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Analysis of the seasonal and spatial variation of surface water quality parameters in Enugu Urban Rivers, Southeast, Nigeria

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Abstract

Seasonal quality assessment of surface water provides not only a better understanding about pollution dynamics in water bodies but also information for the implementation of sustainable water-use management strategies. Such vital information is lacking for surface waters in most cities in sub-Sahara Africa region, especially Nigeria. The study aimed, therefore, to examine the seasonal physio-chemical characteristics of surface waters in Enugu urban, southeast Nigeria, during the dry and wet seasons. Twelve Surface water samples were collected from the six major rivers in Enugu urban during two seasons (wet and dry seasons). Their physico-chemical characteristics were determined by specific analyses between 2020 and 2022. Some of the parameters were measured in situ whereas bacterial analysis were analysed in the laboratory. Seasonal fluctuations in surface water quality characteristics were determined and the pollution status was compared to WHO standards. The results revealed that the parameters like Turbidity, Ammonia, Nitrate, Nitrogen, Fecal coliform and total coliform were above the WHO permissible limit at all sites and for all seasons. Various anthropogenic activities, untreated sewage and effluent were the major sources of pollution to the river ecology and the surface water. Overall monitoring network results must be used to control pollution in catchments where industrial and urban activities are increasing in other to ensure effective water quality management, sustainability and safety.
Keywords: *physical parameters, water quality, seasons, monitoring, management*

Introduction

Water is an essential resource for human survival. According to the *2021 World Water Development Report* released by UNESCO, the global use of fresh-water has increased six-fold in the past 100 years and has been growing by about 1% per year since the 1980s. With the increase of water consumption, water quality is facing severe challenges. Industriali-zation, agricultural production, and urban life have resulted in the degradation and pollution of the envi-ronment, adversely affecting the water bodies (rivers and oceans) necessary for life, ultimately affecting human health and sustainable social development (Olapido et al., 2020). Globally, an estimated 80% of industrial and municipal wastewater is discharged into the environment without any prior treatment, with adverse effects on human health and ecosys-tems. This proportion is higher in the least developed countries, where sanitation and wastewater treat-ment facilities are severely lacking (Ongley, 2001).

Rivers are important freshwater systems across the world, providing main water resources for various uses including agricultural, domestic, recreational and industrial purposes. In recent years, rivers are amongst the most vulnerable water bodies to pollution as a consequence of unprecedented development (Duan et al., 2016). Inadequate water supply is still one of the major challenges in developing coun-tries, especially in Nigeria. This agrees with the assertion that surface water quality is a matter of critical concern in developing countries because of a growing population, rapid industrialization, urbanization, and agricultural modernization (Wang et al., 2018). Of all water bodies, lakes and rivers are the most vulnera-ble to pollution because of their role in carrying agricultural run-off, and municipal and industrial wastewater (Hung et al., 2010).

Water quality experts and decision-makers are confronted with significant challenges in their efforts to manage surface water resources due to these complex issues (Elhatip et al., 2007). Regarding the quality of drinking water, microbiological contamination is a primary concern of developing countries.

In addition, inorganic contaminants, concerning both health and aesthetic aspects, can be present in the waters. An anthropogenic influences like urbanization, industrialization, agricultural activities as well as natural sources like precipitation rate, weathering processes and soil erosion also degrade the surface water (Najafpour et al., 2008; Bu et al., 2010; Shimba and Jonah, 2016). Thus, the water quality of these water resources is a subject of ongoing concern and has resulted in an increasing demand for monitoring river water quality. The urban environment has profound impact over global ecosystem (Nezband and Jurgens, 2020). The urban impervious surfaces influence the non-point source pollution and water quality by directly af-fecting the amount of runoff to water bodies (Dougherty, 2004). The surface water contamination is observed mainly due to the presence of physical substances and biological pathogens that make them unfit for human consumption (Shimba and Jonah, 20016).

Various physicochemical parameters such as Hydrogen Ion Concentration (pH), Biological Oxygen Demand (BOD), Dissolved Oxygen, (DO), Chemical Oxygen Demand (COD), Total Solids (TS), Total Sus-pended Solids (TSS), Total Dissolved Solids (TDS), Total Hardness (TH), etc. have a significant role in determining the potability of drinking water (Sheikh & Yeragi, 2003). All water resources have reached to a point of crisis due to unplanned urbanization and industrialization (Singh et al., 2008).

The quality of water is described by its physical, chemical and microbiological characteristics (Ven-katesharaju et al., 2010). Water quality varies both spatially and temporally. River discharge and pollu-tant concentration in water bodies vary with tem-poral variations in precipitation, surface runoff, interflow and groundwater flow (Vega et al., 1998). Seasonal changes in surface water quality are used to interpret temporal variations in river pollution caused by natural or anthropogenic inputs from point and non-point sources (Ouyang et al., 2006; Fan et al., 2012). Therefore, seasonal changes in surface water quality must be considered when establishing a water quality management program (Ouyang et al., 2006).

Study has shown that microbial pollution of water has been a growing crisis in environmental and public health and this has not been fully addressed through scientific research and risk assessment (Joan et al., 1998). This phenomenon has proved to be the greatest threat worldwide and accounted for 70-80% of health-related problem in the developing world. More so, majority of waterborne diseases have resulted from use of untreated surface water. There are few studies that confirmed microbial pollution of surface water quality in developing countries. Nola et al. (1998) identified indicators of fecal contamination such as *Pseudomona aeruginosa*, *Aeromonas hydrophila* in spring and well water in surface waters in Yaoundé, Cameroun. Also, the result of ground water quality analysis carried out in Abeokuta, Nigeria showed that ground water is grossly polluted with microorgan-isms and heavy metals (Joan et al., 1998).

Surface water is easily contaminated because they receive water from surrounding areas. The spatial and temporal changes in the water quality parameters can directly reflect the environmental conditions of the river, as variations in water quality parameters can lead to changes in lake trophic status (Iqbal et al., 2018). It is of practical significance to strengthen the monitoring and analysis of water quality parameters, especially for preventing and controlling eutrophication and protecting wa-ter quality and safety.

Studies portend that quality of water bodies' change in different regions under different conditions. The Ara Waterway, located in the wet regions, has a higher water quality variation in seasonal scale than that of the Yamuna Waterway, which is in the dry region (Iqbal et al., 2022). In the southern estuarine water ecosystem of the Boseong County in Korea, there is a high Carlson Trophic State Index in the cropping area and land settlements in summer and autumn (Farid et al., 2019). Through the groundwater monitoring data in Pakistan, it can be found that excessive groundwater abstraction has caused adverse impacts on groundwater quality (Baterdene et al., 2020). Thermal stratification is the result of geographic location and summer–winter climatological differences and the depth of the lake. The seasonal vertical distribution of nutrients accompanies the thermal structure dynamics (Ellah, 2020; Kalff, 2011). The thermal stratification of lakes may lead to a lack of oxygen in the hypolimnion and a boom in algae growth in the epilimnion in summer. This could destroy the balance of aquatic ecosystems and damage water quality.

