analyzed for various parameters. Raw data (water samples) were analysed at Greater Makurdi Water Works Laboratory, Makurdi while the results were presented via frequencies in a tabular form. Results showed that all locations exceeded Nigerian Standard for Drinking Water Quality (NSDWQ) and World Health Organization (WHO) limits for colour, turbidity, Cr6+, and total coliform. High biochemical oxygen demand (BOD) levels indicated organic pollution. The study concludes that water quality in all locations is compromised, posing potential health risks. The study recommended strengthening environmental regulations on waste management before discharging in to the river, regular monitoring, treatment, and mitigation measures to improve water quality as well as engaging in public health education in and around the communities around riverine areas.*

Keywords: water quality, river Benue, industrial pollution, public health, environmental regulations

INTRODUCTION

Water is a universal solvent and an abundant natural resource, crucial for sustenance of all aspects of life and it is a valuable resource that needs to be well-cared-for (Kumar, Kumar, Dhindwal & Sewhag, 2011). About 75% of the earth's surface is covered with water but fresh water accounts for only less than 2.7% (Kumar et al., 2011). Water is a vital renewable resource for the sustenance of life. It is required by humans for domestic, agricultural and industrial uses. Thus, humans are closely connected to freshwater resources, and the utilization of this resource has played a critical role in the development of societies and economies in the world (AI Jayyousi, 2007).

In nature, water occurs on the surface and sub-surface, normally called surface and groundwater respectively. Groundwater is the body of water which occupies the earth's mantle, and which forms the sub-surface section of the hydrological cycle. Maintaining high standards of surface water quality is crucial across the globe, given its direct connection to the provision of potable water and the far-reaching consequences it has on both human health and ecological systems. Surface waters, which include rivers, lakes, and streams, on the other hand, are often a primary resource for the drinking water supplies of numerous communities. The integrity of these water sources is essential, as any pollutant or diminishment in quality can lead to serious health hazards for the population and can also have a detrimental impact on the balance of local ecosystems (Cheng, Zhang, Shi & Kung, 2022).

When surface water quality is compromised, the repercussions are multifaceted. For humans, the ingestion of or exposure to contaminated water can lead to waterborne diseases and can also affect community health indirectly through the food chain. For the environment, poor water quality can impact aquatic habitats, reduce biodiversity, and disrupt the natural functions of ecosystems, which can have cascading effects on food security and biodiversity (Papa, Creteaux & Grippa, 2023).

Surface water, which includes rivers, lakes, and streams, is inherently vulnerable to changes and contamination. Even slight deviations from quality standards can lead to severe repercussions. Contaminated surface water often translates into compromised drinking water quality, which can pose a threat to public health by spreading waterborne diseases and can disrupt delicate ecosystems, adversely affecting both aquatic species and broader ecological dynamics (Johnson, Brusseau, Carroll, Tick & Duncan, 2022; Mashala, Dube, Mudereri, Ayisi & Ramudzuli, 2023). Human-induced pollution substantially compromises surface water quality, reducing its suitability for essential uses such as industrial operations, agricultural and recreational activities. Industrial effluents and agricultural runoffs are prime contributors to the contamination of these waters, leading to their unsuitability for industrial and irrigation usages. This contamination can impede industrial productivity and agricultural yields. Moreover, recreational pursuits like swimming and boating can become hazardous in polluted waters, posing health risks to the public.

The detriments of water pollution extend beyond immediate health risks; they can also cause long-term ecological damage, disrupting aquatic ecosystems and reducing biodiversity. Contaminated water can affect fish and wildlife populations, alter their habitats, and impede natural water purification processes (AL-Aizari, Osan, Fatima & Hefdhallah, 2023; Kolewole, Iyiola, Ibrahim & Isibor, 2023; Mai, Zheng, Zeng, Wang, Liu, Ma, Zhou, Zhao, Wu, Wang, Yan, He & Shu, 2023). Agricultural activities significantly pollute water bodies with organic matter, nutrients, pesticides, and heavy metals. Runoff leads to eutrophication and contamination, while pesticides and heavy metals pose risks to aquatic life and human health. These pollutants cause chronic toxicity and environmental issues.

The degradation of water resources is a much-studied phenomenon and can be caused by natural processes (climate change, water-rock interactions, and geological factors) and human activity (agricultural practices and urban waste and industrial waste), as well as the presence of considerable chemical compounds since the industrial revolution (Nagaraju, Balaji & Thejaswi, 2016). Despite this, the management of surface water and groundwater resources remains complicated in many circumstances and relevant information remains unknown (Macdonald and Davies, 2002). Apart from anthropogenic activities, natural heterogeneities of rock/soil interact with water, influencing natural water cycles and affecting water quality across domains (Trabelsi and Zouari, 2019). Such modifications can have severe repercussions for the functioning of human health and living organism (Akhtar, Syakir, Rai, Saini, Pant, Anees, Qadir & Khan, 2019).

The quality of surface water in many parts of the developed world had noticeably improved in recent decades, but is being challenged as economic growth, demographic and climate changes lead to widespread and severe degradation. The need to reverse this damage is reflected in the 2030 Agenda for Sustainable Development, both as a dedicated goal and as an integral element of many others. By providing a snapshot of the current situation, this report offers a baseline to measure progress, a framework for global assessment and a pathway towards sustainable solutions that will deliver on that agenda (United Nations Environment Programme, 2016).

