ANALYSIS OF THE SEASONAL 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 the pollution in water but also information regarding integrated water resource management processes. The information can be helpful for treating the water and making it potable and also for the development of water treatment policy. However, 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. Surface water samples were collected in two seasons (wet and dry seasons), which correspond to the wet and dry seasons, respectively. 12 surface water samples were collected from the six major rivers in Enugu urban. Their physico-chemical characteristics were determined by specific analyses between 2020 and 2022. The following parameters were measured in situ: pH, dissolved oxygen (DO), and electrical conductivity (EC), whereas bacterial analysis, major anions (sulphate, nitrate, and chloride) and some trace metals 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. Anthropogenic activities, untreated sewage and effluent infiltrated the river ecology and polluted the surface water. Monitoring of water quality needs to be regular for effective water quality management, sustainability and safety.

1. Introduction

Water is an essential resource for human survival. According to the 2021 World Water Development Report released by UNESCO, the global use of freshwater 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. Industrialization, agricultural production, and urban life have resulted in the degradation and pollution of the environment, 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 ecosystems. This proportion is higher in the least developed countries, where sanitation and wastewater treatment facilities are severely lacking.

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. Inadequate water supply is still one of the major challenges in developing countries, 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 vulnerable to pollution because of their role in carrying agricultural run-off, and municipal and industrial wastewater (Huang 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. 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 affecting the amount of runoff to water b o dies (Dougherty et al. 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, 2016). Various physicochemical parameters such as Hydrogen Ion Concentration (pH), Biological Oxygen

Demand (BOD), Dissolved Oxygen, (DO), Chemical Oxygen Demand (COD), Total Solids (TS), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Total Hardness (TH), etc have a significant role in determining the potability of drinking water (Sheikh and Yeragi, 2003). All water resources have reached to a point of crisis due to unplanned urbanization and industrialization (Singh et al. 2008). Again, 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, Aeromonashydrophilain 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 microorganisms and heavy metals (Joan et al., 1998). Surface water are 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 water quality and safety. Studies portend that change of water bodies 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 2022b). 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 attendant shortage of water supply (Onuigbo and Madu, 2013; Chima et al., 2009; Utomi et al., 2012 and 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, du e to seasonal and regional characteristics in rivers hydro geomorphology and water quality, identifying spatial-temporal variations and trends of water quality as it relate to the water quality indicators have become a major focus of research in many developed and emerging economies especially in sub-Sahara African region of the world. Yet this research area remains largely unexplored in environmental management studies in Enugu, southeast of Nigeria. This concern has made the study more imperative. The aim of this study is to examine the seasonal physicochemical characteristics of surface water in Enugu urban during the dry and wet

seasons. Information derived from the assessment 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.

2. 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 kilometer. Enugu urban is the state capital of Enugu State, southeast of Nigeria of Nigeria as seen in figure 1 and 2 below.

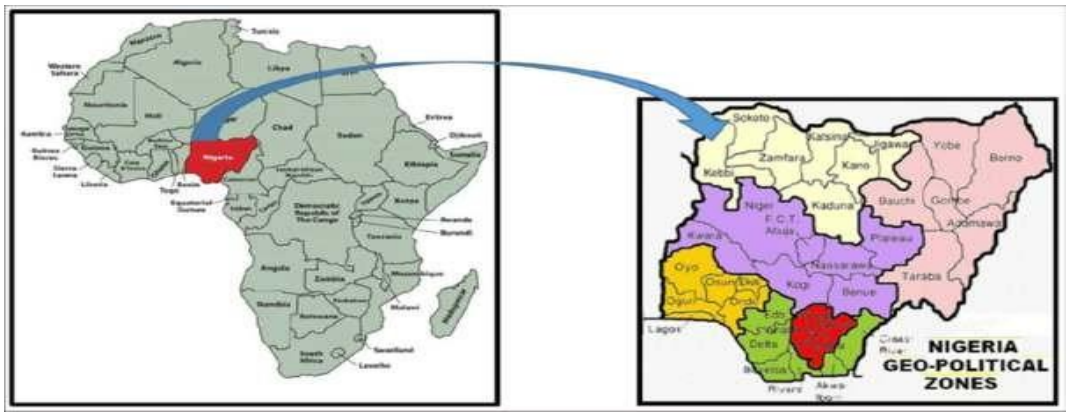
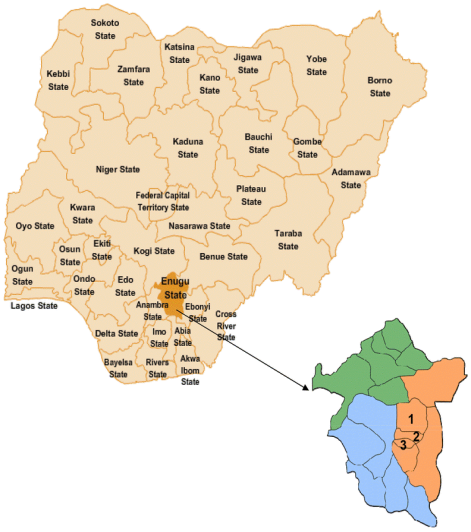