The increase in water pollution in Enugu and at-tendant shortage of water supply (Onuigbo, 2013; Chimaet al., 2019; Utomi et al., 2012; Ezenwaji, 2008) has continued to grow unabated. Water supply shortages in Enugu urban area is attributed to poor quality of water supply and increase in population density, which place high demand on surface water supply. Mushrooming of high rising building and industries within the urban landscape have substantially affected water quality in their vicinity due to the contamination of municipal and industrial wastes in the river and water reservoir. There has been argument as to which period or season of the year is the water quality more affected. More so, due to seasonal and regional charac-teristics in rivers' hydro geomorphology and water qualities, identifying spatial-temporal variation and trend of water quality as it relates to the water quality indicator have become a major focus of research in many developed and emerging econo-mies especially in sub-Sahara African region of the world (Chima et al., 2009; Ezenwaji, 2008). Yet this research area remains largely unexplored in environmental management studies in Enugu, south-east of Nigeria. This concern has made the study more imperative. The aim of this study is to exam-ine the seasonal physicochemical characteristics of surface water in Enugu urban during the dry and wet seasons. Information derived from the assess-ment of the seasonal water quality of the rivers would provide basic information and source of scientific knowledge on surface water in Enugu, a typical African emerging city. It will also form baseline data for users of these rivers and help policy makers in water resources to prevent future deterioration of water quality. The study hypothesized that the surface water quality (as measured by the physio-chemical characteristics) across the study area is not significantly different from WHO water quality desirable limits.

Study area

Enugu urban is located within latitude 06°21'N and 06°30'N and longitude 07°26'E and 07°37'N. It is situated at the foot of Udi escarpment and has a total land area of about 12,831 square meters.

Enugu urban is the state capital of Enugu State, southeast of Nigeria (Fig. 1, Fig. 2). Residential activities account for the highest land use comprising about 54.3% of total urban area in Enugu.

Enugu has about 16 distinct neighborhoods that may be broadly categorize as low, medium and high-density areas (Fig. 3).

Figure 1: Administrative Map of Nigeria Showing Enugu State (Source: Googled, 2023)

However, due to rapid urbanization, mixed densities exist and many organic and unplanned areas sprang alongside Enugu metropolis as a result of a high demand for residential accommodations. Enugu is commonly referred to as coal city (Newcastle of Nigeria) because of abundance of coal deposit in the area. Enugu urban area drains rivers such as Asata, Ekulu, Akwata, Ogbete, Emene and its tributaries; and they are captured by Nyaba River and also drain into Cross River basin. Dry and rainy seasons occur between November to March and April to October respectively. Geographically, the study area lies in transitional-savanna region. The population of Enugu urban according to 2006 National Population Census was 722,644 (National Population Commission, 2007). Using 2.8% annual urban population growth rate, the projected popu-lation as at 2022 was 873,043 (National Population Commission, 2007).

Figure 4 depicts the map of Enugu showing the various neighbourhoods and surface water in the study area.

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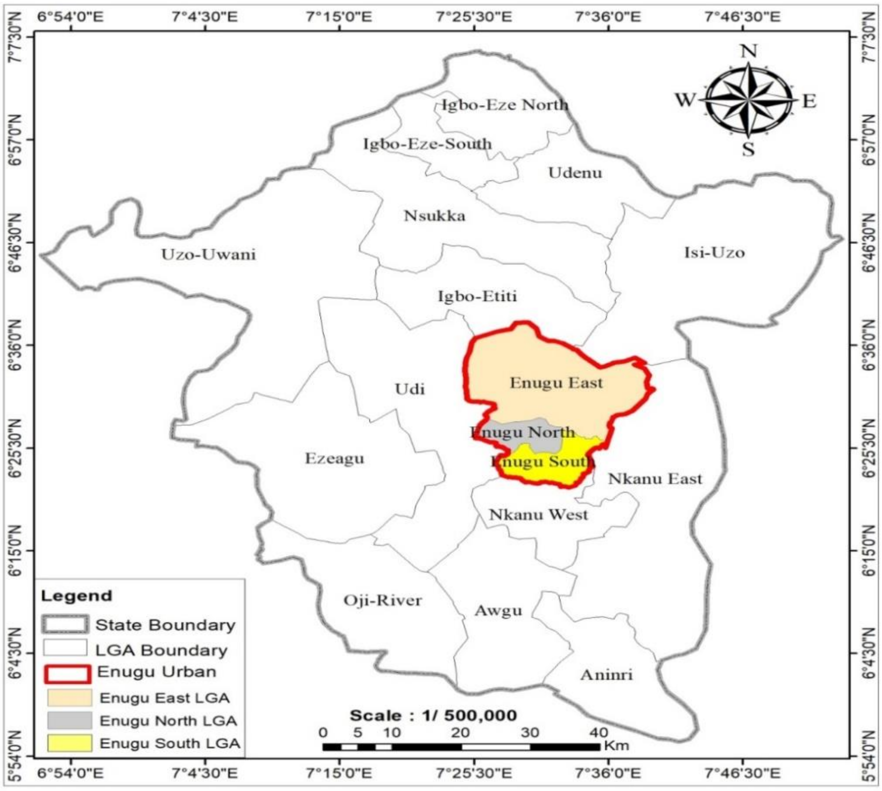

Figure 2: Administrative Map of Enugu State Showing Enugu Urban (Source: Googled, 2023)

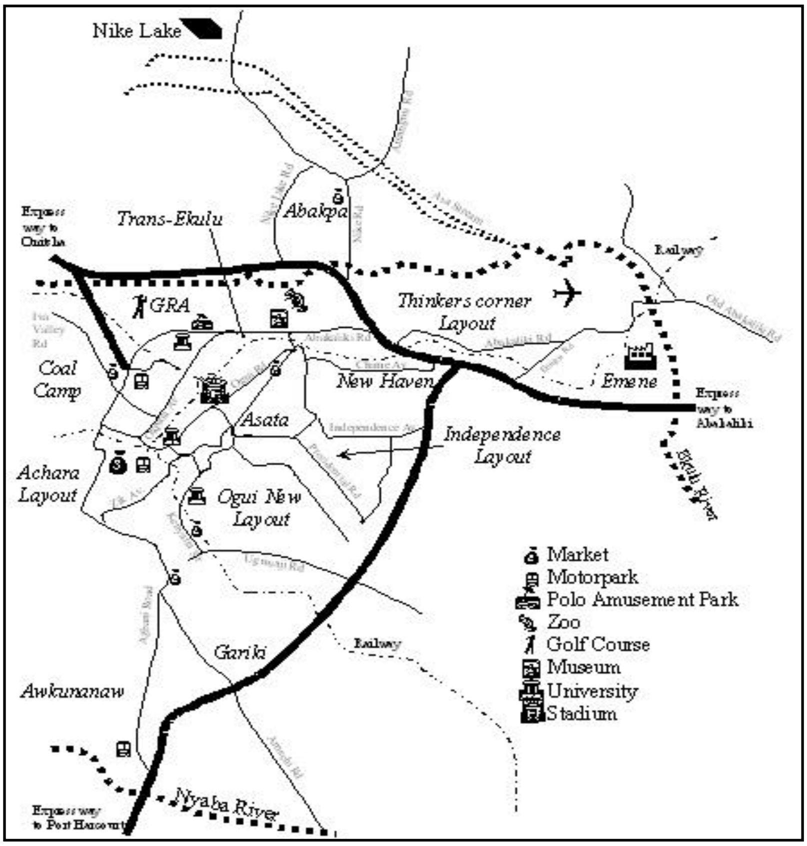

Figure 3: Map of Enugu urban showing locations of major neighborhoods (Source: Enugu State)