Surface water pollution has a greater impact than groundwater contamination, and the environmental implications of climate change have been a major threat to surface water quality (Uhl, Hahn, Jager, Luftensteiner, Siemensmeyer, Doll, Noack, Schwenk, Berkhoff & Weiler, 2022), with human activities seen as the most significant cause of the worsening of surface water quality in many nations and areas throughout the world in recent decades (Zheng, Jiang, Chen, Li, Li & Zheng, 2022). The conflict between people and water resources has gotten worse as a result of the rapid expansion of society and the economy as well as the acceleration of global climate change. As a result, the creation of water management plans, including the creation of precise and logical techniques to evaluate surface water quality, is necessary (Mararakanye, Le Roux & Franke, (2022).

Assessing the current state of water quality in river basins and its driving factors are critical for understanding how geography, human socio-economics, and land use impact water quality changes (Ahn & Kim, 2017). A new problem being presently faced is how to precisely identify the important variables that influence water quality due to the numerous water quality monitoring indicators and the intricate pollution process (Aboelnga, El-Naser, Ribbe & Frechen, 2020).

In Nigeria, studies have shown that most of the water bodies are the endpoints of effluents discharged by industries (Elemile, Raphael, Omole, Oloruntoba, Ajayi, & Ohwavborua, 2019; Adeolu, Okareh & Duda, 2016; Akange, Chaha & Odo, 2016). These effluents contain toxic and hazardous materials that settle in river water as bottom sediments and constitute health hazards to the population that depends on the water as a source of supply for domestic uses (Armaya, Zango, Kadir & Musawa, 2020). Heavy metals are known to be persistent in industrial effluents and can become bio-available for uptake by other aquatic organisms under favourable conditions. Health challenges like genetic mutation, deformation, cancer, kidney problems have been linked to pollution by heavy metals (Jiang et. al, 2016; Antoniadis, Shaheen, Boersch & Frohne, 2017). The outbreaks of water-borne diseases like cholera, hepatitis, gastro-enteritis have also been reported as a result of the ingestion of effluent polluted water (Wear, Vicenc, Rob & Carme, 2021).

One of the most critical problems in developing countries including Nigeria and Makurdi town is improper management of the vast amount of waste generated by various anthropogenic activities which influence are known sources of water pollution. These activities include urban, industrial and agricultural activities with increasing exploitation of water resources as well as natural processes, such as precipitation inputs, erosion and weathering of crustal materials degrade surface waters and damage their use for drinking water, recreational and other purposes (Irfan, 2012). Hence the justification for this study n Makurdi town.

MATERIALS AND METHODS

Study Area

Makurdi town is located between Latitude $7^0$36' and $7^0$48' North of the equator and between longitude $8^0$27' and $8^0$38' East of the Greenwich Meridian. The town falls within the tropical humid and mega thermal climate with wet and dry season (Aw) according to Koppen's classification. The climate condition is influenced by two air masses; the warm moist South Westerly air mass is a rain-bearing wind that brings about rainfall from the months of March/April to October. The dry north easterly air mass blows over the region from November to April thereby bringing about seasonal dryness. The annual rainfall in Makurdi is between 1200 1500mm (Adamgbe and Ujoh, 2012). The temperature condition is however, generally high throughout the year with a daily range of 23 - 28 and maximum of 37 (Tyubee, 2005). The town, like most other cities in the Lower Benue Valley is drained by the Benue River and its tributaries including Idye, Fete, Kpage, Mu and Kereke streams. Usually, most partof the town is waterlogged and flooded during heavy rainfall or storm (Ogwuche and Abah, 2014; FMWRRD, 1998; Nyagba, 1995). Makurdi is the largest city in Benue state with a projected population of 391,924 people as at 2016 (Tser, 2013). Politically, the town is the administrative capital of Benue state and Makurdi local government council. Socio-economic activities in the town include government establishments, urban daily markets, banks, industries, two universities among other educational institutions, hotels, filling stations. These activities generate various degrees of effects that tend to pollute both surface and ground water sources in the study area.

British Journal of Environmental Sciences 14(1),11-27, 2026
Print ISSN : 2055-0219 (Print)
Online ISSN: 2055-0227(online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development UK

The vegetation in Makurdi and the surrounding Benue State is characterized by savanna grasslands and woodland. The area features tall grasses, shrubs, and scattered trees, including species such as baobab, acacia, and shear trees. As the capital city of Benue State, Makurdi has a diverse range of economic activities such as agriculture, trade and commerce, government and public services (Figures 1-4)