Figure 1: Map of Africa showing Nigeria

Figure 2: Map of Nigeria highlighting the study area in Enugu State.



1 = Enugu North LGA; 2 = Enugu South LGA; 3 = Enugu West LGA

Residential land- use 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. See figure 3

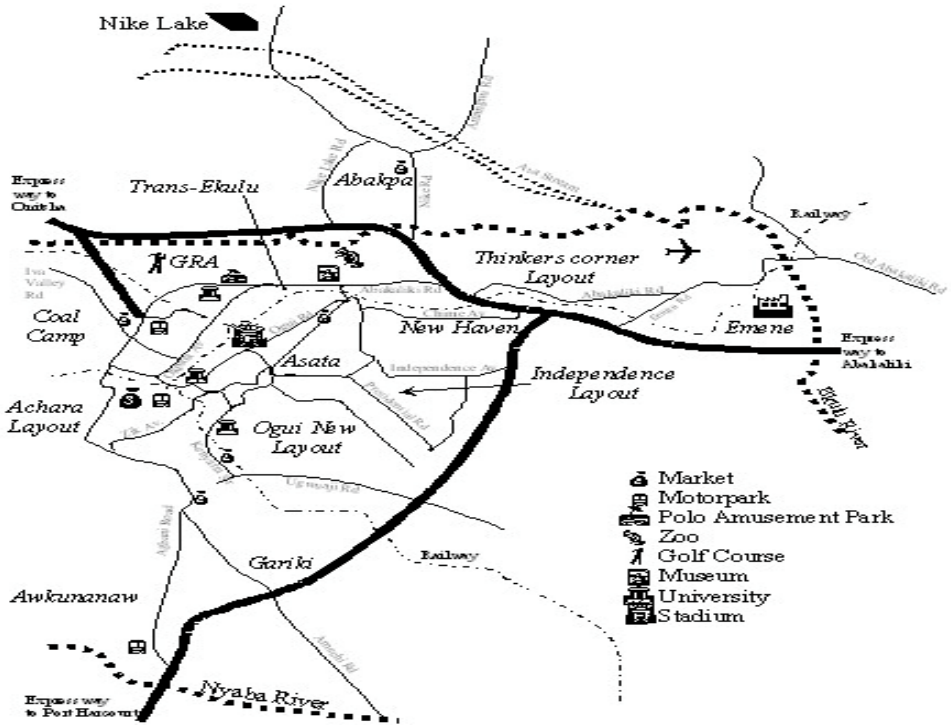


Figure 3: Map of Enugu urban showing locations of major neighborhoods

However, due to the influences of spread effects, 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 abundant 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, (NPC, 2007). Using 2.8% annual urban population growth rate, (NPC, 2007), the projected population as at 2022 is estimated to be 873,043. Figure 4 depicts the map of Enugu showing the various neighbourhoods and surface water in the study area.