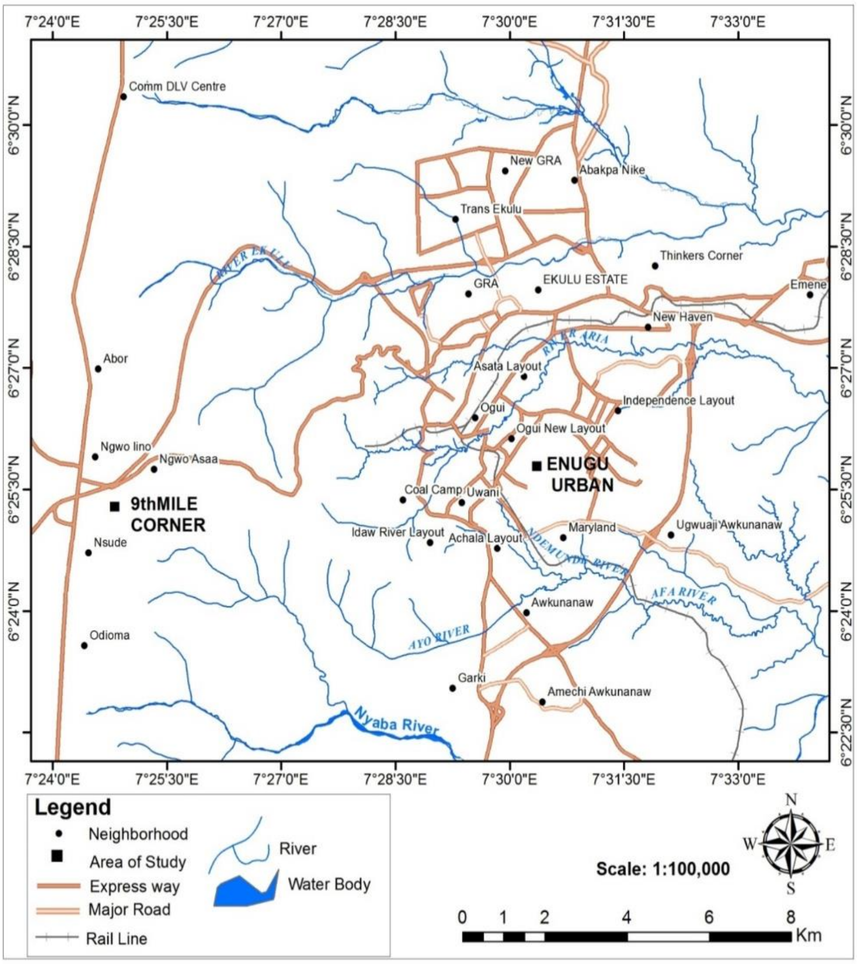

Figure 4: Map of Enugu Urban showing major neighbours and prominent rivers (Source: Quick bird Satellite imagery 2018)

In Enugu, there is little or no ground water potential. The area is situated near the western edge of the Cross River plain on Asata-Nporo shale. An average borehole specific capacity of 410 liters/hour/meter of draw down can be expected from the underground water table in this area. Borehole depths are generally about 110 meters (Ubani, 2014). Enugu lies in transitional-savanna region; and this is derived from prolonged cultiva-tion. It is important to know that rivers in the study area are linked to one another across some neigh-borhoods. In other words, some of them are tribu-taries of others as they move along neighborhoods. Study has shown that, Ekulu river is the largest river that cuts across the study area, (Adinna, 2001; Ubani, 2014) other rivers in the study area include Asata River, Aria River, Ikiriki river, Idaw River and Ogbete river.

Materials and methods

The surface water to be sampled in the study are all the six major surface water in Enugu urban and they are Ekulu river, Asata river, Aria river, Ikiriki river, Idaw River and Ogbete river. Their locations, depths, stations and reach were shown in Table 1.

Water samples were collected from two sampling sites in each of the 6 rivers, one from the upper section (upstream), another from the lower section (downstream) of the river. Out of the 12 sampling sites, (Table 1), sites with even numbers were located at downstram areas of the river, then those with even numbers at the upper part of the river. There was no water sample collected from the middle course. This was similar to some previous studies (Wang et al., 2012; Dayap et al. 2023). A total of 12 sampling sites were used in the study. The samples were collected from January 2020 to September 2022 on a monthly basis in the early hours (7.00 a.m. to 9.00 a.m.) of the day. The sampling period covered both the dry (January – early April) and the wet seasons (late April to Septem-ber). This was used to determine seasonal varia-tions of the water quality during the two seasons. Water samples for analysis were collected with white bottles that were sterilized in an autoclave at 121°C for 15 min, while samples for physicochemi-cal analysis were collected in clean sterile screw capped polypropylene bottles.

Sample collection from the rivers was done according to guidelines outlined by Federal Ministry of Water Resources (2004). A capped sterile bottle covered with a sterile handkerchief was used to store the samples. A 50m length of clean string was rolled around a stick and tied to the sample bottle. The bottle was completely immersed in water and submerged below the water, without hitting the bottom or disturbing any sediment. The string was unwinding immediately the bottle was filled up. For bacterial analysis, 25cl of water was discarded to provide for air space and it was then capped with stopper. All samples were properly labeled with waterproof marker, and they provided information on (i) sample site, (ii) date of sample collection, (iii) time of sample collection and (iv) purpose of sam-ple collection. Samples were put in ice packed plas-tic boxes. The selected physico-chemical and mi-crobiological parameters that were investigated in the study were: Temperature, PH, Turbidity, sus-pended solid (SS), Electrical Conductivity, Dissolved Oxygen (DO), Total Solid (TS), Biochemical Oxygen Demand (BOD), Total Faecal Coliform Bacteria, Dis-solved Solid, Oxygen Consumed, Chemical Oxygen Demand, Nitrite, Nitrate, Phosphorus, Chloride, Sulphate, Potassium and Total coliform. The metal content of the water samples was determined using APHA 301 Atomic.

Table 1: Description of the sample location

s/n	Station	Sample Locations	Latitude	Longitude	Depth (m)	Reach
1.	**S1**	Ekulu River at New market fly over	331160	15126	1.67	Upper
2.	**S2**	Ekulu River at Ujodo development centre	332483	715284	1.83	Lower
3.	**S3**	Asata River at Enugu Port-Harcourt Express Way, New Artisan	338568	71323	0.98	Upper
4.	**S4**	Asata River at Amigo Lane CIC.	335499	713803	1.32	Lower
5.	**S5**	Aria River at Works Road	332125	713009	1.55	Upper
6.	**S6**	Aria River at Access Bank, Garden Avenue	333501	713578	0.91	Lower
7.	**S7**	Idaw River at Maryland, Timber Shed	334454	709239	2.10	Upper
8.	**S8**	Idaw River at Abalukwu Street	33335	709384	2.34	Lower
9.	**S9**	Ikiriki River at Enugu Port-Harcourt Express Way, Ugwuaji Bridge	337584	708958	1.98	Upper
10.	**S10**	Ikiriki River at Amechi Road	333999`	707648	2.09	Lower
11.	**S11**	Ogbete River at Old UNTH	331781	711408	1.77	Upper
12.	**S12**	Ogbete River at Holy Ghost Cathedral	332946	71132	2.65	Lower

Source: Field work, 2022

Absorption spectrophotometer (AAS) method. The water samples were digested using HNO_3 solution. The digested water was quantitatively transferred into 100ml volumetric flask. Known standard solutions were taken through the same process to determine the recovery percentage, which is usually higher than 98%. The metal concentrations were determined by aspiration using the AAS model BUCK SCIENTIFIC 210 VGP. Standard samples were used to calibrate the AAS and the concentrations of metals in the sample were read at the calibration curve. Other laboratory instruments used in this study include: HACH Turbidimeter, mercury thermometer, Barnant pH meter, Millipore filter paper, and ACH Spectrophotometer. The mean values for the results collected from the laboratory test determined. Difference in the physico-chemical and microbiological parameters was tested for statistical difference using student's t-test. Student's t-test was apt since the values are parametric in nature and data were meas-ured at interval scale. Previous studies that sought to understand the difference between the mean values of these parameters and the Standard (WHO water safety guidelines) used similar statistical tool (Duan et al., 2016; Ouyang et al., 2006). All the analyses were done using the statistical package for social science (SPSS). The water quality analysis was carried out at the water laboratory of Projects Development Authority (PRODA), Enugu. Values were compared with water quality standard set by World Health Organization (WHO), this corresponds with the study done by (Chima et al. 2009; Ubani et al. 2014) and (Iqbal et al., 2022) where WHO standard was used as control sample. WHO permissible standard (Ubani et al., 2014) was found to be the same with that of the National Environmental Standards and Regulations Enforcement Agency (NESREA) (Federal Ministry of Water Resources, 2004), a national body responsible with regulating and maintaining the quality and standards in Nigeria.