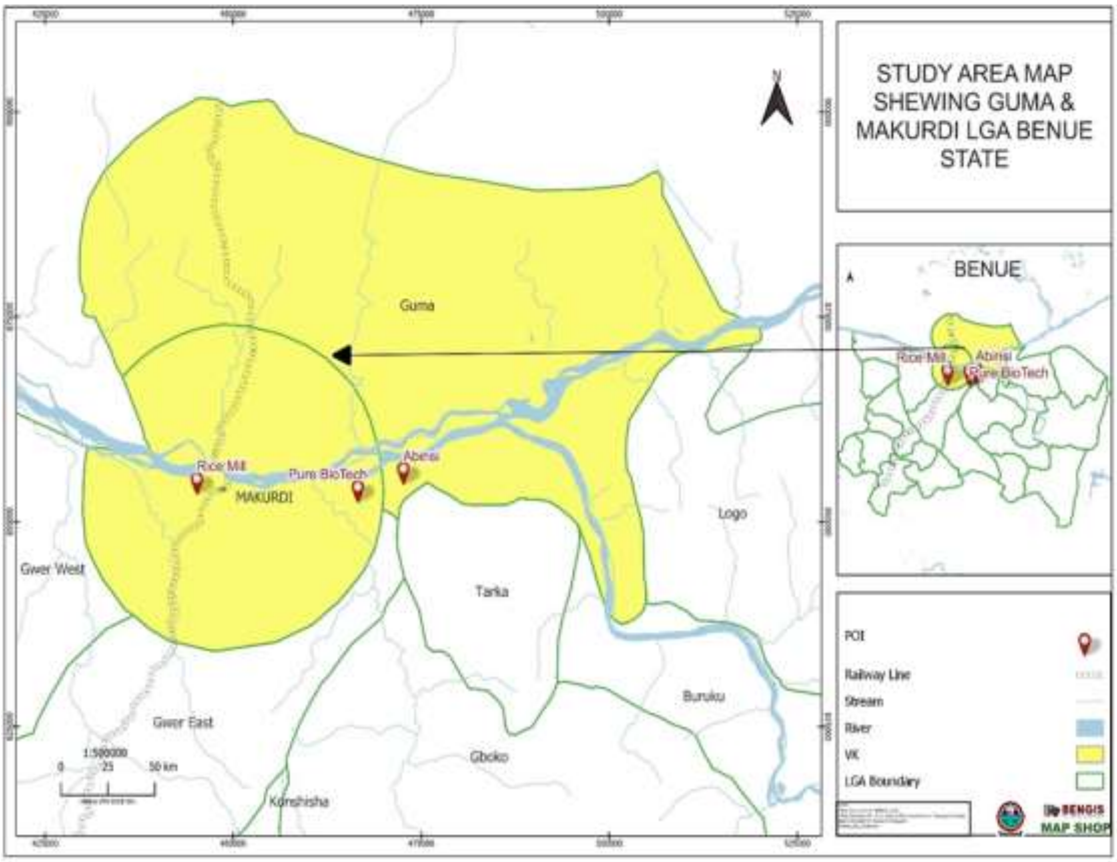

Fig. 1: Makurdi Local Government Showing the Study Area
Source: GIS Laboratory, Department of Geography, Rev. Fr. Moses Orshio Adasu University, Makurdi (2025)

British Journal of Environmental Sciences 14(1),11-27, 2026
Print ISSN : 2055-0219 (Print)
Online ISSN: 2055-0227(online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development UK

Fig. 2: Aerial Photography showing study point at pure biotech
Source: Field Work, 2025

British Journal of Environmental Sciences 14(1),11-27, 2026
Print ISSN : 2055-0219 (Print)
Online ISSN: 2055-0227(online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development UK

Fig. 3: Aerial Photograph showing study location at Abinsi
Source: Field Work, 2025

Fig. 4: Aerial Photograph showing study location at Rice Mill Wadata
Source: Field Work, 2025

British Journal of Environmental Sciences 14(1),11-27, 2026
Print ISSN : 2055-0219 (Print)
Online ISSN: 2055-0227(online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development UK

METHODS

The study population comprises of water samples obtained from the discharge points into the River Benue, as well as regulatory agencies' acceptable water quality limits or standards. The study purposively sampled water in the upstream, midstream and downstream of the study area. The sample points include River Benue (Abinsi), Bioethanol Plant and Rice Mill (Wadata) Makurdi. Purposive sampling method was preferred to ensure even spatial coverage of the study area. The water quality parameters selected for the study are presented in Table 1. The criteria for the selection of these parameters included potential health risk associated with the parameters, occurrence statistics and ease of interpretation.

Table 1: The (NSDWQ) Guidelines and WHO Drinking Water Standard

Physico-Chemical Parameter	NSDWQ	WHO
Colour	15TCU	15TCU
pH	6.5- 8.5	7.0-8.5
Turbidity	5NTU	5NTU
Total Coliform	0mpm	10mpm
Chromium	0.01mgl	10mg/L

Source: NSDWQ (2007, 2015, 2017) and WHO (2010, 2011, 2017)
Adapted from Mshelia and Mbaya (2024)

Data were collected on physical parameters such as pH which is acidity or alkalinity (a measure of the hydrogen ion concentration in water, indicating whether it is acidic ($pH < 7$), neutral ($pH = 7$), or alkaline ($pH > 7$)), colour (the visual appearance of water, which can be affected by dissolved substances, suspended particles, or organic matter), total Dissolved Solids (TDS) which is the total concentration of inorganic and organic substances dissolved in water, typically expressed in milligrams per liter (mg/L), turbidity (the cloudiness or haziness of a liquid caused by suspended particles, which can affect the clarity of the water), iron (a naturally occurring element that can be found in water. It is an essential nutrient for humans and many organisms, but elevated levels of iron in water can have detrimental effects on water quality), Nitrite ($NO2-$) which is a chemical compound that can be considered as a water quality parameter, particularly in the context of environmental monitoring and assessment of water quality. Nitrite is one of the nitrogen compounds that can be found in water, and it is an intermediate product in the nitrogen cycle, Chloride (the concentration of chloride ions in water, which can impact the taste of drinking water and the health of aquatic ecosystems), dissolved oxygen (DO) which is a crucial water quality parameter that measures the amount of oxygen dissolved in water. It is essential for the survival of aquatic organisms, as most aquatic life depends on oxygen to carry out vital biological processes like respiration, biochemical oxygen demand (BOD): which is the amount of dissolved oxygen consumed by microorganisms as they decompose organic matter in water, often measured in mg/L and total coliforms (a group of microorganisms found in the intestines of warm-blooded animals and are commonly used as indicators of fecal contamination).