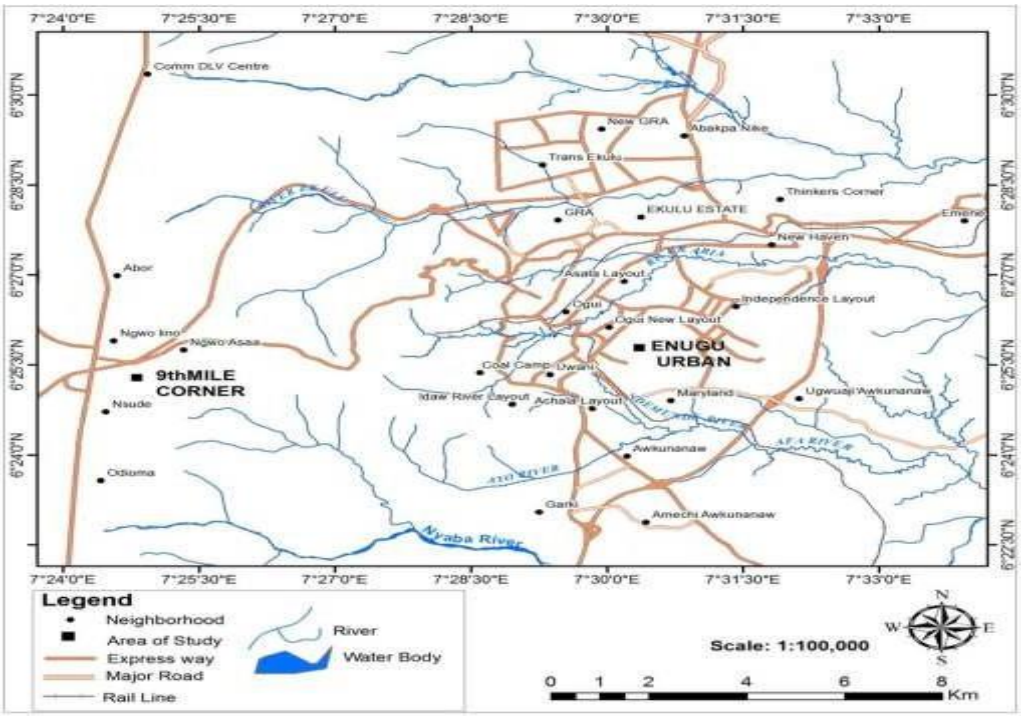


Figure 4: Map of Enugu Urban showing the neighbours andSource: Quick bird Satellite imagery 2018
1 = Enugu North LGA; 2 = Enugu South LGA; 3 = Enugu West LGA

In Enugu subsurface, 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 bore hole specific capacity of 410 liters/hour/meter of draw down can be expected from the subsurface water table in this area. Borehole depths are generally about 110 meters. It lies in transitional-savanna region; and this is derived from prolonged cultivation. It is important to know that rivers in the study area are linked to one another across some neighbourhoods. In other words, some of them are tributaries of others as they move along neighbourhoods. Study has shown that, Ekulu river is the largest river that cuts across the study area, other rivers in the study area include Asata river, Aria river, Ikiriki river, Idaw River and Ogbete river. (Adinna, 2001)

3. Methods and Materials

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 below

Table 1: Description of the sample location

S/N	Station	Sample Locations	Latitude	Longitude	Depth (m)	Reach
1.	S1	Ekulu River at Newmarket 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

Two sampling locations were assigned in each of the river, one at the Upper section (upstream), another at the Lower section (downstream) of the river. There was no sample got from the middle course. This was similar to studies done by Wang et al (2018) and Dayap et al, (2023). Thus, a total of 12 sampling locations were used in the study been examination contacts since there are 6 water bodies in use. Each of the 12 locations were sampled between 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 September). This was used to determine seasonal variations 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 physicochemical 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, with a piece of string, and a clean weight attached to the sample bottle. A 50 m 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 unwound immediately the bottle was filled up. For bacterial analysis, some water was discarded to provide for air space and it was then capped with stopper. All samples were properly labeled with marker, and they had information on (i) sample site, (ii) date of sample collection, (iii) time of sample collection and (iv) purpose of sample collection. Samples were put in ice packed plastic boxes. The selected physico-chemical and microbiological parameters that was investigated in the study were: Temperature, PH, Turbidity, Suspended solid (SS), Electrical Conductivity,

Dissolved Oxygen (DO), Total Solid (TS), Biochemical Oxygen Demand (BOD), Total Faecal Coliform Bacteria, Dissolved 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 Absorption spectrophotometer (AAS) method. The water samples was digested using HNO3 . The digested water was quantitatively transferred into 100ml volumetric flask. Known standard solutions were taken through the same process to determine the recovery factor, 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
Data were analyzed for mean.

Difference in parameter was tested for statistical difference using student's t-test. 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 sync with the study done by Chima et al (2009), Ubani et al (2014) and Igbal et al (2022a) where WHO standard was used as control sample. WHO permissible standard was found to be the same with that of the National Environmental Standards and Regulations Enforcement Agency (NESREA), a national body responsible with regulating and maintaining the quality and standards in Nigeria.