Results and discussion

A summary of the physical, chemical, and mi-crobiological parameters per sample point and sea-son are presented in Table 2a and Table 2b. A summary of the raw data for physical parameters and anions were presented on Table 3 for both seasons and representing each sampling station. Table 4 consists of data showing the WHO standards, mean values of the parameters at the seasonal basis as well as the probability significance at 0.05 significance level.

Table 2a: Seasonal variations of physical parameters

s/n	Parameter	Seasons	S1	S2	S3	S4	S5	S6	S7
1	**Temperature**	Wet	29.0	28.6	28.9	30.3	27.9	27.8	29.6
		Dry	32.6	32.4	32.9	32.2	32.3	31.3	34.0
2	**pH@25.0°C**	Wet	8.2	8.1	7.60	7.1	6.5	6.5	6.7
		Dry	6.1	6.96	5.90	6.8	5.7	7.2	5.8
3	**Conductivity (µS/cm)**	Wet	10.6	68.3	45.7	174.0	48.8	195.0	11.0
		Dry	45.4	61.4	303.0	276.0	203.0	66.3	478.0
4	**Total Dissolved solid**	Wet	10.0	41.0	20.0	104.0	10.0	117.0	10.0
		Dry	22.8	20.0	15.0	10.0	9.6	10.0	23.0
5	**Total Suspended**	Wet	10.0	8.8	20.0	16.7	10.0	7.3	10.0
		Dry	18.0	20.0	18.0	15.0	83.0	10.0	25.0
6	**Total Solids (mg/L)**	Wet	20.0	38.0	40.0	45.0	20.0	19.0	20.0
		Dry	21.0	40.0	34.0	25.0	18.0	20.0	36.0
7	**Turbidity (NTU)**	Wet	58.0	47.8	21.3	140.0	14.6	12.7	8.5
		Dry	30.4	33.4	47.2	65.9	19.0	27.9	43.5
8	**Nitrate (mg/LN)**	Wet	7.4	8.6	27.3	4.6	6.5	6.9	6.0
		Dry	2.8	10.3	14.3	15.44	9.90	12.36	5.4
9	**Nitrite(mg/LN)**	Wet	0.9	0.2	2.5	1.0	1.6	0.5	0.6
		Dry	2.4	2.5	0.8	2.9	1.8	2.5	1.2
10	**Ammonia (mg/LN)**	Wet	0.3	1.0	0.4	1.1	2.3	0.6	7.7
		Dry	4.0	3.6	6.0	5.9	10.0	7.9	39
11	**Total Nitrogen**	Wet	3.1	10.7	28.5	37.2	13.0	4.7	14.3
		Dry	4.6	4.2	23.6	33.7	13.7	11.9	9.8
12	**Phosphorus (mg/L)**	Wet	0.2	0.5	0.6	0.6	0.0	0.9	0.0
		Dry	0.1	0.2	0.1	0.6	0.2	0.2	0.4
13	**Dissolved Oxygen**	Wet	7.7	12.0	6.5	8.3	7.5	6.7	8.1
		Dry	7.3	6.2	6.9	7.2	6.2	6.0	5.5
14	**Biochemical Oxygen**	Wet	0.5	0.6	0.9	0.5	0.3	0.2	0.3
		Dry	1.5	0.5	5.2	0.8	0.7	0.7	0.0
15	**COD (mg/L)**	Wet	6.2	18.0	8.0	12	5.2	6.9	5.1
		Dry	10.0	6.0	8.0	8.2	3.0	5.2	9.0
16	**FaecalColifor**	Wet	4350	6000	6800	99600	6600	2200	11000
		Dry	3300	2500	2700	1800	10500	6700	2800
17	**Total Coliform**	Wet	2020	6500	19000	13400	174000	7300	14000
		Dry	5000	4500	4500	5500	15000	11000	35000
18	**Chloride**	Wet	11.4	4.5	32.0	2.4	39.7	4.1	10.0
		Dry	10.2	13.9	10.4	11.9	10.9	15.9	10.1
19	**Hardness**	Wet	11.2	30.1	35.4	30.6	37.5	23.7	8.0
		Dry	174.0	166.3	569.8	660.0	171.2	200.0	20.9
20	**Sulphate**	Wet	61.9	46.3	52.4	23.2	49.3	38.8	41.2
		Dry	14.1	14.4	14.6	13.1	14.1	12.6	4.1
21	**Potassium**	Wet	0.1	0.3	0.3	0.5	0.1	0.6	0.0
		Dry	0.7	0.4	0.6	0.5	0.6	0.6	0.6

Station	Sample Locations
S1	*Ekulu River at New market fly over*
S2	*Ekulu River at Ujodo development centre*
S3	*Asata River at Enugu Port-Harcourt Express Way, New Artisan*
S4	*Asata River at Amigo Lane CIC.*
S5	*Aria River at Works Road*
S6	*Aria River at Access Bank, Garden Avenue*
S7	*Idaw River at Maryland, Timber Shed*

Table 2b: Seasonal variations of physical parameters

s/n	Parameter	Seasons	S8	S9	S10	S11	S12	WHO limits
1	**Temperature**	Wet	30.8	28.8	29.9	32.2	31.6	**25**
		Dry	30.1	31.2	32.6	33.1	31.6	
2	**pH@25.0°C**	Wet	6.11	6.71	6.66	5.83	6.5	**6.5 – 8..5**
		Dry	6.48	6.00	5.90	5.90	6.10	
3	**Conductivity (µS/cm)**	Wet	621	21.2	419	11.47	510	**500**
		Dry	208	318	244	284	568	
4	**Total Dissolved solid**	Wet	27	20	76	10	42	**250**
		Dry	20	16	122	14	15	
5	**Total Suspended**	Wet	15	20	18	10	9.0	**30**
		Dry	10	12	10	15	14	
6	**Total Solids (mg/L)**	Wet	35	30	47	20	54	**500**
		Dry	20	28	25	30	40	
7	**Turbidity (NTU)**	Wet	10.6	18.9	19.7	16.8	20.4	**10**
		Dry	33.8	15.5	23.9	12.5	18.0	
8	**Nitrate (mg/LN)**	Wet	12.5	12.8	14.9	8.4	0.8	**11.4**
		Dry	8.0	20.6	9.0	11.8	5.7	
9	**Nitrite(mg/LN)**	Wet	0.0	1.7	0.0	0.7	0.1	**0.2**
		Dry	2.3	4.4	5.0	1.7	0.8	
10	**Ammonia (mg/LN)**	Wet	8.8	2.8	4.5	3.7	7.1	**0.20**
		Dry	32	22	19	25	19	
11	**Total Nitrogen**	Wet	24.2	27.9	21.1	17.2	13.7	**1.0**
		Dry	23.7	18.9	34.6	12.9	34.7	
12	**Phosphorus (mg/L)**	Wet	2.1	0.3	1.1	0.04	1.5	**0.01**
		Dry	0.0	0.1	0.2	0.17	0.3	
13	**Dissolved Oxygen**	Wet	1.2	6.7	3.7	7.30	3.1	**5-14**
		Dry	8.0	7.2	7.0	6.82	5.1	
14	**Biochemical Oxygen**	Wet	0.2	0.7	0.6	0.50	0.4	**2-4**
		Dry	0.4	0.6	0.4	0.90	1.7	
15	**COD (mg/L)**	Wet	7.9	7.1	6.2	6.1	3.9	
		Dry	7.2	7.0	6.2	5.0	3.0	
16	**Faecal Colifor**	Wet	25000	11000	17000	10500	31000	**1000**
		Dry	1200	700	500	1860	2000	
17	**Total Coliform**	Wet	30100	24400	18800	10900	37600	**5000**
		Dry	20000	1200	1300	25000	20000	
18	**Chloride**	Wet	5.1	21.8	4.6	10.9	6.1	**250**
		Dry	12.0	14.2	38.2	5.41	3.3	
19	**Hardness**	Wet	7.8	16.4	13.7	11.2	12.0	**200**
		Dry	18.2	600.3	666.7	458.9	460.7	
20	**Sulphate**	Wet	38.5	58.5	49.7	60.2	44.2	**500**
		Dry	3.74	13.9	10.8	5.8	3.9	
21	**potassium**	Wet	0.0	0.1	0.5	0.1	0.8	**0.01**
		Dry	0.5	1.2	0.7	0.8	0.5	