Water samples collection was done in three areas of River Benue; upstream, midstream, downstream using sterilized and well labelled 1 litre plastic containers. A total of 3 water samples were collected following a standard procedures and well protected. The water samples were preserved with ice packs in a light proof insulated box to ensure rapid cooling so as to minimize chemical reactions and microbial growth in the samples. The ice packs encased in sealed containers to prevent them from contaminating the samples. Prior to packaging, the samples were chilled below 10^0C but not frozen and transported under iced condition within 24 hours to the laboratory for analysis of the selected physicochemical and bacteriological parameters. The water samples were subject to standard laboratory analysis at Greater Makurdi Water Works Laboratory. All quantitative data generated from the field-study were analyzed and presented in tabular form.

RESULTS AND DISCUSSION

Physical Water Quality Parameters at River Benue (Abinsi), Rice Mill (Wadata) and Bioethanol Plant Makurdi

The data on table 2 represents the physical water quality of the River Benue, Rice Mill and Bioethanol Plant in the study area comparing it to standards set by the Nigerian Standard for Drinking Water Quality (NSDWQ, 2007) and the World Health Organization (WHO, 2017). The breakdown of the analysis indicates the following:

Colour (TCU): the water colours at the River Benue (63.0 TCU), Rice Mill (85.0 TCU) and Bioethanol Plant (126.0 TCU) exceeds both NSDWQ (15 TCU) and WHO (15 TCU) standards. All locations have high colour levels, with Bioethanol Production Plant having the highest indicating potential aesthetic and health concerns due to pollution.

Turbidity (NTU): River Benue and Rice Mill Wadata effluent have high turbidity levels (67.1 NTU) respectively exceeding the NSDWQ (5 NTU) and WHO (5 NTU) standard limits, suggesting high levels of suspended particles with potential health risk. Whereas, Bioethanol has a relatively lower turbidity level (7.59 NTU) but still exceeds the limits. This agree with WHO (2017 and NSDWQ, 2007), that water quality parameters such as color, turbidity, and microbial contaminants can have significant impacts on human health. The results of this study suggest that industrial activities, particularly the Rice Mill and Bioethanol Company, are contributing to water pollution. This also agree with a study by Olajire, Adenuga & Bunmah (2019), which indicates that industrial effluents have significant impacts on surface water quality. Similarly, a study by Fagbayide, Francis, Olawale & Abulude (2017) on the effects of human activities on water quality assessment of Ala River in Akure, Ondo State, Nigeria reveals that there were variations in the quality of the sampled water when compared with the WHO standards for domestic and commercial water. The traces of some hazardous physical and chemical impurities in the river were above the acceptable limits, and thereby pose a health risk to several rural communities who rely heavily on the river primarily as their source of domestic water.

The current study also indicates that all locations have Total Dissolved Solids (TDS) within the NSDWQ (500 ppm) and WHO (1000 ppm) limits. Although Bioethanol has the highest TDS level (318 ppm), while River Benue has a very low level (0.15 ppm).

Table 2: Result of Physical Water Quality Parameters

Parameter/ Location	Abinsi	Rice Mill,	Biotech Company	NSDWQ	WHO
Colour (TCU)	63.0	85.0	126.0	15	15
Turbidity (NTU)	67.1	67.1	7.59	5	5
Total Dissolved Solids (mg/L)	0.15	024	318	500	1000

Source: Fieldwork 2024

Chemical Water Quality Parameters at River Benue (Abinsi), Rice Mill (Wadata) and Bioethanol Plant, Makurdi

The pH indicated on table 3 reveals that all locations: River Benue (7.0), Rice Mill (7.1) and Bioethanol (7.4) have pH levels within the NSDWQ and WHO limits (6.0-8.5), indicating neutral to slightly alkaline water. Sodium (Na): All locations have sodium levels within the NSDWQ and WHO limits (200 mg/L). River Benue and Bioethanol range between 40.313-40.749 (Na-mg/L) while Rice Mill has 67.821(Na).

Chromium (Cr6+): All locations exceed the NSDWQ and WHO limits (0.01 mg/L) for Cr6+, indicating potential health risks. The result shows that River Benue has 92.769 while Bioethanol Plant has 94.053 whereas, Rice Mill effluent has the highest Cr6+ level (154.401 mg/L) indicating potential toxidity. The data suggests that the water quality in all three locations is compromised, with high levels of Cr6. The presence of this pollutant can pose health risks to humans and aquatic life. Similarly, USEPA (2018) found that excessively high levels of Chromium, poses health and environmental risks. These findings agree with a study by Olalekan et.al (2012) on Influence of human activities on the water quality of River Ogun in Nigeria which established that traces of hazardous physical and chemical impurities in the river were above the acceptable limits; and thereby pose a health risk to several rural communities who rely heavily on the river primarily as their source of domestic water. More so, Offiono, et al (2023) researched on evaluation of the pollution effect of Abattoir Effluent in River Benue. The results indicate that water quality parameters like suspended solid (45.2 mg/L), dissolved oxygen (5.2 mg/L), turbidity (24.1 NTU) fell above the standard stipulated by the WHO, NSDWQ and Standard Organization of Nigeria (SON).