4. Results

A summary of the physical, chemical, and microbiological parameters per sample point and season were 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. Subsequent analysis of these presentations were done in the other sections of the paper

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@25.0oC	Wet	8.21	8.11	7.60	7.09	6.48	6.55	6.75
		Dry	6.10	6.96	5.90	6.85	5.70	7.22	5.80
3	Conductivity	Wet	10.65	68.3	45.7	174	48.8	195	11.0
	(µS/cm)	Dry	45.4	61.4	303	276	203	66.3	478
4	Total Dissolved solid	Wet	10	41	20	104	10	117	10
		Dry	22.8	20.0	15	10.0	9.6	10.0	23
5	Total Suspended	Wet	10	8.8	20	16.7	10	7.3	10
		Dry	18	20	18	15	83.0	10	25
6	Total Solids	Wet	20	38	40	45	20	19	20
	(mg/L)	Dry	21	40	34	25	18	20	36
7	Turbidity (NTU)	Wet	58.0	47.8	21.3	140	14.6	12.7	8.48
		Dry	30.4	33.4	47.2	65.9	19.0	27.9	43.5
8	Nitrate (mg/LN)	Wet	7.39	8.6	27.3	4.56	6.52	6.90	6.01
		Dry	2.80	10.3	14.29	15.44	9.90	12.36	5.40
9	Nitrite(mg/LN)	Wet	0.98	0.16	2.48	1.0	1.65	0.45	0.58
		Dry	2.44	2.51	0.75	2.96	1.85	2.51	1.16
10	Ammonia	Wet	0.34	1.05	0.42	1.10	2.28	0.59	7.70
	(mg/LN)	Dry	4.0	3.6	6.0	5.9	10.0	7.9	39
11	Total Nitrogen	Wet	3.14	10.7	28.5	37.2	13.0	4.74	14.3
		Dry	4.6	4.2	23.6	33.7	13.7	11.9	9.8
12	Phosphorus	Wet	0.16	0.46	0.58	0.56	0.02	0.90	0.01
	(mg/L)	Dry	0.09	0.19	0.12	0.62	0.16	0.18	0.45
13	Dissolved Oxygen	Wet	7.69	12	6.48	8.30	7.52	6.70	8.11
		Dry	7.30	6.24	6.99	7.25	6.25	6.00	5.49
14	Biochemical Oxygen	Wet	0.46	0.65	0.98	0.55	0.35	0.23	0.31
		Dry	1.50	0.52	5.20	0.82	0.70	0.68	0.02
15	COD (mg/L)	Wet	6.2	18	8	12	5.2	6.9	5.14
		Dry	10.00	6.01	8.0	8.16	3.00	5.18	9.0
16	Faecal Coliform	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	11.42	4.84	32	2.41	39.72	4.13	10.02
		Dry	10.25	13.90	10.45	11.91	10.89	15.88	10.06
19	Hardness	Wet	11.20	30.11	35.4	30.6	37.5	23.7	8
		Dry	174.00	166.3	569.88	660.0	171.23	200.0	20.89
20	Sulphate	Wet	61.88	46.33	52.43	23.2	49.33	38.8	41.20
		Dry	14.05	14.37	14.61	13.09	14.13	12.65	4.09
21	potassium	Wet	0.05	0.34	0.27	0.47	0.08	0.56	0.01
		Dry	0.72	0.40	0.64	0.49	0.59	0.65	0.59

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 3: 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 (oC)	30.10	34.00	32.1917	27.80	32.20	29.6167
2	pH @25.0oC	5.70	7.22	6.2425	5.83	8.21	6.8833
3	Conductivity (µS/cm)	45.40	568.00	254.5917	10.65	621.00	178.0100
4	Total Dissolved Solids (mg/L)	9.60	122.00	24.7833	10.00	117.00	40.5833
5	Total Suspended (mg/L)	10.00	83.00	20.8333	7.30	20.00	12.9000
6	Total Solids (mg/L)	18.00	40.00	28.0833	19.00	54.00	32.3333
7	Turbidity (NTU)	12.50	65.90	30.9167	8.48	140.00	32.4400
8	Nitrate (mg/LN)	2.80	20.60	9.5567	.80	27.30	11.6483
9	Nitrite (mg/LN)	.75	5.01	2.3775	.05	2.48	.8417
10	Ammonia (mg/LN)	3.60	39.00	16.1167	.34	8.80	3.3750
11	Total Nitrogen (mg/L)	4.20	34.70	18.8583	3.14	37.20	17.9733
12	Phosphorus (mg/L)	.08	.62	.2317	.01	2.14	.6658
13	Dissolved Oxygen (mg/L)	5.13	8.02	6.6517	1.20	12.00	6.5692
14	Biochemical Oxygen (mg/L)	0.02	5.20	1.1233	.23	.98	.5108
15	Chemical Oxygen Demand	3.00	10.00	6.4842	3.90	18.00	7.7217
16	Faecal Coliform (cfu)	500.00	10500.00	3046.6667	2200.00	99600.00	19254.1667
17	Total Coliform (cfu/100)	1200.00	35000.00	12333.3333	2020.00	174000.00	29835.0000
18	Chloride	3.32	38.23	13.0542	2.41	39.72	12.7650
19	Hardness	18.28	666.76	347.242	7.80	37.50	19.8008
20	Sulphate	3.74	14.61	10.4275	23.20	61.88	47.0275
21	Potassium	.40	1.21	.6467	.01	.78	.2672