Source: Researchers' result, 2022

Note
S8 Idaw River at Abalukwu Street
S9 Ikiriki River at Enugu Port-Harcourt Express Way, Ugwuaji Bridge
S10 Ikiriki River at Amechi Road
S11 Ogbete River at Old UNTH
S12 Ogbete River at Holy Ghost Cathedral

Table 3: Shows the mean, minimum and maximum values of the parameters at the seasonal basis

		Dry Season			Wet Season		
	Parameter	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
1	**Temperature (°C)**	30.10	34.00	32.19	27.80	32.20	29.61
2	**pH @25.0°C**	5.70	7.22	6.24	5.83	8.21	6.88
3	**Conductivity (µS/cm)**	45.40	568.00	254.59	10.65	621.00	178.01
4	**Total Dissolved Solids (mg/L)**	9.60	122.00	24.78	10.00	117.00	40.58
5	**Total Suspended (mg/L)**	10.00	83.00	20.83	7.30	20.00	12.90
6	**Total Solids (mg/L)**	18.00	40.00	28.08	19.00	54.00	32.33
7	**Turbidity (NTU)**	12.50	65.90	30.91	8.48	140.00	32.44
8	**Nitrate (mg/LN)**	2.80	20.60	9.55	.80	27.30	11.64
9	**Nitrite (mg/LN)**	.75	5.01	2.37	.05	2.48	.84
10	**Ammonia (mg/LN)**	3.60	39.00	16.11	.34	8.80	3.37
11	**Total Nitrogen (mg/L)**	4.20	34.70	18.85	3.14	37.20	17.9
12	**Phosphorus (mg/L)**	.08	.62	.23	.01	2.14	.66
13	**Dissolved Oxygen (mg/L)**	5.13	8.02	6.65	1.20	12.00	6.56
14	**Biochemical Oxygen (mg/L)**	0.02	5.20	1.12	.23	.98	.51
15	**Chemical Oxygen Demand**	3.00	10.00	6.48	3.90	18.00	7.72
16	**Faecal Coliform (cfu)**	500.00	10500.00	3046.66	2200.00	99600.	19254.16
17	**Total Coliform (cfu/100)**	1200.00	35000.00	12333.33	2020.00	174000.00	29835.00
18	**Chloride**	3.32	38.23	13.05	2.41	39.72	12.76
19	**Hardness**	18.28	666.76	347.24	7.80	37.50	19.80
20	**Sulphate**	3.74	14.61	10.42	23.20	61.88	47.02
21	**Potassium**	0.40	1.21	0.64	0.01	0.78	0.26

Source: Researchers' result, 2022

Table 4: Shows the WHO standard, mean values of the parameters at the seasonal basis as well as the probability significance at 0.05 significance level

		Dry Season	Wet Season	WHO standard	P sig
	Parameter	**Mean**	**Mean**		
1	**Temperature (°C)**	32.19	29.61	25	**0.00**
2	**pH @25.0°C**	6.24	6.88	6.5 – 8.5	**0.01**
3	**Conductivity (µS/cm)**	254.59	178.01	500	0.29
4	**Total Dissolved Solids (mg/L)**	24.78	40.58	250	0.22
5	**Total Suspended (mg/L)**	20.83	12.90	30	0.23
6	**Total Solids (mg/L)**	28.08	32.33	500	0.23
7	**Turbidity (NTU)**	30.91	32.44	10	0.85
8	**Nitrate (mg/LN)**	11.55	8.64	11.40	0.12
9	**Nitrite (mg/LN)**	2.37	.84	0.20	**0.00**
10	**Ammonia (mg/LN)**	16.11	3.37	0.20	**0.00**
11	**Total Nitrogen (mg/L)**	18.85	17.97	1.0	0.73
12	**Phosphorus (mg/L)**	.23	.66	0.01	0.05
13	**Dissolved Oxygen (mg/L)**	6.65	6.56	5 -14	0.92
14	**Biochemical Oxygen (mg/L)**	1.12	.51	2 - 4	0.11
15	**Chemical Oxygen Demand**	6.48	7.72	-	0.31
16	**Faecal Coliform (cfu)**	3046.66	19254.16	1000	0.06
17	**Total Coliform (cfu/100)**	12333.33	29835.00	5000	0.21
18	**Chloride**	13.05	12.76	250	0.95
19	**Hardness**	347.24	19.80	200	**0.00**
20	**Sulphate**	10.42	47.02	500	**0.00**
21	**Potassium**	0.64	0.26	0.01	**0.00**

Source: Researchers' result/T test value, 2022

Water Temperature

Temperature has both direct and indirect effects on aquatic ecosystems. The study revealed that the mean water temperatures ranged between 29.62 and 32.19°C (Table 3), during the wet and dry season respectively. Seasonal variations for temperature were statistically significant ($P < 0.05$) and this can be associated to the mean daily temperature during the dry season which was noted be high. Air temperature was maximal in dry season due to photoperiod. From the Table 3, the minimum water temperature 27.8°C was recorded during rainy season at sites and the maximum 32.2°C at the dry season. The low water tem-perature in rainy season can be explained on the basis of high-water levels and lower solar radiations where-as higher temperature in dry was on account of low water level, low velocity, greater solar radiations and clear atmosphere. Temperature, being one of the most important water physical parameters, is closely related to latitude, altitude and season (Shimba and Jonah, 2016). In general, lower mean temperature values were recorded during the heavy rainfall period i.e. the wet season (27.80 to 32.20°C) and high mean values (30 – 33°C) were recorded during the dry season. This occurred because during the wet season, the meteorological conditions are usually cloudy and rainy (Suratman et al., 2006), resulting in cooler temperatures because of the absence of direct sunlight. This trend also occurred in the Sungai Besut basin (Suratman et al., 2006), the Daya Bay, South China Sea (Wu and Wang, 2007) and the Jinshui River, China (Bu et al., 2010).

pH

Water pH is the term indicating the hydrogen ion (positively charged hydrogen atom) concentration of a solution, a measure of the solution's acidity. It is a measure of the acidic or alkaline content of water. The pH level of drinking water reflects how acidic it is. In the study, the concentration of pH varied from 5.83 to 8.21 and 5.70 to 7.22 in wet and dry season, respec-tively (Table 3). Mean concentrations were 6.8 in wet season and 6.2 in dry season. Maximum values reached 8.21 at Ekulu river – near new market road, in rainy season and the lowest value of Ph 5.8 at Og-bete River recorded in rainy season. The lower values of pH recorded during dry season could be attributed to decreased decomposition rate owing to reduced microbial activity and increased algal productivity (Ahipathy and Puttaiah, 2006). The statistical analysis shows that there was significant different ($P < 0.05$) between the wet and dry seasons (table 4). All the pH values collected at different seasons shows to be within the permissible limit of WHO permissible safe-ty limit. Surprisingly, the higher mean pH levels were recorded during the heavy rainfall periods, especially the wet season. Generally, pH is normally influenced by the deposition and accumulation of substances such as livestock wastes, fertilizers, municipal landfill waste and agriculture runoff from the soil and these are usually discharged into the wetland during the wet season (Xiong et al., 2020).