Table 3: Result of Chemical Water Quality Parameters

Parameter/ Location	Abinsi	Rice Mill,	Biotech Company	NSDWQ	WHO
pH	7.0	7.1	7.4	6.0-8.5	6.0-8.5
Sodium (Na)–mg/L	40.749	67.821	41.313	200	200
C_r^{6+} (mg/l)	92.769	154.401	94.053	0.01	0.01

Source: Fieldwork 2024

Bacteriological and Microbiological Water Quality at the River Benue (Abinsi), Rice Mill (Wadata) and Bioethanol Plant, Makurdi

Table 4 portray Biochemical Oxygen Demand (BOD) and Total Coliform: River Benue and Rice Mill Wadata effluent have high BOD levels (69 mg/L and 82 mg/L, respectively). These exceeded the NSDWQ and WHO standard limit (5-10 mg/L) indicating organic pollution (potential microbial contamination) while Bioethanol has a very low BOD level (0.00258 mg/L).
Total Coliform: All locations exceed the NSDWQ and WHO limits for total coliform (0-10 MPN). River Benue and Rice Mill Wadata effluent have the highest total coliform levels (240 MPN), indicating potential health risks from microbial contamination. Also, Payment and Hunter (2001) state high level of total coliform constitute microbial contamination and potential health risks.

Table 4: Bacteriological and Microbiological Surface Water Quality of River Benue

Parameter/ Location	Abinsi	Rice Mill	Biotech Company	NSDWQ	WHO
BOD	69	82	0.00258	Less than 5	10
Total Coliform	240	240	122	0	10

Source: Fieldwork 2024

Suitability of the Water in the Study Area for Human Consumption and Public Health
Laboratory analysis indicates that the colour of the surface water of the River Benue at Abinsi (the control point) was 63.0ptco. This value falls into high colour or highly coloured category. The high colour was accounted for as a result of high rainfall, degree of suspended particles and human activities. As a result of these, high colour indicates; presence of organic matter (humic acid tannins), algae blooms, sediment or particulate matters and industrial or agricultural runoff with potential risks such as aesthetic concerns (unpleasant appearance), interference with disinfection process and increased risk of trihalomethane (THM) formation.

For Rice Mill and Bioethanol Production Plant effluents, the results obtained revealed that colour 85.0 TCU and 126.0 TCU) respectively were above the stipulated NSDWQ guidelines (15 TCU) and WHO (15 TCU) standards and USEPA (15 TCU). Both surface water and discharge could be due to cleaning process and raw materials used. These very high colours indicate the presence of organic materials (eg. Humic acid and tannins), algae blooms, sediments or particulate matters and industrial or agricultural runoff with potential risk or threat to environment and humans such as aesthetic concerns (unpleasant appearance), interference with disinfection process, increases risk of trihatomethan (THM) formation and potential impacts on aquatic life.

The result obtained also showed that turbidity was analysed and found to be relatively higher than the recommended standard approved by NESREA, WHO and USEPA at all the locations. At the River Benue, turbidity appeared to be very cloudy. This signifies reasonable presence of suspended particles such as sediments (silt, clay, and sand), algae, micro-organic and organic matter. High turbidity could be as a result of non-implementation of mitigation strategies as well as high rainfall, erosion and sedimentation, algae blooms and waste water discharge. The result obtained for rice mill effluent also showed that turbidity exceeds the stipulated standards by NSDWQ, WHO and USEPA. This turbidity indicates significant presence of suspended particles such as starch, cellulose, proteins, fibre and sediments. The high turbidity of the rice mill effluent is as a result of the milling process and waste water generation. Whereas, the result obtained for Bioethanol effluent showed a lower turbidity (7.59). This indicates minimal presence of suspended particles such as yeast cell, bacteria, residual starch, and fibre. This is due to effective treatment compliance and regulation and environment benefits.

The TDS results for River Benue at the three sampled points were low and within the limit (table 2) indicating that the surface was very pure in terms of TDS. This value suggests minimal pollution and excellent water quality, low hardness, low conductivity and good aquatic habitat. While The TDS value for Rice Mill effluent was also below the maximum permitted limit for waste water effluent (table 3). The potential constituents of the TDS are starch and cellulose, proteins and amino acid, mineral (potassium, Sodium (Na)) and residual chemical from rice processing. However, the TDS value for Pure Biotech effluent studies was low to moderate and was within acceptable effluent quality for waste water discharge. Potential constituents of the Pure Biotech Company's effluent for are organic compounds (acetic acids), inorganic compounds (ammonia and phosphate), mineral (phosphorus and sodium) as well residual yeast and bacteria.

The pH of River Benue is exactly neutral (neither acidic nor alkaline) due to the geological formation, vegetation/organic matter, human activities (agricultural runoff) and atmosphere deposition. It does not pose any potential risk to the environment but rather supports biodiversity, maintain water quality, reduces treatment costs and enhance recreational activities (swimming and fishing). Similarly, the pH value for rice mill effluent is slightly above neutral, indicating a mild alkaline condition. The pH value was accounted for by rice milling process, water source, chemical additives and biological treated processes. The ph of the waste water does not pose any risk rather it reduces environmental risk and increase water reuse opportunities. More so, the pH for Pure Biotech effluent waste water was slightly alkaline and above neutral, indicating a mild-alkaline condition at the time of sampling. The value of this pH could be as a result of fermentation process, yeast and bacteria activities, chemical additives and water source. The implication is that waste water has been discharged into the environment though with educed environment risk.