Source: Researchers' result, 2022

Table 4: 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 (oC)	32.1917	29.6167	25	0.000
2	pH @25.0oC	6.2425	6.8833	6.5–8.5	0.019
3	Conductivity (µS/cm)	254.5917	178.0100	500	0.292
4	Total Dissolved Solids (mg/L)	24.7833	40.5833	250	0.236
5	Total Suspended (mg/L)	20.8333	12.9000	30	0.233
6	Total Solids (mg/L)	28.0833	32.3333	500	0.233
7	Turbidity (NTU)	30.9167	32.4400	10	0.853
8	Nitrate (mg/LN)	11.5567	8.6483	11.4	0.123
9	Nitrite (mg/LN)	2.3775	.8417	0.20	0.007
10	Ammonia (mg/LN)	16.1167	3.3750	0.20	0.001
11	Total Nitrogen (mg/L)	18.8583	17.9733	1.0	0.736
12	Phosphorus (mg/L)	.2317	.6658	0.01	0.055
13	Dissolved Oxygen (mg/L)	6.6517	6.5692	5-14	0.928
14	Biochemical Oxygen (mg/L)	1.1233	.5108	2-4	0.113
15	Chemical Oxygen Demand	6.4842	7.7217		0.312
16	Faecal Coliform (cfu)	3046.6667	19254.1667	1000	0.067
17	Total Coliform (cfu/100)	12333.3333	29835.0000	5000	0.219
18	Chloride	13.0542	12.7650	250	0.952
19	Hardness	347.242	19.8008	200	0.001
20	Sulphate	10.4275	47.0275	500	0.000
21	Potassium	.6467	.2672	0.01	0.004

Source: Researchers' result/T test value, 2022

5.1 Water Temperature

Water temperature is the hotness and coldness of the water bodies measured with a definite scale (degree centigrade and degree Fahrenheit). It indicates the level of dissolve oxygen and bacteria activity in water. 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^{o}C was recorded during rainy season at sites and the maximum 32.2^{o} C at the dry season. The low water temperature in rainy season can be explained on the basis of high water levels and lower solar radiations whereas 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 parameter, 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 32.20ºC) and high mean values (30 – 33ºC) 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 et al. 2009) and the Jinshui River, China (Bu et al. 2010).

5.2 pH

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, respectively (table 3). Mean concentrations was6.8 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 Ogbete 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 safety limit. Surprisingly, the higher mean pH levels were recorded during the heavy rainfall periods, especially the wet season. Generally, pH are 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)

5.3 Conductivity

Conductivity is an indirect measure of the salt concentration. The conductivity of polluted water is higher. This measure therefore is often used as an index of pollution. The values of conductivity shows 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 neighbourhood. However, the variation was not significantly different ($P = 0.292$, $P > 0.05$) between the two seasons and all the values measured were observed to be within the WHO safety guideline. Yuet.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.

5.4 Total Dissolved Solids (TDS)

Total dissolved solid is a measure of the amount 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 season. Its lowest values were recorded during dry season 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 Singhet.al (2003). Gupta (2004) 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

5.5 Chemical oxygen demand (COD)

Chemical oxygen demand (COD) measures the total 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 season at Ekulu River. This could be associated with active land development in this area, which could contribute to high amount of dissolved organic matter (DOM) (Josephine et al., 2004). The statistical analysis shows that there was no significant different ($P > 0.05$) between the wet and dry seasons. Previous studies have similar finding, 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., 2023). Inversely, high COD values during the dry season have been observed in other studies: Semarang, Indonesia (Mangimbulude et al., 2008); Pearl River Delta, China (Fan et al., 2012); and upper Ogun River in Nigeria (Adeogun et al., 2011).