Conductivity

Conductivity is an indirect measure of the salt concentration. This measure therefore is often used as an index of pollution. The values of conductivity show different trend in both seasons, with the mean of 178 and 254.5 mS/cm observed in wet and dry season respectively (Table 2) with maximum value in rainy season at Idaw River and minimum at Ekulu river in rainy season. The maximum conductivity value at Ogbete river indicates the mixing of sewage in river water and the runoff from Ogbete neighbour-hood. However, the variation was not significantly different ($P = 0.292$, $P > 0.05$) between the two sea-sons and all the values measured were observed to be within the WHO safety guideline Yu et al. (2018) found high conductivity in downstream of Cauvery River and suggested an immediate attention from the concerned authorities in order to protect the river from further pollution.

Total Dissolved Solids (TDS)

Total dissolved solid is a measure of the number of particulate solids that are in solution. The observed values of TDS were comparatively lower at Aria, Idaw and Ogbete Rivers (10.0 mg/l) during rainy season and highest at Ikiriki River (122 mg/l) during dry sea-son. Its lowest values were recorded during dry sea-son which gradually increased with the onset of rainy season due to addition of solids from runoff water, sewage and erosion of the river bank. This result was supported by the finding of Singh et.al (2008). Gupta (2014) reported higher concentration of TDS in the Damodar River due to mixing of sewage and industrial wastes. Total Dissolved Solids (TDS) values collected at different seasons shows to be within the permissible limit of WHO safety Standard of 250 mg/l.

Chemical oxygen demand (COD)

Chemical oxygen demand (COD) measures the to-tal quantity of oxygen required to oxidize all organic material into carbon dioxide and water. Interestingly, the study revealed that the COD values fluctuated between 3.0 – 18.0 mg/l, highest being recorded in dry season at Aria River and lowest during rainy sea-son at Ekulu River. This could be associated with ac-tive land development in this area, which could con-tribute to high amount of dissolved organic matter (DOM). The statistical analysis shows that there was no significant different ($P > 0.05$) between the wet and dry seasons. Previous studies have similar find-ing, COD concentration was found higher in the wet season in Danjiangkou Reservoir, China (Hung et al., 2010) and in the Lake of the Francesa, Brazil (Dayap et al., 2003). Inversely, high COD values during the dry season have been observed in other studies: Sema-rang, Indonesia (Hunget al., 2010); Pearl River Delta, China (Fan et al., 2012); and upper Ogun River in Ni-geria (Adeogun et al., 2011).

Dissolved Oxygen (DO)

Fish and other aquatic animals depend on dissolved oxygen (the oxygen present in water) to live. The amount of dissolved oxygen in streams is dependent on the water temperature, the quantity of sediment in the stream, the amount of oxygen taken out of the system by respiring and decaying organ-isms, and the amount of oxygen put back into the system by photosynthesizing plants, stream flow, and aeration. In the study, the values of dissolved oxygen varied between 1.20mg/L and 12.00mg/L; 5.13mg/L and 8.02mg/L in wet and dry season, respectively (table.3). High values recorded in dry season can be correlated to the low values of temperature in the season. The similar mean values were 6.5 mg/L and 6.6 mg/L in wet and dry season, respectively. The variation shows no statistically significant difference ($P > 0.05$) between the two seasons. It was highest at Asata River and least in Idaw river. In the dry season, water samples ranged from 8.02 to 5.13 mg/l were highest and least values were recorded at Idaw river and Ogbete river respectively.

All samples were within the WHO provisional guideline value of 5 -14 mg/l. The statistical analysis shows that there was no significant different ($P > 0.05$) between the wet and dry seasons (Table 4). The DO values in rainy season were possibly due to low water temperature and considerable growth of algae, which release appreciable amount of oxygen as a result of photosynthetic activities and DO observe during dry season, might be due to high metabolic rate of organisms. DO content, which plays a vital role in supporting aquatic life in running water, is susceptible to slight environmental changes (Chen et al., 2022). Very low DO may result in anaerobic condi-tions that cause bad odors.

Nitrites

Nitrites are often used as corrosion inhibitors in industrial process water and cooling towers. Nitrites come from fertilizers through run-off water, sewage, and mineral deposits. Nitrite is used in food production for the curing of meat products. Unfortunately, it can also stimulate the grown of bacteria when intro-duced in high levels into a body of water. The study showed that Nitrite value ranged between 0.75 mg/l to 5.01 mg/l and between 0.05 mg/l to 2.48 mg/l during wet and dry seasons respectively. Nitrite was statistically found to vary significantly between the two seasons ($P < 0.05$). All samples apart from two during the wet season (S2 and S12) were above the WHO provisional guideline value of 0.2 mg/l posing a health hazard. (Reedy, 2004) observed that nitrites are abundant during monsoon season. These changes are commonly associated with erosion and transpor-tation of nitrogenous rich fertilizers into the water. The maximum values of nitrite were recorded in Ikiriki river than rest sites during dry season due to influx of nitrogen rich flood water that brings large amount of contaminated sewage water.

Phosphorus

Phosphorus is a nutrient that increases plant growth; it's great for food crops, but it's not great for aquatic systems because it enhances the growth of plants over the growth of other wildlife—eutrophication. Phosphorus is an essential element for plant life, but when there is too much of it in water, it can speed up eutrophication (a reduction in dissolved oxygen in water bodies caused by an increase of mineral and organic nutrients) of rivers and lakes. The range for phosphate was from 0.01mg/l to 2.14mg/l and 0.08 to 0.062 mg/l during the wet and dry season respectively too. The mean concentrations of phosphorus were 0.66 mg/l and 0.23 mg/l in wet and dry season, respectively. The concentration of Phosphorus showed no significant variation ($P > 0.05$) between the water samples measured in wet and dry season. In the study, the lowest value 0.01mg/l was found at Idaw river (Upper section) in rainy season while highest 2.14mg/l was still noted at Idaw river (lower) in wet season. The phosphate concentration high value in the month of June and July (rainy season) could be attributed to agricultural runoff and discharge of water containing detergents. The slight seasonal difference observed is attributed to accumu-lation of phosphates from surface runoff of anthro-pogenic activities such as agriculture, washing and laundry, domestic and industrial waste discharges.

Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand (BOD) is a measure of the amount of oxygen that bacteria consume while decomposing organic matter under aerobic condi-tions. It is an approximate measure of the amount of biochemical degradable organic matter present in a water sample. Biological Oxygen Demand (BOD) is a widely used indicator of water quality as it reflects the level of organic pollution present in a body of water. Excessive BOD loads damage the quality of river water. It causes low DO concentration and un-suitable life conditions for flora and fauna in the river. The study shows that the highest mean BOD concentrations were recorded during the dry season. During this period, the surface water was characterized by large quantities of suspended matter and high sedi-ment loads.