The concentration of Sodium (Na) at the river at Abinsi as at the time of sampling was within the guideline as recommended by NESREA for NSDWQ and WHO but higher than that of USEPA

(20mg/L). River Benue's Sodium level typically range from 2-10mg/L with an average concentration of around 5-6mg/L. The possible sources of Na presence in the river Benue is due to the geological weathering, agricultural runoff (from fertilizer and pesticides), industrial effluents and atmospheric deposition. However, to the environment the elevated sodium level could pose the following potential risks to aquatic life, soil structure and fertility impacting on agricultural productivity and mankind. Also, sodium concentration of the effluents from the Rice Mill and Bioethanol are within the guidelines recommended by NESREA (for NSDWQ) and WHO though higher than that the value recommended by the USEPA (20mg/L). The potential risks to the ecosystem are concentration of sodium above 50-60mg/L which can be toxic to the ecosystem and some aquatic organisms.

The results obtained indicates that River Benue at Abinsi has chromium concentration level above the compliance level by NESREA (for NSDWQ), the WHO and USEPA. Similarly, the value observed at the Rice Mill which was found to be too high and greatly exceeds the permissible limits set by all the regulatory bodies (NESREA, WHO and USEPA). This discharged effluent value thus constitutes very serious environmental hazard. The discharged waste water is not fit for irrigation purpose and this poses a serious risk as it will lead Chromium poisoning. More so, result from the Pure Biotech Company indicates that the concentration level is above the standard stipulated by NESREA, WHO and US EPA. Chromium is a higher toxic heavy metal that can harm human and aquatic life. It enters the river Benue through industrial effluents, agricultural runoffs and atmospheric deposition and the Rice Mill and Pure Biotech effluents through contamination from equipment, processing chemicals or raw materials.

BOD results obtained from the three locations of surface water (Abinsi), Rice Mill, Wadata and Pure Biotech Company exceeded the allowable surface water and discharge permissible limit of the regulatory bodies of 30mg/L and 40mg/ by NESREA and WHO. The high BOD levels can lead to decrease Oxygen Demand (DO) levels causing stress or death to aquatic organisms. The values can contribute to the degradation of water quality making it unsuitable for human consumption, creation or irrigation water. Lastly, another environmental and health implication of these high BOD levels is the transmission of water borne diseases. Dissolved Oxygen depletion in water can encourage microbial retention of Nitrates to Nitrites and Sulphate to Sulphide giving rise to odour problems. It can also cause increase in Iron concentration.

CONCLUSION

Based on the findings, the study concludes that multiple water quality parameters from economic activities deviated from recommended standards (NSDWQ, 2007 and WHO, 2017), indicating potential health implications for the residents relying on these water for drinking water since many communities depend on the river for consumption and other domestic activities. The data suggests that the water quality in all three locations is compromised, with high levels of colour, turbidity, Cr6+, and total coliform. These suggest organic pollution and poor water clarity. The presence of these pollutants can pose health risks to humans and aquatic life. The high BOD levels in River Benue and Rice Mill Wadata effluent indicate organic pollution, which can lead to decreased oxygen levels in the water with implications for the environment and human health. The

Bioethanol location has relatively better water quality in terms of BOD and turbidity but still exceeds the limits for colour, Cr6+, and total coliform.

The study recommends strengthening environmental regulations and enforcement: Government regulatory bodies such as the National Environmental Standards and Regulations Enforcement Agency (NESREA) and Benue State Environmental Protection Agency (BENSEPA) to enforce environmental laws relating to industrial waste water discharge. Both the Rice Mill and Pure Biotech Company should be mandated to comply with national effluent discharge standards, with regular inspections and penalties for non-compliance.

Regular monitoring of water quality to ensure compliance with regulatory standards in order to protect public health. To enhance treatment and mitigation of compromised water quality, measures such as wastewater treatment and pollution control technologies should be implemented and installed to reduce affluent pollution particularly at the Wadata Rice Mill and Bioethanol Plant. This will help reduce bio chemical waste and other pollutants being discharged into River Benue and other water bodies.

Creation of Buffer Zones: The establishment of vegetative buffer zones or riparian strips along the riverbanks can help filter out pollutants from runoff before they enter the river. These buffer zones also prevent soil erosion and act as natural bio-filters for contaminants. Creating public awareness and health education: Educating the public particularly the communities around the Rice Mill and Bioethanol Plant on water quality issues relating to pollution and promoting water conservation which can help to mitigate environmental problems. By addressing these concerns, the water quality at Rice Mill, Wadata can be improved, reducing potential risks to the environment and human health. These recommendations align with a study by Adeniyi et al (2021) recommended effective treatment of the wastewater with a view to meeting acceptable standards before final discharge into the river Benue to avert pollution of the river.

REFERENCES

Aboelnga, H. T., El-Naser, H., Ribbe, L and Frechen, F. B (2020). Assessing Water Security in Water-Scarce Cities: Applying the Integrated Urban Water Security Index (IUWSI) in Madaba. *Jordan. Water*, 12, 1299.

Adamgbe, E and Ujoh, F (2012) Variations in Climatic Parameter and Food Yields: Implications on Food Security in Benue State, Nigeria. *Con. J. Envtal Stds*, 7: 59-67.