5.6 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 organisms, 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 statistical 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 observed 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, 2022). Very low DO may result in anaerobic conditions that cause bad odors.

5.7 Nitrite

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. Reddy (2004) observed that nitrites are abundant during monsoon season. These changes are commonly associated with erosion and transportation 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.

5.8 Phosphorus

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 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.

There was a slight fluctuation in the values during study period. The slight seasonal difference observed is attributed to accumulation of phosphates from surface runoff of anthropogenic activities such as agriculture, washing and laundry, domestic and industrial waste discharges

5.9 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 conditions. 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 unsuitable 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 sediment 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 observed 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 consumption of oxygen and a higher pollution load. Conversely, during the dry season, higher mean concentrations 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 maintained an acceptable BOD level at the dry and wet seasons, as evidenced by the low BOD values

5.10 Nitrate

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 were significantly 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 uses a large amount of fertilizers compared to other crops and that this usage is increasing gradually over the years. Nitrate varied significantly 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.

5.11 Sulphate

Wet season sulphate was higher and ranged from 23.20mg/l to 61.88 mg/l compared to dry season 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

5.12 Chloride

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).

5.13 Potassium

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 concentrations of potassium were all below the WHO guideline limit. There was significant ($P = 0.004$) seasonal variation for potassium and this indicating land use changes occurring. Street car washing and laundry activities add considerable amounts that accumulate downstream. Again, this shows fertilizer leaching from agricultural land contributing to potassium concentration. Cars/vehicles are commonly washed at the bank of rivers like Ogbete and Ikiriki, this could account for the high potassium content value. (Ubani et al, 2014)

5.14 Bacterial analysis - Total Coliform (TC) and Faecal Coliform

The study observed that the TC which had the mean values of 29,835. 0cfu/100 during rainy season decreased to 12,333.3 cfu/100 during dry season respectively. The noticed high values of bacterial pollution of the sampled water during rainy season were similar and consistent with the findings by Adekunle et al. (2007) 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

Coliform 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 indication of possible outbreak of cholera, dysentery, typhoid and yellow fever, if consumption of water from these surface water was not discontinued.

6. Discussions and Planning Implications

Anthropogenic activities, as well as untreated sewage and effluent, infiltrate the river ecology and polluted the surface water in the study area. The study shows that the surface water in Enugu became contaminated where the concentrations of nutrients were relatively high, due to the continuous discharge of untreated sewage, detergents chemical and agricultural wastes from the surroundings. 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 portend 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 pollution 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 dangerous state of these noted polluted streams in the study area. Furthermore, the level of phosphate and potassium 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; Kilonzo 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, 2022, Yu et al, 2018). Hence, it is necessary to take adequate steps to minimize water pollution 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 (Tromboni and Dodds, 2017, Moncayo- Estrada et al. 2017)..

Some of the planning implications of these findings are the imminent aquatic life distortion and endangering 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 these aquatic life and is always dependent on natural processes within and outside the water bodies. The observed presence of foreign materials like chemicals, wastes from industries, septic tank content discharged 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 decays. This is worsened by the nefarious attitude of some local fishermen who often use harmful chemicals 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 stakeholders. The discharge of chemical wastes into the streams can result to aquatic animals consuming them and then consumed by humans. When consumed, 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, 2010). Due to the accumulative effects of dumping and runoff, some chemical toxins introduced into the water can cause kidney failure and reproductive disorders. 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 especially 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 (especially human). Sources of faecal pollution include sewage, surface runoff, domestic animals, and wildlife. (Hlavsa, et al, 2014; Wade et al, 2013). Studies have tended to establish relationships between faecal indicator bacteria and the risk of gastrointestinal illness. (Pruss,1998 and Wade et al, 2003). 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. 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 chemical indices are employed without the biological parameters, thus the water quality assessment parameter types can be more comprehensive with the biological 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

6. Conclusion and Recommendation

The study investigated the seasonal physicochemical characteristics of surface water in Enugu urban during the dry and wet seasons with a view to understanding 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 variation in terms of their spatial distribution. The significant difference observed in surface water shows that there was a change i n w ate r 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 l and 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 environmental 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 prosecuted. Industrial and agricultural sectors should also be compelled to treat their wastes before being discharged 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 are 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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