The recorded high levels of BOD were probably due to the washing out of organic materials from the land into the river catchment. This observation is contrary to the study undertaken at the Nyando River (Raburu, 2003), Mara River (Kilonzo et al., 2014), in Kenya and Pangani and Ruvu Rivers, Tanzania (Kaaya et al., 2015) where the BOD concentrations were high during the wet season. The least BOD value was ob-served at Aria River at Abakpa in rainy season while the highest value (5.2mg/l) was noticed at Asata River in dry season which could be due to the influence of sewage. Higher values of BOD indicate a higher con-sumption of oxygen and a higher pollution load. Con-versely, during the dry season, higher mean concen-trations of BOD were recorded, suggesting that there were movement of organic matter from the land. The values of BOD in all samples did not exceed maximum permissible limit of 2-4 mg/l during rainy season. A result attributed to the efficient absorption of organic pollutants from various sources. It was only values obtained at Asata River (5.20) that fell outside the standard limit.

This study, however, revealed that there was no significance difference (p>0.05) in values of variables irrespective of season of the year. These results indicate that the surface water in Enugu urban main-tained an acceptable BOD level at the dry and wet seasons, as evidenced by the low BOD values.

Nitrate

Nitrate (NO3-) is an ion with one central nitrogen atom surrounded by three oxygen atoms. It readily dissolves in water and is an essential plant nutrient often applied to crops to help aid growth. Besides runoff from croplands and lawns, sources of nitrate in the environment include discharge from wastewater treatment plants, septic systems, manure storage areas, and industrial facilities. Natural sources of nitrate, such as decaying plant debris, also exist. Increased nitrogen inputs can stimulate excess growth of algae, which leads to low dissolved oxygen levels, potential for harmful algal toxins, blockage of sunlight needed by organisms and plants in the water and degraded habitat conditions for benthic macroinver-tebrates and other aquatic life. The concentrations of nitrate ranged from 0.80 to 27.30 mg/l in wet season and 2.80 to 20.60 mg/l in dry season. Highest concentration measured in wet season can be attributed to the use of nitrogenous fertilizers in agricultural areas. For example, the concentration of nitrate was 27.30 mg/l at Asata River during wet season and it decreases to 14.29 mg/l in dry season. The mean values of nitrate were 11.64 mg/l in wet season and 9.55 mg/l in dry season. The variation was signifi-cantly different (P <0.05) between the two seasons, this was expected since the runoff from agricultural land is the main source of nitrate in water. Seasonal variations for nitrate were found to be statistically significant indicating that there is more nitrate being carried to the river during the wet season than during the dry season.

High nitrate concentration upstream, like in the Ikiriki river, during the wet season was rather unexpected and can be explained by surface runoff carrying nitrogen-based fertilizers into the river. Cassava and maize cultivation use a large amount of fertilizers compared to other crops and that this usage is in-creasing gradually over the years. Nitrate varied signif-icantly between the seasons with higher nitrate during rainy season and this is because temperature is low and oxygen tension is also low due to saturation with water.

Sulphate

Sulphate not only impairs drinking water quality, it also affects the material cycles of carbon, nitrogen and phosphorus. Among other things, this increases the nutrient loads in water bodies and thus the growth of plants and algae as well as the food supply for aquatic organisms. At high levels, sulfate can give water a bitter or medicinal taste and can have laxative effects. Wet season sulphate was higher and ranged from 23.20mg/l to 61.88 mg/l compared to dry sea-son whose range was 2.74 mg/l to 14.61 mg/l. High concentration at Ekulu river from both seasons is contributed by industrial, municipal and domestic waste water discharges. The mean concentration was 47.02 mg/l in wet season and 10.42 mg/l in dry season. Low values recorded in wet season could be attributed to the dilution effect from heavy rainfalls in rainy season.

Chloride

Chloride is essential for proper functioning in the human body and is not harmful if ingested with adequate amounts of fresh water. However, increases in chloride concentrations can indicate that natural water sources have been contaminated by sewage. Chloride increases the electrical conductivity of water and thus increases its corrosivity. In metal pipes, chlo-ride reacts with metal ions to form soluble salts (8), thus increasing levels of metals in drinking water. In lead pipes, a protective oxide layer is built up, but chloride enhances galvanic corrosion.

Chloride ranged between 2.41 mg/l to 39.72 mg/l and 3.22 mg/l to 38.23 mg/l during the wet and dry season respectively. Seasonal variations were found to be statistically insignificant indicating that land use changes and anthropogenic activities do not add extra chloride to the river. Chloride concentrations were however below the WHO guideline of 250 mg/l. However, it was observed that the concentrations were within the recommended WHO values (Table 2).

Potassium

Although potassium does not pose a health risk for healthy individuals, its presence in well water may indicate groundwater quality issues or other problems with the well. Increased potassium in the water should initiate for an inspection of the well construc-tion and testing for coliform bacteria. This is not a concern for the general population; however, increased exposure to potassium could result in signifi-cant health effects in people with kidney disease or other conditions, such as heart disease, coronary artery disease, hypertension, diabetes,and adrenal insufficiency.

In the study, Potassium ranged from 0.01 mg/l to 0.78 mg/l during the wet season and from 0.40 mg/l to 1.21 mg/l during the dry season. The concentra-tions of potassium were all below the WHO guideline limit. There was significant (P = 0.004) seasonal varia-tion for potassium and this indicating land use chang-es occurring. Street car washing and laundry activities add considerable amounts that accumulate down-stream. Again, this shows fertilizer leaching from agricultural land contributing to potassium concen-tration. Cars/vehicles are commonly washed at the bank of rivers like Ogbete and Ikiriki, this could ac-count for the high potassium content value (Ubani et al., 2014).

Bacterial analysis - Total Coliform (TC) and Faecal Coliform

Coliform bacteria include a large group of bacteria that can be found in drinking water. Most types of coliform bacteria will not necessarily make you sick, but since these bacteria have found a way into your water system, other disease-causing bacteria could also enter it. Total coliforms include bacteria that are found in the soil, in water that has been influenced by surface water, and in human or animal waste. Fecal coliforms are the group of the total coliforms that are considered to be present specifically in the gut and feces of warm-blooded animals. The study observed that the TC which had the mean values of 29,835.0cfu/100 during rainy season decreased to 12,333.3cfu/100 during dry season respectively. The noticed high values of bacterial pollution of the sam-pled water during rainy season was similar and consistent with the findings by (Adekunle et al., 2014) in Igbora river, Oyo state, Nigeria. The work confirmed increase in bacterial pollution during rainy season. The results of bacterial analysis showed that only Ikiriki river was free from microorganisms during dry season. The presence of Total Coliform and Facal Coli-form in all the river, except Ikiriki, was an indication of fecal pollution by untreated sewage disposal. The presence of bacterial in water from these rivers used for various purposes in the study area was an indica-tion of possible outbreak of cholera, dysentery, ty-phoid and yellow fever, if consumption of water from this surface water was not discontinued.

Anthropogenic activities, untreated sewage and effluent infiltrate the river ecology and pollute surface water in the study area. The study shows that surface water in Enugu are more contaminated where the concentrations of nutrients were high. This is due to the continuous discharge of untreated sewage, deter-gents chemical and agricultural wastes from the sur-roundings. It was observed that the three most polluted rivers in the study area were Ikiriki, Ogbete and Asata rivers having scored high in TDS, conductivity and nitrite values even above the permissible level. This portends dangers for the users of these water bodies especially those that use it for drinking and cooking (Gupta, 2014). The constant washing of cars, vegetables and dirty household utensils at the bank of these rivers by dwellers added to increase the pollu-tion load. Untreated sewage discharges and constant littering of roads with refuse especially during the rainfall in Ikiriki, Ogbete and Asata areas could also contribute to this unhealthy and pitiable, yet danger-ous state of these noted polluted streams in the study area. Furthermore, the level of phosphate and potas-sium concentration noticed in the surface waters, though not much loaded, was found to be relatively high during the rainy seasons in Ogbete and Ikiriki rivers. Caution should be taking to this this level to an acceptable limit. The increase in the loading of these elements according to studies are attributed surface runoff of anthropogenic activities such as agriculture, washing and laundry, domestic and industrial waste discharges into the river bodies (Raburu, 2003; Ki-lonzo et al., 2014; Kaaya et al., 2015). The phosphorus emissions from detergents and household food consumption constituted primary sources of phosphorus pollution in water (Xiong et al., 2020; Olapido et al., 2021).