Adeniyi, O., Garba, B and Afeez, O (2021). Physicochemical and Bacteriological Assessment of ricemill wastewater discharged into river Benue, Nigeria. *Biological Environment and Pollution*. 1(1): 1-10.

Adeolu, A. T,, Okareh, O. T and Duda A. O (2016). Adsorption of Chromium ion from Industrial Effluent using Activated Carbon derived from Plantain (Musa Paradisiaca) Wastes. *American Journal of Environmental Protection*, 4(1): 7 -20.

Ahn, S. R and Kim, S. J (2017). Assessment of Integrated Watershed Health based on the Natural Environment, Hydrology, Water Quality, and Aquatic Ecology. *Hydrol. Earth Syst. Sci*., 21, 5583–5602.

Akange, E. T., Chaha J. A and Odo, J. I (2016) Impact of Wurukum Abattoir Effluent on River Benue-Nigeria, using Macro-Invertebrates as *Bioindicators. International Journal of Aquaculture*, 6(22): 1-11. http://dx.doi.org/10.5376/ija.2016.06.0022

Akhtar, N., Syakir, M. I., Rai, S. P., Saini, R., Pant, N., Anees, M. T., Qadir, A and Khan, U. (2019). Multivariate Investigation of Heavy Metals in the Groundwater for Irrigation and Drinking in Garautha Tehsil, Jhansi District, India. *Analytical Letters*, 53(5):774–794. https://doi.org/10.1080/00032719.2019.1676766

Al Jayyousi, O. (2007). Water as a Human Right: Towards Civil Society Globalization. International *Journal of Water Resources Development*, 23 (2):329–339.

AL-Aizari, A. R., Osan, M., Fatima, A and Hefdhallah, A (2023). Assessment of Groundwater Quality For Irrigation Purpose Using Irrigation Water Quality Index (IWQI). *Journal of Environmental Engineering and Landscape Management* 32(1): 1-11 DOI:10.3846/jeelm.2024.20598.

Annette, P., Wolf, J., Bartram, J., Clasen, T., Cumming, O., Freeman, C. M., Gordon, B., Hunter, R. P., Medlicott, K and Johnston, R (2019). Burden of Disease from Inadequate Water, Sanitation and Hygiene for Selected Adverse Health Outcomes: An Updated Analysis with a Focus on Low- and Middle-Income Countries. *International Journal of Hygiene and Environmental Health*, 222 (5):765-777. https://doi.org/10.1016/j.ijheh.2019.05.004.

Antoniadis, V., Shaheen, S. M., Boersch, J and Frohne, T. D (2017). Bioavailability and Risk Assessment of Potentially Toxic Elements in Garden Edible Vegetables and Soils Around a Highly Contaminated Former Mining Area in Germany. *Journal of Environmental Management* 186: 192-200.

Armaya, U. U., Zango, Z. U., Kadir, H. A. and Musawa, S. R (2020). Assessment of Heavy Metals in Soils Samples from lambun Sari Irrigation Sites of Katsina Metropolis. *Resources and Environment*, 10 (1): 4-9. https://doi.org/10.5923/j.re.20201001.02.

Cheng, C., Zhang, F., Shi, J and Kung, T. H (2022). What is the relationship between land use and surface water quality? A review and prospects from remote sensing perspective. *Environ sci Pollut Res*, 29: 56887-56907. https://doi.org/10.1007/s11356-022-21348-x.

Elemile, O. O., Raphael, D. O., Omole, O. D., Oloruntoba, O. E., Ajayi, O. E and Ohwavborua, N. A (2019). Assessment of the Impact of Abattoir Effluent on the Quality of Groundwater in a Residential Area of Omu-Aran, Nigeria. *Environ Sci Eur,* 31 (16):1-10. https://doi.org/10.1186/s12302-019-0201-5

Federal Ministry of water Resources and Rural Development (FMWRRD). (1988). *Managing Flood Problems in Nigeria*. https://doi.org/10.1080/07900620601182943

GIS Laboratory (2025). Makurdi Local Government Showing the Study Area. Department of Geography, Rev. Fr. Moses Orshio Adasu University, Makurdi

Irfan, Z. B (2012). Arsenic Contamination in Water. A Conceptual Framework of Policy Options with Particular Reference to Bengal Delta Basin. *International Journal of Hydrology Science and Technology,* 2(4): 391-401.

Jiang, L., He, P., Chen, J., Liu, Y., Liu, D., Qin, G., & Tan, N. (2016). Magnesium Levels in Drinking Water and Coronary Heart Disease Mortality Risk: A Meta-Analysis. *Nutrients*, *8*(1), 5. https://doi.org/10.3390/nu8010005

Johnson, G. R., Brusseau, M. L., Carroll, K. C., Tick, G. R and Duncan, C. M (2022). Global Distributions, Source-Type Dependencies, and Concentration Ranges of Per- and

Polyfluoroalkyl Substances in Groundwater. *Sci. Total Environ*. 841,156602. https://doi.org/10.1016/j.scitotenv.2022.156602.

Kolewole, T. O., Iyiola, O., Ibrahim, H and Isibor, R.A (2023). Contamination, Ecological and Health Risk Assessments of Potentially Toxic Elements in Soil around a Municipal Solid Waste Disposal in Southwestern Nigeria. *Journal of Trace Elements and Minerals*, 5: 1-9.

Kumar, S., Kumur, P., Dhindwal, A. S and Sewhag, M (2011). *Manual on Irrigation Water Management (p.104)*. Haryana, India: CCS Haryana Agricultural University.

MacDonald, J and Davies, D (2002). *Simple Methods for Assessing Groundwater Resources in Low Permeability Areas of Africa*. "British Geological Society, Nothingham, Uk.

Mai, Y., Zheng, J., Zeng, J., Wang, Z., Liu, F., Ma, L., Zhou, M., Zhao, S., Wu, B., Wang, C., Yan, Q., He, Z., & Shu, L. (2023). Protozoa as Hotspots for Potential Pathogens in the Drinking Water of a Subtropical Megacity: Diversity, Treatment, and Health Risk. *Environ sci. & technol*. 57(15): 6108–6118. https://doi.org/10.1021/acs.est.2c09139

Mararakanye, N., Le Roux, J. J., & Franke, A. C. (2022). Long-term water quality assessments under changing land use in a large semi-arid catchment in South Africa. *The Science of the total environment*, 818, 151670. https://doi.org/10.1016/j.scitotenv.2021.151670

Mashala, M. J., Dube, T., Mudereri, B. T., Ayisi, K. K., & Ramudzuli, M. R. (2023). A Systematic Review on Advancements in Remote Sensing for Assessing and Monitoring Land Use and Land Cover Changes Impacts on Surface Water Resources in Semi-Arid Tropical Environments. *Remote Sensing*, 15(16), 3926. https://doi.org/10.3390/rs15163926

Nagaraju, A., Balaji, E and Thejaswi, A (2016) Hydrogeochemical Evaluation of Groundwater in certain parts of Vinukonda Area, Guntur District, Andhra Pradesh South India. *Fresenius Env Bull* 25:1519-1532.

NSDWQ (2007). *Nigerian Standard for Drinking Water Quality*. Nigerian Industrial Standard.

Nyagba, J. L (1995). Effect of Variability in Rainfall characteristics on maize yield in Gboko Nigeria.

Ogwuche, J. O and Abah, I. A (2014). Assessment of Flood Disaster Vulnerability for Food Insurance Programme in Part of Makurdi Floodplain, Benue State, Nigeria.

Olajire, A. A., Adenuga, A. A and Bunmah, D. V (2019). Assessment of industrial effluent impact on surface water quality in Ibadan, Nigeria. *Journal of Environmental Science and Health*, 54: 147-155.

Olusola, A., Opeyemi, A and Olufemi, D (2017). Groundwater Quality Levels and Human Exposure, SW Nigeria. *Journal of Environmental Geography* 10(1-2), 23- 29. DOI: 10.1515/jengeo-2017-0003.

Papa, F., Creteaux, J. F., and Grippa, M (2023). Water Resources in Africa under Global Change: Monitoring Surface Waters from Space. *Surveys in Geophysics*, 44: 43-93. https://doi.org/10.1007/s1071202209700-9.

Payment, P and Hunter, P. R (2001). *Endemic and epidemic infectious intestinal disease and its relationship to drinking water*. In Fewtrell & Bartram (Eds.), Water quality: Guidelines, standards and health (pp. 61-88). IWA Publishing.

Trabelsi, R and Zouari, K. (2019). Coupled Geochemical Modeling and Multivariate Statistical Analysis Approach for the Assessment of Groundwater Quality in Irrigated Areas: A Study from North Eastern of Tunisia. *Groundwater for Sustainable Development* 8:413-427. https://doi.org/10.1016/j.gsd.2019.01.006.

Tser, A (2013) *The dynamics of Benue State Population 1963-2016*. Makurdi, Macro Teacher and Associate.

Tyubee, B (2005). Spatial Organization of daily rainfall in the Middlebelt of Nigeria. The Benue Valley, *Journal of Interdisciplinary Studies*. 4 (1).

Uhl, A., Hahn, H.J., Jager, A., Luftensteiner, T., Siemensmeyer, T., Doll, P., Noack, M., Schwenk, K., Berkhoff, S and Weiler, M (2022). Making waves: Pulling the plug-Climate change effects will turn gaining into losing streams with detrimental effects on groundwater quality. *Water Res*. 220, 118649.

United Nations Environment Programme (2016). UNEP Frontiers 2016 Report. *Emerging issues of Environment Concern*. Doi: https://doi.org/10.18356/4392feb8-en

USEPA (2018). *Chromium in Drinking Water*. United States Environmental Protection Agency.

Wear, L. S., Vicenc, A., Rob, M and Carme, F (2021). Biological conservation. www.elsevier.com/locate/biocom.

WHO. (2017). *Guidelines for drinking-water quality*: Fourth edition incorporating the first addendum. World Health Organization.

Zaharaddeen, I. (2015). Assessment of Spatial and Temporal Distribution of Some Physiochemical Parameters of Ground water Quality Of Birnin Gwari, North West Of Nigeria. *International Journal of Technology Enhancements and Emerging Engineering Research,* 3, 43-52.

Zheng, L., Jiang, C., Chen, X., Li, Y., Li, C., & Zheng, L. (2022). Combining hydrochemistry and hydrogen and oxygen stable isotopes to reveal the influence of human activities on surface water quality in Chaohu Lake Basin. *Journal of environmental management,* 312, 114933. https://doi.org/10.1016/j.jenvman.2022.114933