The fast rising of the number of motor mechanic shops at the nook and crannies of Enugu urban has its own attendant problem in the water bodies especially during the wet season. Enugu urban, though, a state capital does not have planned drainage system that manages the flood and water waste in the area. Flooding in the area empties itself in the surrounding surface water and it carries along grease and oil from these mechanic shops to these rivers. Most times, this contaminated water carries sediments, oxygen-demanding materials, petroleum, toxic metals, and pathogens. Such water pollution results from sewage and industrial waste such as chemicals, grease, oil, and other toxic debris from motor mechanic shops (Xiong et al., 2020; Yu et al., 2018). Hence, it is necessary to take adequate steps to minimize water pollu-tion for sustainable urban development. Again, it was noted that the nitrite and nitrate content of the rivers was high. The anthropogenic ammonium sources increasing with the growing population have led to a high concentration of nitrogen and nitrate contents in the river through the direct discharge of wastewater or via runoff in this kind of low-income cities (Trom-boni and Dodds, 2017; Moncayo-Estrada et al., 2017).

Some of the planning implications of these find-ings are the imminent aquatic life distortion and en-dangering in the water bodies in Enugu urban. Inside the water bodies, like in Ikiriki, Asata and Aria rivers are several life forms including plants, fish, crabs, among many others that depend on water dissolved oxygen and varieties of nutrients. The basic needs for the survival and continuity of this aquatic life and is always dependent on natu-ral processes within and outside the water bodies. The observed presence of foreign materials like chem-icals, wastes from industries, septic tank content dis-charged into the waters alters most of these natural processes. These wastes take considerable time to decompose thereby leaving the water contaminated for relatively long durations, ranging from months to years. As an outcome, these pollutants harm and even kill aquatic flora and fauna. Thousands of aquatic animals like crabs and fish do wind up dead and de-cays. This is worsened by the nefarious attitude of some local fishermen who often use harmful chemi-cals for fishing activities in these water bodies. Again, the increased human morbidity and mortality rate in the urban area has remain a source of worry to stake-holders. The discharge of chemical wastes into the streams can result to aquatic animals consuming them and then consumed by humans. When con-sumed, they can give rise to life-threatening illnesses. For example, people can acquire diseases such as hepatitis and cancer by consuming fish or seafood that has been poisoned by chemical compounds (Graczyk et al., 2018).

Due to the accumulative effects of dumping and runoff, some chemical toxins introduced into the water can cause kidney failure and reproductive dis-orders. People in some regions of the world have also suffered the consequences of waterborne diseases such as cholera by drinking contaminated and untreated water from streams, lakes or rivers (Chen et al., 2022).

Furthermore, contaminated surface water cannot be readily fit for tourist and recreational activities. The obvious planning implication g was that these surface waters which should have been used for recreational activities is not fit or such activities especial-ly Ekulu and Asata rivers. This is due to the pollution level of the rivers. Recreational water users can be exposed to a range of disease-causing microorganisms, including those naturally present in water. Many of the infectious agents of concern in recreational water, however, are the result of faecal pollution (es-pecially human). Sources of faecal pollution include sewage, surface runoff, domestic animals, and wildlife (Hlavsa et al., 2014; Wade et al., 2003). Studies have tended to establish relationships between faecal indicator bacteria and the risk of gastrointestinal illness (Wade et al., 2003; Prüss, 1998). Graczyk et al. (2010) found a significant relationship between bather numbers at a marine beach in the USA and turbidity. The detection of three selected pathogens was significantly correlated with both enterococci levels and bather density. It has become clear that the pollution load of the rivers in most rivers in Enugu could be inimical to the recreational water users in the area. Therefore, there is a need to regularly monitor and control the source of pollutants to the water bodies (Nola et al., 1998).

The limitation of this paper is the non-inclusion of the biological indices in the assessment of the pollution loading of the rivers, only the physical and chem-ical indices are employed without the biological pa-rameters, thus the water quality assessment parameter types can be more comprehensive with the biolog-ical factor included. Furthermore, although NESERA adopted the WHO permissible standard, the suitability of these standard values to Africa rivers needs further study. Future study should collect water samples from the middle of the stream, only the upper stream and downstream samples are not very reliable.

Conclusions

The study investigated the seasonal physicochemical characteristics of surface water in Enugu urban during the dry and wet seasons with a view to under-standing the seasonal water quality of the rivers for effective management and sustainability. It will also form baseline data for users of these rivers. The statistical analysis shows that there was a significant difference between the level of certain parameters measured in surface water samples from the wet and dry season, respectively. A decreasing trend was observed from wet to dry season. The study revealed that the parameters like Turbidity, Ammonia, Nitrate, Nitrogen, Faecal coliform and total coliform were above the WHO permissible limit at all sites and for all seasons. Elevated concentration measured in wet season can be attributed to the large flow of effluents from anthropogenic sources, especially run off activities. However, the parameters which did exhibit significant change are also those less susceptible to varia-tion in terms of their spatial distribution.

The significant difference observed in surface water shows that there was a change in water geochemistry. The study of this seasonal surface water quality assessment provides valuable information that allows local governments to formulate evidence-based water resource management strategies. Domestic waste water and industries located along the river discharge their untreated waste water to the river resulting to point based pollutants downstream.

On the upper areas of the rivers, non-point-based pollution is a menace and contribute to poor water quality for the downstream water users. Poor farming practices and lack of better land management practices contributed to such pollution upstream. It is therefore recommended that monitoring of water quality which at present is inadequate and haphazard needs to be more organized and regular, covering streams and rivers, and domestic water wells. The permissible standards for good quality water recommended by NESERA should serve as yardstick for monitoring. In this way, it should be possible to detect outbreaks of diseases, for example, typhoid, cholera, bilharzias, or guinea worm and to take appropriate preventive measures. Additionally, the study recommends that biological indicators and their indices should be adopted for use by relevant authorities as tools for assessing the condition of rivers and other streams in Nigeria.

Furthermore, the regulatory bodies to constantly monitor water quality and use strong legislative envi-ronmental laws to implement control measures for proper effluent treatment to curb point based contaminants. There is urgent need for the establishment of a National Water Monitoring Programme aside NESERA that will monitor the surface water of Nigeria, since NESERA has a lot of environmental issues to handle in their mandate. The Ministry of Environment must strengthen the present environmental laws such that the polluters of water bodies could be prosecut-ed. Industrial and agricultural sectors should also be compelled to treat their wastes before being dis-charged into the water bodies. Policies that would ensure proper management of urban agriculture should be pursued by the government at all level since cassava and maize cultivation has been the commonest plants done around most residential buildings in the study area. Large quantity of fertilizers is normally used by these local farmers on these plants, thus this survival and coping strategies by these seemingly low-income residents must be monitored and regulated.

Proper sensitization and enlightenment should be made by the government on the health and environmental implication of discharging waste water and domestic waste into the water bodies. The inclusion of water management in primary and secondary school curriculum should be encouraged.

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Data availability statement

On behalf of all the authors, the corresponding author states that our data are available upon reasonable request.

Author contribution

Conceptualization, - O.J C. S; methodology, writing – original draft, O.J, M N. All authors have read and agreed to the published.

Conflicts of interest

The authors declare no conflict of interest.

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